NIST NCSTAR 1-1

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Design, Construction, and Maintenance of Structural and Life Safety Systems

H. S. Lew
Richard W. Bukowski
Nicholas J. Carino

NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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Richard W. Bukowski
Nicholas J. Carino, retired
Building and Fire Research Laboratory
National Institute of Standards and Technology

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U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

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In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

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NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

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ABSTRACT

The collapse of World Trade Center (WTC) 1, 2, and 7 resulted from structural damage from direct and indirect effects of aircraft impact and the ensuing fires. Thus, for collapse analyses of these buildings, knowledge of the physical state of the structural and fire safety systems prior to the aircraft impact is essential. To obtain information for the collapse analysis of the buildings, National Institute of Standards and Technology reviewed design and construction documents, correspondence, and memoranda related to the building projects; interviewed individuals involved in the design, construction, and maintenance of the buildings; obtained information from regulatory and emergency services agencies of New York City; and reviewed books and published journal and magazine articles related to the WTC building projects. Information obtained from various sources are synthesized and summarized in this report. Specifically, this report presents (1) provisions used to design and construct the structural, fire protection and egress systems of the buildings; (2) tests performed to support the design of these systems; (3) criteria that governed the design of the structural and fire protection systems; (4) methods used to proportion structural members and other components of the buildings; (5) innovative features, technologies and materials that are incorporated in design and construction of the structural and fire protection systems; (6) details of deviations to the contract documents granted by Port Authority of New York and New Jersey; (7) fabrication and inspection requirements at the fabrication yard; and (8) inspection protocols during construction.

This report also documents the fuel system for the diesel generators that supplied emergency power to many of the tenants in WTC 7.

Findings from the synthesis of the information collected and resulting issues are presented.

Keywords: Buildings, codes, construction, design, egress, elevators, fire, loads, maintenance, regulations, standards, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

3M	Minnesota Mining and Manufacturing Company
ACI	American Concrete Institute
AIA	American Institute of Architects
AISC	American Institute of Steel Construction
ASME	American Society of Mechanical Engineers
ASTM	ASTM International
AWCI	Association of Wall and Ceiling Industries
AWS	American Welding Society
BBC	Basic Building Code
BOCA	Building Officials and Code Administrators International
CMU	concrete masonry unit
Con Edison	Consolidated Edison
CSU	Colorado State University
FDNY	New York City Fire Department
FSES	Fire Safety Equivalency Systems
GA	Gypsum Association
HVAC	heating, ventilating, and air conditioning
IBC	International Building Code
JB&B	Jaros, Baum & Bolles
KKE	Karl Koch Erecting Company
LERA	Leslie E. Robertson Associates
LL	Local Law
MER	Mechanical Equipment Room
MCC	Municipal Code of Chicago
MIT	Massachusetts Institute of Technology
NBC	National Building Code
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology

NPL	National Physical Laboratory
NYC	New York City
OEM	Office of Emergency Management
PANYNJ	Port Authority of New York and New Jersey
PCF	Pacific Car & Foundry Co.
PDM	Pittsburgh-Des Moines Steel Company
P.L.	Public Law
PONYA	Port of New York Authority (in 1972 PONYA changed to PANYNJ)
RJA	Rolf Jensen & Associates
RS	Reference Standard
SBCCI	Southern Building Code Congress International, Inc., published *Southern Standard Building Code*
SFRM	sprayed fire-resistive material
SHCR	Skilling, Helle, Christiansen, & Robertson (structural engineers)
SII	Structural Integrity Inspection
SSPC	Steel Structures Painting Council
TRCC	Tishman Realty & Construction Company
UBC	Uniform Building Code
UL	Underwriters' Laboratories, Inc.
USC	United States Code
WSHJ	Worthington, Skilling, Helle & Jackson
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
cfm	cubic foot per minute
cps	cycles per second
F_y	yield strength of steel
ft	foot

ft^2	square foot
gal	gallon
gph	gallons per hour
in.	inch
$in.^2$	square inch
kip	a force equal to 1,000 pounds
ksi	1,000 pounds per square inch
kW	kilowatt
L	liter
lb	pound
m	meter
μm	micrometer
min	minute
mph	miles per hour
pcf	pounds per cubic foot
plf	pounds per linear foot
psf	pounds per square foot
psi	pounds-force per square inch
s	second

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METRIC CONVERSION TABLE

To convert from	to	Multiply by
AREA AND SECOND MOMENT OF AREA		
square foot (ft^2)	square meter (m^2)	9.290 304 E-02
square inch ($in.^2$)	square meter (m^2)	6.4516 E-04
square inch ($in.^2$)	square centimeter (cm^2)	6.4516 E+00
square yard (yd^2)	square meter (m^2)	8.361 274 E-01
ENERGY (includes WORK)		
kilowatt hour (kW · h)	joule (J)	3.6 E+06
quad (1015 BtuIT)	joule (J)	1.055 056 E+18
therm (U.S.)	joule (J)	1.054 804 E+08
ton of TNT (energy equivalent)	joule (J)	4.184 E+09
watt hour (W · h)	joule (J)	3.6 E+03
watt second (W · s)	joule (J)	1.0 E+00
FORCE		
dyne (dyn)	newton (N)	1.0 E-05
kilogram-force (kgf)	newton (N)	9.806 65 E+00
kilopond (kilogram-force) (kp)	newton (N)	9.806 65 E+00
kip (1 kip=1,000 lbf)	newton (N)	4.448 222 E+03
kip (1 kip=1,000 lbf)	kilonewton (kN)	4.448 222 E+00
pound-force (lbf)	newton (N)	4.448 222 E+00
FORCE DIVIDED BY LENGTH		
pound-force per foot (lbf/ft)	newton per meter (N/m)	1.459 390 E+01
pound-force per inch (lbf/in.)	newton per meter (N/m)	1.751 268 E+02
HEAT FLOW RATE		
calorieth per minute (calth/min)	watt (W)	6.973 333 E-02
calorieth per second (calth/s)	watt (W)	4.184 E+00
kilocalorieth per minute (kcalth/min)	watt (W)	6.973 333 E+01
kilocalorieth per second (kcalth/s)	watt (W)	4.184 E+03

To convert from	to	Multiply by
LENGTH		
foot (ft)	meter (m)	3.048 E-01
inch (in)	meter (m)	2.54 E-02
inch (in.)	centimeter (cm)	2.54 E+00
micron (m)	meter (m)	1.0 E-06
yard (yd)	meter (m)	9.144 E-01
MASS and MOMENT OF INERTIA		
kilogram-force second squared per meter ($kgf \cdot s^2/m$)	kilogram (kg)	9.806 65 E+00
pound foot squared ($lb \cdot ft^2$)	kilogram meter squared ($kg \cdot m^2$)	4.214 011 E-02
pound inch squared ($lb \cdot in.^2$)	kilogram meter squared ($kg \cdot m^2$)	2.926 397 E-04
ton, metric (t)	kilogram (kg)	1.0 E+03
ton, short (2,000 lb)	kilogram (kg)	9.071 847 E+02
MASS DIVIDED BY AREA		
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428 E+00
pound per square inch (*not* pound force) ($lb/in.^2$)	kilogram per square meter (kg/m^2)	7.030 696 E+02
MASS DIVIDED BY LENGTH		
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164 E+00
pound per inch (lb/in.)	kilogram per meter (kg/m)	1.785 797 E+01
pound per yard (lb/yd)	kilogram per meter (kg/m)	4.960 546 E-01
PRESSURE or STRESS (FORCE DIVIDED BY AREA)		
kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	9.806 65 E+04
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	9.806 65 E+00
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	9.806 65 E+06
kip per square inch (ksi) ($kip/in.^2$)	pascal (Pa)	6.894 757 E+06
kip per square inch (ksi) ($kip/in.^2$)	kilopascal (kPa)	6.894 757 E+03
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026 E+01
pound-force per square inch (psi) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
pound-force per square inch (psi) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00
psi (pound-force per square inch) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
psi (pound-force per square inch) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00

To convert from	to	Multiply by
TEMPERATURE		
degree Celsius (°C)	kelvin (K)	T/K = t/°C + 273.15
degree centigrade	degree Celsius (°C)	t/°C ≈ t /deg. cent.
degree Fahrenheit (°F)	degree Celsius (°C)	t/°C = (t/°F - 32)/1.8
degree Fahrenheit (°F)	kelvin (K)	T/K = (t/°F + 459.67)/1.8
kelvin (K)	degree Celsius (°C)	t/°C = T/K 2 273.15
TEMPERATURE INTERVAL		
degree Celsius (°C)	kelvin (K)	1.0 E+00
degree centigrade	degree Celsius (°C)	1.0 E+00
degree Fahrenheit (°F)	degree Celsius (°C)	5.555 556 E-01
degree Fahrenheit (°F)	kelvin (K)	5.555 556 E-01
degree Rankine (°R)	kelvin (K)	5.555 556 E-01
VELOCITY (includes SPEED)		
foot per second (ft/s)	meter per second (m/s)	3.048 E-01
inch per second (in./s)	meter per second (m/s)	2.54 E-02
kilometer per hour (km/h)	meter per second (m/s)	2.777 778 E-01
mile per hour (mi/h)	kilometer per hour (km/h)	1.609 344 E+00
mile per minute (mi/min)	meter per second (m/s)	2.682 24 E+01
VOLUME (includes CAPACITY)		
cubic foot (ft^3)	cubic meter (m^3)	2.831 685 E-02
cubic inch ($in.^3$)	cubic meter (m^3)	1.638 706 E-05
cubic yard (yd^3)	cubic meter (m^3)	7.645 549 E-01
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412 E-03
gallon (U.S.) (gal)	liter (L)	3.785 412 E+00
liter (L)	cubic meter (m^3)	1.0 E-03
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353 E-05
ounce (U.S. fluid) (fl oz)	milliliter (mL)	2.957 353 E+01

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PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

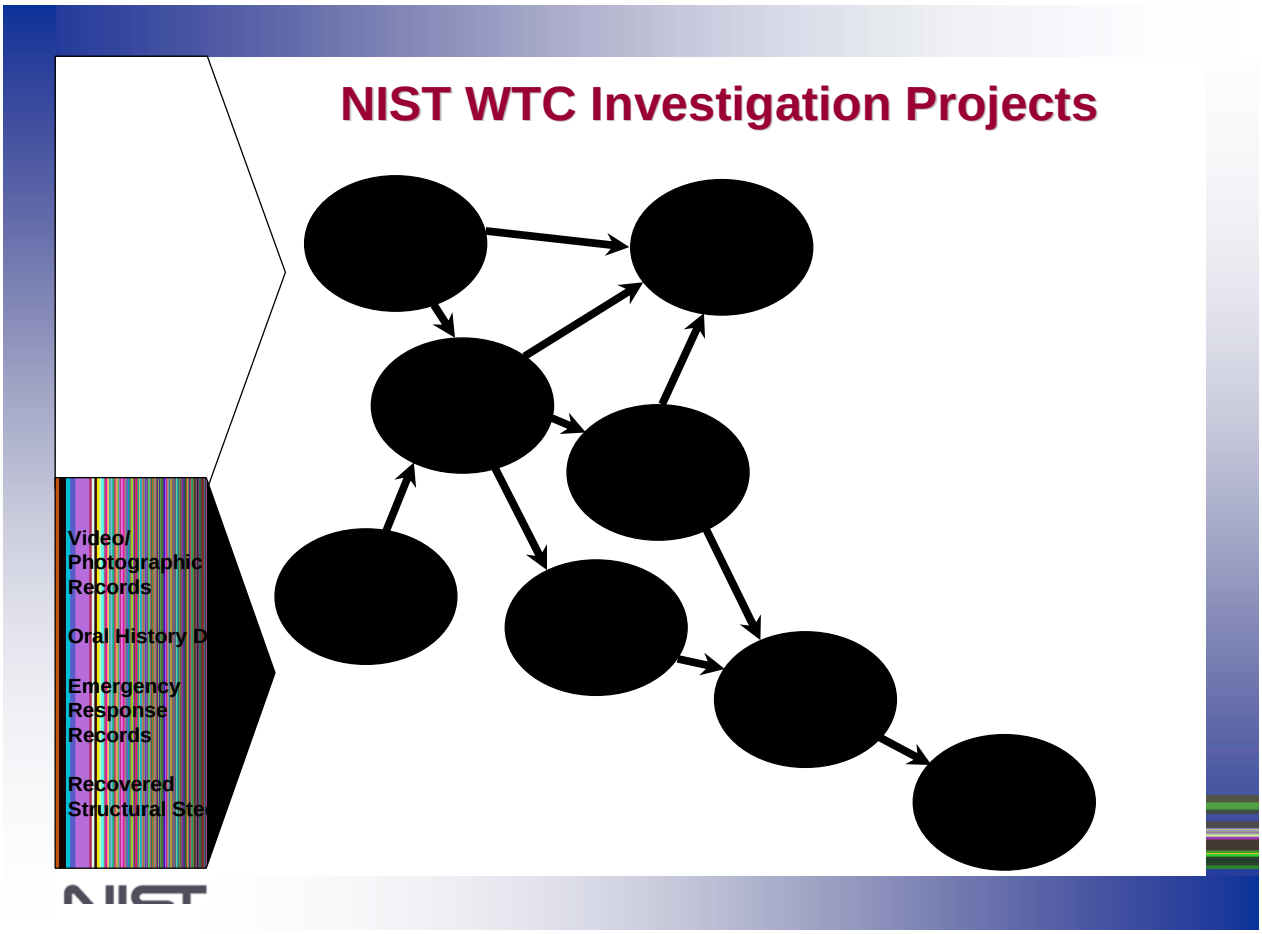

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

NIST (National Institute of Standards and Technology). 2008. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of World Trade Center 7.* NIST NCSTAR 1A. Gaithersburg, MD, November.

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EXECUTIVE SUMMARY

E.1 INTRODUCTION

One of the four primary objectives of the National Institute of Standards and Technology (NIST) Investigation of the World Trade Center (WTC) disaster is to determine the procedures and practices that were used in the design, construction, operation, and maintenance of the structural, passive and active fire protection, and emergency and evacuation systems of WTC 1, 2, and 7 and the impacts these had on the buildings over their life, up to the attacks of September 11, 2001.

To accomplish this objective, relevant information was collected by reviewing design and construction documents, correspondence, and memoranda related to the building projects; and tenant alterations; interviewing individuals involved in the design, construction, and maintenance of the buildings; obtaining information from regulatory and emergency services agencies of New York City; and reviewing books and published journal and magazine articles related to the WTC building projects. Information obtained from various sources was synthesized and summarized in this report. Specifically, this report presents:

1. Provisions used to design and construct the structural, fire protection, and egress systems of the buildings;

2. Tests performed to support the design of these systems;

3. Criteria that governed the design of the structural and fire protection systems;

4. Methods used to proportion structural members and other components of the buildings;

5. Innovative features, technologies, and materials that were incorporated in the design and construction of the structural and fire protection systems;

6. Details of deviations to the contract documents granted by the Port Authority of New York and New Jersey (PANYNJ or Port Authority);

7. Fabrication and inspection requirements at the fabrication yard; and

8. Inspection protocol during construction.

9. Alterations made to the buildings to accommodate specific needs of tenants or to respond to changes to the Building Code of New York City as implemented in Local Laws (LL) and interpreted in rules.

This report also addresses the fuel systems for the diesel generators that supplied emergency power to many of the tenants in WTC 7.

E.2 DESCRIPTION OF WTC 1, 2, AND 7

The WTC complex was located at lower west side of Manhattan, New York City, near the Hudson River. The complex was composed of seven buildings (referred to in this report as WTC 1 through WTC 7). The two towers, WTC 1 (North Tower) and WTC 2 (South Tower), were each 110 stories high. WTC 3 (Marriott Hotel) was 22 stories. WTC 4 (South Plaza Building) and WTC 5 (North Plaza Building) were both nine-story office buildings. WTC 6 (U.S. Customs House) was an eight-story office building. These six buildings were built around a 5 acre WTC Plaza. WTC 7 was a 47-story office building that was built just north of the six-building WTC site.

The first six buildings on the sixteen-acre site were developed by the Port Authority. Groundbreaking for WTC 1 and WTC 2 was in 1966, and the first tenant began to occupy WTC 1 in December 1970 and WTC 2 in January 1972. Construction of the other buildings continued during the 1970s and the 1980s. WTC 7 was developed by a consortium comprising the Seven World Trade Company, and Silverstein Development Corporation, and was completed in 1987.

The NIST Investigation is focused only on WTC 1, 2, and 7.

WTC 1 and WTC 2

Although the WTC towers were similar, they were not identical. The height of WTC 1 at the roof level was 1,368 ft above the Concourse level, was 6 ft taller than WTC 2, and supported a 360 ft tall antenna for television and radio transmission. Each tower had a square plan with the side dimension of approximately 207 ft. The corners of the tower were chamfered 6 ft 11 in. Each tower had a core service area of approximately 135 ft by 87 ft. All elevators and three egress stairs were located within the core, although on any given floor the arrangements of the elevators and the location of the stairs varied. Placing all service systems within the core provided a nearly column-free floor space of approximately 31,000 ft^2 per floor outside the core. The two towers had about 10 million ft^2 of rentable floor area.

The towers were designed as a “framed-tube” structural system with closely spaced exterior perimeter columns connected by spandrel beams around the perimeter at each floor level. The core was designed as a conventional frame with a grid of columns interconnected with beams.

The exterior walls were composed of box-shaped welded steel columns and spandrel beams comprised of a steel plate. Each building face consisted of 59 columns spaced at 3 ft 4 in. on center. As part of the framed-tube system, the exterior columns were designed structurally such that they resisted the total lateral loads and about 50 percent of gravity loads. Below floor 7, the columns were combined in groups of three to form single base columns which were spaced 10 ft on center and extended to the footings. An important architectural feature of the towers was the uniform look of the exterior walls, presented by the uniform width of the exterior columns up the height of the buildings. This was produced by maintaining a constant exterior dimension the columns and changing the strength of the steel with height. Thus, twelve different grades of steel, with yield strengths ranging from 36 ksi to 100 ksi, were used for the exterior columns. The external cladding, which covered the columns and spandrel beams, consisted of aluminum sheets. The window openings were infilled with glass fitted into aluminum covers and sealed with neoprene gaskets.

The core columns were of two types: welded box columns for the lower floors and rolled wide flange shapes for the upper floors. They were designed to support about 50 percent of gravity loads. Below floor 7 to the foundation, where there were fewer perimeter columns in the outer walls, bracings were used in the outer perimeter of the core area to increase lateral stiffness. In the lower part of the towers, the outer core columns were designed to resist a portion of the lateral forces. Hidden within the building, the core columns were thicker and larger on the lower floors. Thus, core columns used fewer grades of steel. The box columns were either 36 ksi or 42 ksi. Core wide flange columns were one of four grades, yield strengths ranging from 36 ksi to 50 ksi, but most (approximately 90 percent) were primarily 36 ksi or 42 ksi steel.

The floor system of WTC 1 and WTC 2 was composed of concrete-steel composite members. The area inside the cores and on the mechanical floors was framed with rolled structural steel shapes with welded shear studs acting compositely with normal-weight concrete slabs. The thickness of the slabs varied from 4.5 in. to 8 in. depending on design loads. The area outside the core, typically on tenant floors, was framed with steel trusses acting compositely with 4 in. thick lightweight concrete slabs cast on 1½ in., 22 gauge fluted metal deck. The trusses consisted of double angle top and bottom chords with round bar webs. Some floors, immediately adjacent to the mechanical floors, used a hybrid of beam and truss framing acting compositely with the concrete slab.

Fire protection of exposed structural steel members in the WTC towers was provided by applied fire resistive materials. They were either sprayed fire-resistive materials (SFRMs), gypsum wallboards, or a combination of the two, depending upon the type of structural members, to meet the requirements of Construction Classification of 1B of the 1968 New York City (NYC) Building Code. All floor trusses and beams were protected with SFRM. The columns inside the core were either covered with gypsum wall board or a combination of gypsum wall board and SFRM. For the exterior columns, vermiculite plaster was applied to the side of the column facing the interior of the building, whereas SFRM was applied to other three faces. No fire resistive material was specified for the underside of the metal deck, which was in contact with the concrete slab above. For typical tenant floors, the ceiling was suspended from the steel trusses. The space between the ceiling and the floor above was used for the mechanical and electrical systems.

Elevators were the primary mode of routine ingress and egress from the towers for tens of thousands of people daily. In order to minimize the total floor space needed for elevators, each tower was divided vertically into three zones by skylobbies, which served to distribute passengers among express and local elevators. In this way, the local elevators within a zone were placed on top of one another within a common shaft. Local elevators serving the lower portion of a zone were terminated to return to the space occupied by those shafts to leasable tenant space. People transferred from express elevators to local elevators at the skylobbies which were located on the 44th and 78th floors in both towers. Each tower had 99 passenger and 7 freight elevators, all located within the core of the building.

WTC 7

WTC 7 was a 47-story commercial office building constructed by Silverstein Properties as a tenant alteration on land owned by the Port Authority. The overall dimensions of WTC 7 were approximately 330 ft long, 140 ft wide, and 610 ft high. It contained about 2 million ft^2 of rentable floor area. The building was constructed over a pre-existing electrical substation owned by Consolidated Edison

(Con Edison). The original plans for the Con Edison Substation included supporting a high-rise building, and the foundation was sized for the planned structure. However, the final design for WTC 7 had a larger footprint than originally planned.

Above floor 7, the building had typical steel framing for high-rise construction. The floor systems had composite construction with steel beams of 50 ksi yield strength supporting concrete slabs on metal deck, with a floor thickness of 5.5 in. The core and perimeter columns supported the floor system and carried their loads to the foundation. Above floor 7, the perimeter moment frame resisted wind forces. Below floor 7, a combination of moment and braced frames around the perimeter and a series of braced frames in the core resisted the wind load.

Columns above floor 7 did not align with the foundation columns, so braced frames, transfer trusses, and transfer girders were used to transfer loads between these column systems, primarily between floors 5 and 7. Floors 5 and 7 were heavily reinforced concrete slabs on metal decks, with thicknesses of 14 in. and 8 in., respectively.

Core columns were primarily rolled wide-flange shapes with a yield strength of either 36 ksi or 50 ksi, while the exterior columns were typically rolled W14 shapes with a yield strength of 36 ksi.

E.3 CODE PROVISIONS FOR STRUCTURAL DESIGN

The design of WTC 1, 2, and 7 was based on the 1968 edition of the NYC Building Code. As an interstate compact under the U.S. Constitution, the Port Authority was not subjected to any state or local building codes. In May 1963, the Port of New York Authority (PONYA or Port Authority) instructed the architect and structural engineer to prepare their designs for WTC 1 and WTC 2 in accordance with the NYC Building Code. At that time, the 1938 edition of that Code was in effect. In September of 1965, the PONYA instructed the architect and structural engineer to revise their designs for WTC 1 and WTC 2 to comply with the second and third drafts of the new NYC Building Code that was under development. Prior to issuance of this instruction, the Port Authority recognized that the draft version of the new NYC Building Code had incorporated advanced techniques and the Port Authority favored the use of advanced techniques in the design of the WTC towers. By adopting the draft versions of the new NYC Building Code, WTC 1 and WTC 2 could be classified as Type 1-B Construction, and several features related to egress such as the elimination of the fire tower and the reduction of the number of egress stairs required from six to three with narrower doors were incorporated into the final design.

The new Code was adopted on December 6, 1968. Subsequently, the NYC Building Code was amended by numerous Local Laws to improve safety requirements or to incorporate technological advances, some of which had impacts on the towers. When WTC 7 was designed, the 1968 Building Code was in effect and the Local Laws impacting fire, life safety, and structural arrangements were in place, so these were incorporated into the original design of that building.

To put the design of WTC 1, 2, and 7 into the context of building codes and practices of the time, the structural provisions of the 1968 edition of the NYC Building Code were compared with the structural provisions in a number of contemporaneous codes, as well as in the 2001 edition of the NYC Building Code, which is currently in effect. Specifically, the following codes were selected for comparison of the structural provisions: the 1964 New York State Building Construction Code (NYSBC 1964); the 1965 Building Officials and Code Administrators (BOCA) Basic Building Code (BOCA/BBC 1965); the 1967

Municipal Code of Chicago Relating to Buildings (MCC 1967); and the 2001 edition of the NYC Building Code (NYCBC 2001). The 1964 New York State Building Construction Code was selected for comparison, as it would have been a governing building code outside New York City limits. The 1965 BOCA Basic Building Code was selected, as it was typically adopted by local jurisdictions in the northeastern region of the United States. The 1968 NYC Building Code is compared with the 1967 Municipal Code of Chicago to see whether there are any substantial differences in the structural and fire safety requirements of the two codes. In the late 1960s and early 1970s, several tall buildings were built in Chicago, including the Sears Tower (110 stories) and the John Hancock Tower (100 stories). The 2001 edition of the NYC Building Code is compared with the 1968 version to examine the extent to which Local Laws have modified the code provisions.

Structural provisions include those concerning design loads, such as dead loads, live loads (including live load reduction), wind loads, earthquake loads, and other loads. They also include provisions concerning what is called "structural work" in the NYC Building Codes (this term is not used in the other codes). The scope of "structural work" includes, but is not limited to, materials and methods of construction, design methods including design load combinations, and the materials of construction including concrete, masonry, steel, and wood. Structural provisions also include those for foundation design and construction.

With respect to structural design provisions, the major changes from the 1968 to the 2001 edition of the NYC Building Code are the inclusion of seismic design requirements and updating of standards. Of the codes contemporaneous with the 1968 NYC Building Code examined for this investigation, only the BOCA Basic Building Code had seismic design requirements, which were adopted from the 1962 edition of the Uniform Building Code (UBC). Taller buildings have longer periods of vibration, which means lower seismic design forces. Also, since New York City is in an area of moderate seismicity (UBC Zone 2A), additional seismic detailing requirements are minimal to non-existent.

The alternate live load reduction provisions for columns, walls, and piers of the 1968 and 2001 NYC Building Codes are the same as in the Chicago Municipal Code. The New York State Building Code has more liberal live load reduction provisions for upper portions of buildings. The NYC Building Codes also have live load reduction provisions based on contributory floor area and live-to-dead load ratio. For live-to-dead load ratios of 0.625 or less, the New York City code provisions may yield higher live load reduction for columns, walls, and piers than allowed by the other codes. For beams and girders, the live load reduction provisions of the NYC Building Code are comparable to those of the New York State Building Code and the BOCA Basic Building Code. The Chicago Municipal Code has more conservative requirements. The maximum live load reduction allowed for beams and girders in the Chicago Municipal Code is 15 percent, compared with 40 percent in the other codes.

When the wind load provisions in the codes are compared, the largest shear force at the base of a building is obtained from the BOCA Basic Building Code when the height of the building is taken equal to 1,368 ft (i.e., the height of WTC 1). Similarly, the largest overturning moment at the base of a building with the height of the WTC towers is also obtained from the BOCA Basic Building Code. Thus, the NYC Building Code does not have the most stringent wind load provisions.

The 1968 NYC Building Code requires that weights of partitions be considered in two ways: (1) using line loads at locations shown on plans or (2) using the equivalent uniform load. Equivalent uniform loads must be used in areas where the locations of partitions are not shown on plans, or in areas where partitions

can be relocated. The 1964 New York State Building Construction Code did not have a specific provision in this regard. The 1967 Municipal Code of Chicago prescribed a minimum partition load of 20 psf. The BOCA Basic Building Code required consideration of the actual weight of the partitions or an equivalent

E.7 INSPECTION PROTOCOL DURING CONSTRUCTION

WTC 1 and WTC 2

Karl Koch Erecting Co., the company that performed the structural steel erection work for WTC 1 and WTC 2, developed a quality control and safety program. This program included information on ten different key areas that were to be addressed during construction, including:

- Survey control
- Control of construction and erection loads
- Field welding
- Bolting of structural steel
- Control of stud welding operations
- Erection procedures
- Control of workmanship
- Control of erection tolerances
- As-built drawings
- Safety programs

WTC 7

The WTC 7 specifications contained general erection requirements for fasteners, anchor bolts, column bases, installation, and bracing. The specification did not include any requirements for inspection.

E.8 DEVIATIONS GRANTED BY PANYNJ

The Port Authority approved numerous deviations in the fabrication and erection of structural members in WTC 1 and WTC 2. The Office of the Construction Manager at the Port Authority approved deviations to the contract documents after the structural engineer of record; Skilling, Helle, Christiansen, and Robertson (SHCR), reviewed the details of the deviations and recommended approval. In many cases, SHCR submitted alternative methods, which were incorporated into the deviation.

The deviations that were granted for the structural members and their materials may be categorized into the following groups:

- Deviations relating to fabrication/erection tolerances (box columns, box beams, and floor trusses)

- Deviations relating to defective components (column trees and floor trusses)
- Deviations relating to alternative fabrication/erection procedures (core columns, floor trusses, exterior wall columns, and beam seats)
- Deviations relating to product substitutions (exterior wall)
- Deviations relating to inspection practice (exterior wall and welds).

Fabrication and erection inspections identified many deviations from the contract drawings and specifications. Many deviation requests were based on inspection results.

E.9 STRUCTURAL MAINTENANCE AND MODIFICATIONS DURING OCCUPANCY

Both architectural and structural modifications were made to meet the occupancy needs of individual tenants throughout the history of occupancy of WTC 1, 2, and 7. PONYA, later PANYNJ, reviewed all modifications to maintain the structural integrity of the buildings and to ensure that modifications were compatible with existing building conditions. In order to guide tenants in their modification process, the PONYA issued *Tenant Alteration Review Manual* in 1971 and updated the manual periodically through 1997.

In anticipation of structural degradation, the PANYNJ issued in 1986 the *Standard for Structural Integrity Inspection of the World Trade Center Towers A & B* to guide periodic inspection of structural members. Deteriorated and damaged members were identified for repair. The standard was used by consultants who were retained by PANYNJ for systematic examination of WTC 1 and WTC 2.

In 1998, the PANYNJ issued the *Standards for Architectural and Structural Design* for modification works. The standards included not only the design guide, but also included specifications and standard details to be used in modification works. Tenants proposing any modifications were required to follow the specified standards.

Apart from the repairs following the 1993 bombing of WTC 1, most of the structural modifications in WTC 1 and WTC 2 were performed to accommodate tenant requirements. Openings were cut in existing floors to construct new stairways linking two or more floors, and floor systems were reconstructed over previously cut openings. In a number of cases, floor trusses outside of the core area and steel beams in the core area had to be reinforced due to heavy loads imposed by tenant requirements. All such modifications were reviewed and approved by the structural engineer of record (SHCR).

Similar to WTC 1 and WTC 2, most of the structural modifications in WTC 7 were done to accommodate tenant requirements. Horizontal members of the floor framing system were strengthened due to increased loading from high-density files. Strengthening of these beams and girders was achieved by welding cover plates to the bottom flanges, the underside of the top flanges, or both. In some cases, new beams were introduced to carry a portion of the new load.

Structural Integrity Inspection Program

In 1986, PANYNJ implemented an inspection program to detect, record, and correct any signs of distress, deterioration, or deformation that could signal structural problems. This structural integrity inspection program contained detailed guidelines on inspection, record-keeping, and follow-up procedures.

Inspection findings were to be categorized as "Immediate," "Priority," or "Routine." Repairs falling into the "Immediate" category included possible closure of the area and/or structure affected until interim remedial action could be implemented. The "Priority" category was for those conditions where no immediate action was required, or for which immediate action had been completed, but for which further investigation, design, and implementation of interim or long-term repairs were to be undertaken on a priority basis (i.e., taking precedence over all other scheduled work). Repairs falling into the "Routine" or "non-priority" category were to be undertaken as part of a scheduled major work program or other scheduled project, or when routine facility maintenance was to be performed, depending on the type of repair that was required. An important requirement in the inspection program was that where inspection procedures involved the removal of fireproofing, such fireproofing was to be properly replaced on completion of inspection.

In general, the structural integrity inspections findings indicated that the structural systems of WTC 1, 2, and 7 were in good condition. The inspections resulted in numerous routine and some priority recommendations for repairs, as outlined in the inspection standard. According to the PANYNJ, all of the construction records on repairs following the inspections were lost on September 11, 2001. Thus, it cannot be determined whether all of the recommended repairs were performed.

Repair Work Following the 1993 Explosion

The explosion of February 26, 1993, occurred on Level B2 near the center of the south wall of WTC 1 and adjacent to WTC 3 (Vista Hotel). Structural steel columns, diagonal braces, and spandrel beams in the vicinity of the blast were damaged. Concrete floor slabs at Levels B1 and B2 and unreinforced masonry walls were also damaged over a large area.

The explosion severely bent and tore out the diagonal brace between columns. Spandrel beams at level B1 were also damaged by the blast. A crack developed along the field splice in a column. Ultrasonic testing determined that the crack extended across the full width of the weld on the south face of the column and at each end of the weld on the north face. Magnetic-particle testing procedure determined that the crack extended across the east face of the column. The explosion also damaged floor beams at levels B1 and B2. Concrete spandrel beams at level B3 also sustained damage. Masonry walls in WTC 1 were breached over distances of approximately 50 ft to the east and 120 ft to the west of the blast origin.

The diagonal bracing members between levels B1 and B2 that were damaged by the explosion were removed and replaced with new members. New plates were added to the damaged spandrel beam at level B1. Also, the cracked weld on the south face of the spandrel beam at level B1 was removed and replaced.

Six different inspections were performed before and after repairs were made to WTC 1. No anomalies were detected in the welds used to repair structural members.

E.10 CODE PROVISIONS FOR DESIGN OF THE FIRE SAFETY AND EGRESS SYSTEMS

The fire safety provisions of the 1968 NYC Building Code (NYCBC 1968) were compared with four other building codes: the 1964 New York State Building Construction Code (NYSBC 1964), the 1965 BOCA Basic Building Code (BOCA/BBC 1965), the 1967 Municipal Code of Chicago Relating to Buildings (MCC 1967), and the 2001 edition of the NYC Building Code (NYCBC 2001). In addition, comparisons were made to the 1966 edition of National Fire Protection Association (NFPA) 101, Code for Safety to Life in Buildings and Structures. While not a building code, NFPA 101 is widely adopted for its requirements for life safety in fires.

The NYC Building Code was regularly amended by local laws, two of which, Local Law 5 (1973) and Local Law 16 (1984), had a significant influence on WTC 1 and WTC 2, even though the buildings were completed and occupied at the time of adoption. It is normal practice not to apply building code changes to existing buildings except for major renovations or change in primary use, but the Port Authority chose to follow the revised provisions and to retrofit the buildings as required under the new provisions. The resulting changes to WTC 1 and WTC 2 are discussed primarily in the sections on modifications to the building systems.

While New York City developed its own building code, their code development committees were influenced by the same forces that bore on the model codes. Thus, there were relatively few differences between the NYC Building Code and the others.

Construction Classification

In Construction Classifications, the 1968 Building Code, the New York State Building Code, and the 1965 BOCA all recognized Class 1A or Class 1B (with the same fire resistance ratings for building elements) for most unsprinklered buildings of unlimited height, while the 1967 Chicago Code recognized only 1A. New York City imposed a 75 ft height limit on unsprinklered buildings with the adoption of Local Law 16 (1984).

Active Systems

At the time of construction, sprinklers were primarily for property protection and were rare even in high-rise buildings (except for underground spaces). Fire alarm systems were mostly manually initiated but there was concern about smoke being recirculated through the heating, ventilating, and air conditioning (HVAC) systems, so smoke detectors controlled dampers at return shafts to prevent this. This is the arrangement of the fire alarm system originally installed in the towers. Voice communication systems were a response to phased evacuation with the recognition that it was necessary to provide instructions to occupants who were relocated or held within the building at least until they were told to leave. Requirements for voice systems first appeared in national standards in the mid-1980s, at the same time as NYC adopted LL 16 (1984).

Technical Standards

All building codes rely on referenced technical standards to provide the details of design, installation, operation, and maintenance of required systems. Most building codes reference national (consensus) standards as published, but New York City cites their own reference standards that are based on these national standards but are often highly modified. For example, fire alarm systems and fire sprinkler systems are addressed in Reference Standard (RS) 17, with Class E fire alarm systems (required in office occupancies) covered in RS 17-3A and general fire alarm system requirements in RS 17-5. The former is entirely written by a NYC code committee, and the latter is based on NFPA 72 (National Fire Alarm Code) but highly modified by the deletion of many sections and modification of many others. One major modification is that RS 17 does not include the "Survivability" section for high-rise voice communication systems that requires duplicate communication trunks so that loss on one trunk does not result in loss of communication with a floor. However the voice communication system installed in WTC 1 and WTC 2 was consistent with the National Fire Alarm Code (NFPA 72) in addition to RS 17 and had redundant trunks run in Stairways A and C.

Egress Systems

Prior to 1988, all building codes determined egress capacity by the (22 in.) Units of Exit Width method, which New York City still uses. In 1988, other codes changed to a method involving an allowance of width per person, which provides credit for non-standard widths of corridors and doors, but for standard dimensioned components yields the same results. Another difference in egress design is that New York City applies the occupant load factor for business occupancies (100 ft^2 per person) to the net floor area while other codes use the gross floor area. Other codes use net for some and gross for others. The NYC Building Code allows doubling stair capacity allowances with one or tripling of the stair capacity on floors with two or more horizontal exits where other codes only allow doubling for one horizontal exit (see discussion of Windows on the World).

Miscellaneous Details

There are a number of detail differences between the NYC Building Code and the other building codes. The NYC Building Code has no requirements for fire extinguishers since they require occupant hose reels. The 1968 NYC Building Code was the first code to include smoke developed ratings for finish materials in addition to flame spread. Now, all of the codes have similar requirements.

Specifications for the Original Buildings

No contemporaneous documentation has been found that provides the rationale for the decision to select Class 1B for the WTC towers. This decision, however, appears to have been made by the architect-of-record on the basis of economics.

As stated above the primary occupancy group was Group E (Business) with the Windows on the World space in WTC 1 being Group F (Assembly). While there was a Port Authority cafeteria on the 44th floor, employee cafeterias not open to the public are specifically exempted from assembly classification because they do not increase occupant load and are only used intermittently. Incidental mercantile spaces such as

news stands and coffee bars at the concourse level are also exempt from reclassification in most building codes.

The NYC Building Code and Port Authority practice required partitions to separate tenant spaces from each other and from common spaces such as the corridors that served the elevators, stairs, and other common spaces in the building core. Fire rated partitions are intended to limit fire spread on a floor, to prevent spread of fire in one tenant space to that of another, partitions separating tenant space from exit access corridors were permitted to be 1 h, although the Port Authority specified them to be 2 h, allowing dead ends to extend to 100 ft (rather than 50 ft with 1 h partitions), which permitted more flexibility in tenant layouts. Partitions separating tenant spaces (so-called demising walls) were required to be 1 h (see Sec. 10.4.5). Enclosures for vertical shafts, including stairways and transfer corridors, elevator hoistways, and mechanical or utility shafts were required to be of 2 h fire rated construction. Protection of vertical shafts is intended to limit the spread of fire and smoke from floor to floor.

The primary egress system for the office spaces was the three stairways located in the building core. These included two 44 in. (designated A and C) and one 56 in. wide (designated B) stairs which provided exactly the code required capacity for an occupant load of 390 per floor (39,000 ft^2 net at 100 ft^2 per person). The layout within the building core was consistent with the Building Code requirements for maximum travel distance (200 ft unsprinklered, 300 ft sprinklered) and, while the separation was consistent with New York City requirements (15 ft and later 30 ft), it was short of the more common requirements found in all current building codes (one-half the diagonal of the space served if unsprinklered, or one-third the diagonal if sprinklered) on some of the floors where the transfer corridors brought the stair access closer together.

There were 99 passenger elevators in each tower, arranged in three vertical zones to move occupants in stages to skylobbies on the 44th and 78th floors. These were arranged as express (generally larger cars that moved at higher speeds) and local elevators in an innovative system first introduced in WTC 1 and WTC 2. There were 8 express elevators from the concourse to the 44th floor and 10 express elevators from the concourse to the 78th floor as well as 24 local elevators per zone, which served groups of floors in those zones. There were seven freight elevators, only one of which served all floors. All elevators had been upgraded to incorporate firefighter emergency operation per American Society of Mechanical Engineers (ASME) A17.1 and Local Law 5 (1973).

Consistent with practice at the time, the original fire alarm system in WTC 1 and WTC 2 was a manual system with four smoke detectors on each tenant floor, positioned to monitor for smoke entering the HVAC returns and arranged to stop the fans to prevent smoke circulation to non-fire areas. Local Law 5 (1973) included retroactive requirements for fire alarm systems and emergency voice communication systems in business occupancies over 100 ft in height. Subsequently, such systems were installed in WTC 1 and WTC 2 with the required fire command center located in the underground parking garage, where it was destroyed by the blast in the 1993 bombing, rendering most fire safety features inoperable. Following the 1993 bombing, the fire command stations were relocated to the tower building lobbies, with a third monitoring location in the Port Authority offices. The lobby location (within sight of the elevators) is specified in the NYC Building Code for fire command centers required in high-rise buildings. There are no code requirements for off-site monitoring of fire alarm systems in this occupancy.

Modifications to the Fire and Life Safety Systems

The general practice is that buildings are governed by the building code in force at the time the building permits are issued except in the rare case of the adoption of retroactive requirements. Local Laws 5 (1973) and 16 (1984) were adopted after completion of WTC 1 and WTC 2 but did contain some retroactive provisions. However, the Port Authority chose to implement virtually all of the provisions of LL 5/73 and LL 16/84, which drove most of the modifications to the fire and life safety systems that occurred over the life of the buildings. These modifications included the complete sprinklering of the buildings and several upgrades to the fire alarm system.

After the passage of Local Law 5, the Port Authority implemented a program to retrofit sprinklers and to offer tenants the option of sprinklering or compartmentation consistent with Local Law 5 provisions. Sprinklering of WTC 1 and WTC 2 was undertaken in three phases: Phase 1 was the sprinklering of below grade spaces completed with the original construction. Phase 2 was begun after Local Law 5 was adopted and included the installation of sprinkler risers and other infrastructure and the installation of sprinklers in corridors, storage rooms, lobbies, and smaller tenant spaces for tenants not selecting the compartmentation option. Phase 3 involved sprinklering the remaining tenant spaces, initially as tenants changed, and later on negotiated schedules. This process was underway when, in 1984, Local Law 16 was adopted, which required sprinklers in new high-rise buildings, including offices. Under Local Law 16 (1984) all floor spaces had to either be subdivided in accordance with the compartmentation requirement or sprinklered by February 8, 1988. A 1997 report states that there were four floors and the skylobbies (all in WTC 1) left to be sprinklered and that the installation of sprinklers at these floors was underway (Coty 1997). An October 1999 report states that sprinklering of the tenant floors was completed and sprinklering of the skylobbies was "currently underway" (PANYNJ 1999).

Issues identified after completion of the buildings that were not related to amendments to the NYC Building Code that were addressed during the occupancy included the extension of the tenant separation walls to run slab to slab, upgrading of the fireproofing to 1½ in. on the floor trusses, and correction of the egress deficiencies for Windows on the World by creating three areas of refuge on each floor with 2 h separations, each including a stair. These issues were identified through various independent reviews conducted by PANYNJ and contractors hired by PANYNJ to conduct "due diligence" surveys. One example was the surveys conducted in 1996 by Rolf Jensen and Associates and Jaros, Baum & Bolles which identified inconsistencies with the code and programs to address them, which are discussed in this report in detail.

Innovations in Fire and Life Safety Features

Little about the towers' fire and life safety features would be considered novel or innovative. The fire alarm systems as originally provided and as upgraded over the life of the buildings were of high quality and state-of-the-art, but followed accepted practice as it evolved in those years. Similarly, the fire sprinkler system was high quality and state-of-the-art, following accepted practice with a few features following New York City practice that differed from the rest of the nation. This included manually operated fire pumps with a so called "standpipe telephone system" to communicate with the pump operator. Most codes and standards specify automatic fire pumps.

Two features that were novel (and thus innovative) were the use of lightweight trusses in the floor system with fire protection of sprayed fire-resistive material on steel bars (rather than angles). Another was the

shaft enclosure system of reinforced gypsum planks with applied steel channels that formed the framing. While gypsum shaft enclosure systems are now common, this particular arrangement was not used before or since.

Fuel System for Emergency Generators in WTC 7

Several of the tenants in WTC 7 installed generators to supply critical operations with continuous power. These generators were installed on several floors within the building (5, 7, 8, and 9) and fed from small (275 gal) "day tanks" near the generators. These day tanks were kept full by an automatic system of piping running to primary storage tanks (24,000 gal) located under the loading dock or a 6,000 gal tank in a 1st floor storage room associated with the generators for the Mayor's Office of Emergency Management on the 7th floor. Details of the system design and installation are found in NIST NCSTAR 1-1J.[1]

E.11 FINDINGS

The findings of this report are grouped into three categories: (1) general; (2) factors related to structural safety; and (3) factors related to fire safety.

E.11.1 General

Finding 1: The NYC Department of Buildings reviewed the WTC tower drawings in 1968 and provided comments to the PANYNJ concerning the plans in relation to the 1938 NYC Building Code. The architect-of-record submitted to the PANYNJ responses to those comments, noting how the drawings conformed to the 1968 NYC Building Code. All six comments made by the NYC Department of Buildings dealt with egress issues, but none questioned the large occupant loads for Windows on the World in WTC 1 or Top of the World in WTC 2.

Finding 2: In 1993, the PANYNJ and the NYC Department of Buildings entered into a memorandum of understanding that restated the PANYNJ's longstanding stated policy to ensure that its facilities in the City of New York meet and, where appropriate, exceed the requirements of the NYC Building Code. The agreement also provided specific commitments to the NYC Department of Buildings regarding procedures to be undertaken by the PANYNJ to ensure that buildings owned or operated by the PANYNJ are in conformance with the Building Standards contained in the NYC Building Code. Some salient points included in this agreement and the 1995 enhancement to the agreement are:

- Each project would be reviewed and examined for compliance with the Code.
- All plans would be prepared, sealed, and reviewed by New York State licensed professional engineers or architects.
- The PANYNJ engineer or architect approving the plans would be licensed in the State of New York and would not have assisted in the preparation of the plans.

[1] This reference is to one of the companion documents from this Investigation. A list of these documents appears in the Preface to this report.

- The person or firm performing the review and certification of plans for WTC tenants may be the same person or firm providing certification that the project had been constructed in accordance with the plans and specifications unless the proposed alteration would "change the character of the occupancy group under paragraph 27-237 of the NYC Building Code which would have been applicable to such space had such space been located in a privately owned building."

- Deviations from the Code, acceptable to the PANYNJ, would be submitted to the NYC Department of Buildings for review and concurrence. Disagreements between the PANYNJ and the NYC Department of Buildings over such deviations from the Code would be referred to the Port Authority Board of Commissioners for resolution.

Finding 3: While the PANYNJ entered into agreements with the NYC Department of Buildings in the 1990s with regard to conformance of PANYNJ buildings constructed in New York City to the NYC Building Code and sought review and concurrence as required by the agreements, the PANYNJ was not required to yield, and appears not have yielded, approval authority to New York City. The PANYNJ was created as an interstate entity "body corporate and politic," under its charter, pursuant to Article 1 Section 10 of the U.S. Constitution permitting compacts between states, and like many other nongovernmental and quasi-governmental entities in the United States is not subject to building and fire safety code requirements of any governmental jurisdiction.

Finding 4: State and local jurisdictions do not require retention of documents related to the design, construction, operation, maintenance, and modifications of buildings, with few exceptions. These documents are in the possession of building owners, contractors, architects, engineers, and consultants. Such documents are not archived for more than about 6 years to 7 years, and there are no requirements that they be kept in safe custody physically remote from the building throughout its service life. In the case of the WTC towers, the PANYNJ and its contractors and consultants maintained an unusually comprehensive set of documents, a significant portion of which had not been destroyed in the collapse of the buildings but could be assembled and provided to the investigation. In the case of WTC 7, several key documents could not be reviewed since they were lost in the collapse of the building.

Finding 5: Consistent with the practice at the time the (code) architect of record was responsible for specifying the fire protection and designing the egress system in accordance with the prescriptive provisions of the Building Code. The architect and owner engaged the services of structural engineers to perform the structural design and to ensure that his/her design was properly implemented. At that time the fire protection engineering profession was not sufficiently mature to require the same standard of care employed with the structural design. There is no reason to believe that the involvement of a fire protection engineer at that time would have resulted in any differences in the design or performance of the fire protection systems. However, the technical base and sophistication of the practice of fire protection engineering today is well advanced of where it was then. Today, particularly when designing a building employing innovative features, the involvement of a fire protection engineer in a role similar to the structural engineer, and under the overall coordination of the Design Professional in Responsible Charge is central to the standard of care. Further, when designing the structure of selected tall buildings or selected other buildings to resist fires, or evaluating the fire resistance of such structures, it is essential for the structural engineer and the fire protection engineer to jointly provide the needed standard of care.

E.11.2 Structural Safety

Applicable Building Codes

Finding 6: Although not required to conform to New York City codes, the PANYNJ adopted the provisions of the proposed 1968 edition of the NYC Building Code, more than 3 years before it went into effect. The proposed 1968 edition allowed the PANYNJ to take advantage of less restrictive provisions and of technological advances compared with the 1938 edition, which was in effect when design began for the WTC towers in 1962. The 1968 code:

- Changed partition loads from 20 psf to one based on weight of partitions per unit length (that reduced such loads for many buildings including the WTC buildings); and
- Permitted wind tunnel tests using models to establish design values for the wind load.

Many of these newer requirements, instituted in the 1968 NYC Building Code, are contained in current model codes and building regulations.

Structural Integrity

Finding 7: Building codes lack explicit structural integrity provisions to mitigate progressive collapse. Federal agencies have developed guidelines to mitigate progressive collapse and routinely incorporate such requirements in the construction of new federal buildings. The United Kingdom incorporates such code requirements for all buildings. New York City adopted by rule in 1973 a requirement for buildings to resist progressive collapse under extreme local loads. The rules, which were adopted after the WTC towers were built but before WTC 7 was built, applied specifically to buildings that used precast concrete wall panels and not to other types of buildings.

Finding 8: Building codes lack minimum structural integrity provisions for the means of egress (stairwells and elevator shafts) in the building core that are critical to life safety. In most tall buildings the core is designed to be part of the vertical gravity load carrying system of the structure. However, in many of those buildings, especially in regions where earthquakes are not dominant, the core may not be part of the lateral load carrying system of the structure. Thus, the core may be designed to carry only vertical gravity loads with no capacity to resist lateral loads, i.e., overturning moment and shear loads. In such situations, the structural designer may prefer the use of partition walls over structural walls in the core area to reduce building weight. The decision to have the core carry a specified fraction of the lateral design loads or be made part of a dual system to carry lateral loads, each of which would enhance the structural integrity of the core if structural walls were used, is left to the discretion of the structural engineer. Alternatively, stairway/elevator cores built with concrete or reinforced concrete block, which are not part of the lateral load carrying system, may be able to provide sufficient structural integrity if they meet some appropriate performance criteria for impact resistance. In the case of the WTC towers, the core had 2 h fire-rated partition walls with little structural integrity and the core framing was required to carry only gravity loads. Had there been a minimum structural integrity requirement to satisfy normal building and fire safety considerations, it is conceivable that the damage to stairways, especially above the floors of impact, may have been less extensive.

Finding 9: Standards and code provisions for conducting wind tunnel tests and for the methods used in practice to estimate design wind loads from test results do not exist. Building codes allow the determination of wind pressures from wind tunnel tests for use in design. Such tests are frequently used in the design of tall buildings. Results of two sets of wind tunnel tests conducted for the WTC towers in 2002 by independent commercial laboratories as part of insurance litigation, and voluntarily provided to NIST by the parties to the litigation, show large differences, of as much as about 40 percent, in resultant forces on the structures, i.e., overturning moments and base shears. Independent reviews by a NIST expert on wind effects on structures and a leading engineering design firm contracted by NIST indicated that the documentation of the test results did not provide sufficient basis to reconcile the differences. Wind loads were a major governing factor in the design of structural components that made up the frame-tube steel framing system.

E.11.3 Fire Safety

Applicable Building Codes

Finding 10: Although not required to conform to New York City codes, the PANYNJ adopted the provisions of the proposed 1968 edition of the NYC Building Code, more than 3 years before it went into effect. The 1968 edition allowed the PANYNJ to take advantage of less restrictive provisions compared with the 1938 edition that was in effect when design began for the WTC towers in 1962. The 1968 code:

- Eliminated a fire tower[2] as a required means of fire department access;
- Reduced the number of required stairwells from 6 to 3 and the size of doors leading to the stairs from 44 in. to 36 in.(by increasing stairway and door capacity allowances);
- Reduced the required fire rating of the shaft walls in the building core from 3 h to 2 h; and
- Permitted a 1 h reduction in fire rating for all structural components (columns from 4 h to 3 h and floor framing members from 3 h to 2 h) by allowing the owner/architect to select Class 1B construction for business occupancy and unlimited building height.

Many of these newer requirements, instituted in the 1968 NYC Building Code, are contained in current codes.

Finding 11: In 1993, the PANYNJ adopted a policy providing for implementation of fire safety recommendations made by local government fire departments after a fire safety inspection of a PANYNJ facility and for the prior review by local fire safety agencies of fire safety systems to be introduced or added to a facility. Later that year, the PANYNJ entered into an agreement with the New York City Fire Department (FDNY), which reiterated the policy adopted by the PANYNJ, recognized the right of FDNY to conduct fire safety inspections of PANYNJ properties in the City of New York, provided guidelines for FDNY to communicate needed corrective actions to the PANYNJ, ensured that new or modified fire

[2] A fire tower (also called a smoke-proof stair) is a stairway that is accessed through an enclosed vestibule that is open to the outside or to an open ventilation shaft providing natural ventilation that prevents any accumulation of smoke without the need for mechanical pressurization.

safety systems are in compliance with local codes and regulations, and required third-party review of such systems by a New York State licensed architect or engineer.

Standard Fire-Resistance Tests

Finding 12: Code provisions with detailed procedures to analyze and evaluate data from fire resistance tests of other building components and assemblies to qualify an untested building element do not exist. Based on available data and records, no technical basis has been found for selecting the SFRM used (two competing materials were under evaluation) or its thickness for the large-span open-web floor trusses of the WTC towers. The assessment of the fireproofing thickness needed to meet the 2 h fire rating requirement for the untested WTC floor system evolved over time:

- In October 1969, the PANYNJ directed the fireproofing contractor to apply ½ in. of fireproofing to the floor trusses.
- In 1999, the PANYNJ issued guidelines requiring that fireproofing be upgraded to 1½ in. for full floors undergoing alterations.
- Unrelated to the WTC buildings, an International Conference of Building Officials Evaluation Service report (ER-1244), re-issued June 1, 2001, using the same SFRM recommends a minimum thickness of 2 in. for "unrestrained steel joists" with "lightweight concrete" slab.

Finding 13: Code provisions that require the conduct of a fire resistance test if adequate data do not exist from other building components and assemblies to qualify an untested building element are needed. Instead, several alternate methods based on other fire-resistance designs or calculations or alternative protection methods are permitted with limited guidance on detailed procedures to be followed. Both the architect-of-record (in 1966) and the structural-engineer-of-record (in 1975) stated that the fire rating of the floor system of the WTC towers could not be determined without testing. NIST has not found evidence indicating that such a test was conducted to determine the fire rating of the WTC floor system. The PANYNJ has informed NIST that there are no such test records in its files.

Finding 14: Use of the "structural frame" approach, in conjunction with the prescriptive fire rating, would have required the floor trusses, the core floor framing, and perimeter spandrels in the WTC towers to be 3 h fire-rated, like the columns for Class 1B construction in the 1968 NYC Building Code. Neither the 1968 edition of the NYC Building Code which was used in the design of the WTC towers, nor the 2001 edition of the code, adopted the "structural frame" requirement. The "structural frame" approach to fire resistance ratings requires structural members, other than columns, that are essential to the stability of the building as a whole to be fire protected to the same rating as columns. This approach, which appeared in the Uniform Building Code (a model building code) as early as 1953, was carried into the 2000 International Building Code (one of two current model codes) which states: "The structural frame shall be considered to be the columns and the girders, beams, trusses and spandrels having direct connections to the columns and bracing members designed to carry gravity loads." The WTC floor system was essential to the stability of the building as a whole since it provided lateral stability to the columns and diaphragm action to distribute wind loads to the columns of the frame-tube system.

Finding 15: A technical basis to establish whether the construction classification and fire rating requirements in modern building codes are risk-consistent with respect to the design-basis hazard and the consequences of that hazard is needed. The fire rating requirements, which were originally developed based on experience with buildings less than about 20 stories in height, have generally decreased over the past 80 years since historical fire data for buildings suggested considerable conservatism in those requirements. However, for tall buildings, the likely consequences of a given threat to an occupant on the upper floors are more severe than the consequences to an occupant, say, on the first floor. It is not apparent how the current height and area tables in building codes consider the technical basis for the progressively increasing risk to an occupant on the upper floors of tall buildings that are much greater than about 20 stories in height where access by firefighters without the availability of firefighter elevators is limited by physiological factors. The maximum required fire rating in current codes applies to any building more than about 12 stories in height. There are no additional categories for buildings above, for example, 40 stories and 80 stories, where different building classification and fire ratings requirements may be appropriate, recognizing factors such as the time required for stairwell evacuation without functioning elevators (e.g., due to power failure or major water leakage), the time required for first responder access without functioning elevators, the presence of skylobbies and/or refuge floors, and limitations on the height of elevator shafts. The 110-story WTC towers, initially classified as Class IA based on the 1938 NYC Building Code, were classified as Class 1B before being built to take advantage of the provisions in the 1968 edition of the code. This re-classification permitted a reduction of 1 h in the fire rating of the components (columns from 4 h to 3 h and floor framing members from 3 h to 2 h).

Fire Performance of Structures

Finding 16: Rigorous field application and inspection provisions and regulatory requirements to ensure that the as-built condition of the passive fire protection, such as SFRM, conforms to conditions found in fire resistance tests of building components and assemblies is needed. For example, provisions are not available to ensure that the as-applied average fireproofing thickness and variability (reflecting the quality of application) is thermally equivalent to the specified minimum fireproofing thickness. In addition, requirements are not available for in-service inspections of passive fire protection during the life of the building. The adequacy of the fireproofing of the WTC towers posed an issue of some concern to the PANYNJ over the life of the buildings, and the availability of accepted requirements and procedures for conducting in-service inspections would have provided useful guidance

Finding 17: Structural design does not consider fire as a design condition, as it does the effects of dead loads, live loads, wind loads, and earthquake loads. Current prescriptive code provisions for determining fire resistance of structures—used in the design of the WTC towers and WTC 7—are based on tests using a standard fire that may be adequate for many simple structures and for comparing the relative performance of structural components in more complex structures. A building system with 3 h rated columns and 2 h rated girders and floors could last longer than 3 h or shorter than 2 h depending upon the performance of the structure as a 3-dimensional system in a real fire. The standard tests cannot be used to evaluate the actual performance (i.e., load carrying capacity) in a real fire of the structural component, or the structure as a whole system, including the connections between components. Performance-based code provisions and standards are not available for use by engineers, as an alternative to the current prescriptive fire rating approach, to (1) evaluate the system performance of tall-building structures under real fire scenarios, and (2) enable risk consistent design with appropriate thickness of passive protection being provided where it is needed on the structure. Standards development organizations, including the

American Institute of Steel Construction, have initiated development of performance-based provisions to consider fire effects in structural design.

Finding 18: Detailed procedures to select appropriate design-basis fire scenarios to be considered in the performance-based design of the sprinkler system, compartmentation, and passive protection of the structure are needed. The standard fire in current prescriptive fire resistance tests is not adequate for use in performance-based design. While the NFPA 5000 model building code contains general guidance on design fire scenarios (the IBC Performance Code contains no such guidance), the details of the scenarios are left to the fire engineer and regulatory official. The three major scenarios that are not considered adequately are: frequent but low severity events (for design of sprinkler system), moderate but less frequent events (for design of compartmentation), and a maximum credible fire (for design of passive fire protection on the structure). The maximum credible fire scenario for passive protection of structures would assume that the sprinkler system is compromised or overwhelmed and that there is no active firefighting, as is explicitly considered for U.S. Department of Energy facilities. These building-specific representative fire scenarios are similar in concept, though not identical, to the approach used in building design where the performance objectives and design-basis of the hazard are better defined (e.g., a two-level design that includes an operational event with a 10 percent probability of occurrence in 50 years and a life safety event with a 2 percent probability of occurrence in 50 years). The design-basis fire hazards for the WTC towers and WTC 7 are unknown, and it is difficult to evaluate the performance of the fire protection systems in these buildings under specific fire scenarios.

Finding 19: Code provisions to ensure that structural connections are provided the same degree of fire protection as the more restrictive protection of the connected elements are needed. The provisions that were used for the WTC towers and WTC 7 did not require specification of a fire-rating requirement for connections separate from those for the connected elements. It is not clear what the fire rating of the connections were when the connecting elements had different fire ratings and whether the applied fireproofing achieved that rating.

Finding 20: A technical basis to establish whether the minimum mechanical and durability related properties of SFRM are sufficient to ensure acceptable in-service performance in buildings is needed. While minimum bond strength requirements exist, there are no serviceability requirements for such materials to withstand typical shock, impact, vibration, or abrasion effects over the life of a building. There are existing testing standards for determining many of these properties, but the technical basis is insufficient to establish serviceability requirements. Knowledge of such serviceability requirements is relevant to determine the post-impact fireproofing condition of the WTC towers.

Finding 21: Validated and verified tools for use in performance-based design practice to analyze the dynamics of building fires and their effects on the structural system that would allow engineers to evaluate structural performance under alternative fire scenarios and fire protection strategies are needed. Existing tools are either too simplified to adequately capture the performance of interest or too complex and computationally demanding and lack adequate validation. While considerable progress has been made in recent years, significant work remains to be done before adequate tools are available for use in routine practice. NIST has had to further develop and validate existing tools to investigate the fire performance of the WTC towers and WTC 7.

Compartmentation and Sprinklers

Finding 22: Building fire protection is based on a four-level hierarchical strategy comprising detection, suppression (sprinklers and firefighting), compartmentation, and passive protection of the structure.

- Detectors are typically used to activate fire alarms and notify building occupants and emergency services.
- Sprinklers are designed to control small and medium fires and to prevent fire spread beyond the typical water supply design area of about 1,500 ft^2.
- Compartmentation mitigates the horizontal spread of more severe but less frequent fires and typically requires fire-rated partitions for areas of about 7,500 ft^2. Active firefighting measures also cover up to about 5,000 ft^2 to 7,500 ft^2.
- Passive protection of the structure seeks to ensure that a maximum credible fire scenario, with sprinklers compromised or overwhelmed and no active firefighting, results in burnout, not overall building collapse. The intent of building codes is also for the building to withstand local structural collapse until occupants can escape and the fire service can complete search and rescue operations.

Compartmentation of spaces is a key building fire safety requirement to limit fire spread. The WTC towers initially had 1 h fire-rated partitions separating tenants (demising walls) that extended from the floor to the suspended ceiling, not the floor above (the ceiling tiles were not fire rated). Over the years, these partitions were replaced with partitions that were continuous from floor to floor (separation wall) as required by the 1968 NYC Building Code. Some partitions had not been upgraded by 1997, and a consultant recommended to the PANYNJ that it develop and implement a survey program to ensure that the remediation process occurred as quickly as possible. It appears that with few exceptions, nearly all of the floors not upgraded were occupied by a single tenant, and it is not clear whether separation walls would have mattered in terms of meeting the 1968 code. The PANYNJ adopted guidelines in 1998 that required such partitions to provide a continuous fire barrier from top of floor to underside of slab.

Finding 23: Building codes typically require 1 h fire-rated tenant separations but do not impose minimum compartmentation requirements (e.g., 13,000 ft^2) for buildings with large open floor plans to mitigate the horizontal spread of fire. This is the case with both the 1968 NYC Building Code, which did not require sprinklers in occupied spaces on or above the ground floor, and the 2001 NYC Building Code, which requires sprinklers in Group E (Business) buildings over 100 ft in height. The sprinkler option was chosen for the WTC towers in preference to the compartmentation option in meeting the subsequent requirements of Local Law 5 adopted by New York City in 1973. Thus, if there was only one tenant on a WTC floor there would be no horizontal compartmentation requirement. Conversely, if there were a large number of tenants on a WTC floor, it would be highly compartmented with separation walls. The affected floors in the WTC towers were mostly open—with a modest number of perimeter offices and conference rooms and an occasional special purpose area. Some floors had two tenants and those spaces, like the core areas, were partitioned (slab to slab). Photographic and videographic evidence confirms that even non-tenant space partitions (such as those that divided spaces to provide corner conference rooms) provided substantial resistance to fire spread in the affected floors. For the duration of about 50 to 100 min prior to collapse of the WTC towers that the fires were active, the presence of undamaged 1 h

fire-rated compartments may have assisted in mitigating fire spread and consequent thermal weakening of structural components.

Finding 24: State and local building regulations are needed that require installation of sprinklers in existing buildings on a reasonable time schedule, not as an option in lieu of compartmentation. Functioning sprinklers can provide significant improvement in safety for most common building fires and prevent them from becoming large fires. NYC promulgated local laws in 1973 and 1984 to encourage installation of sprinklers in new buildings and is now considering a law to require sprinklers in existing buildings. The WTC towers were fully sprinklered by 2001, about 30 years after their construction. Sprinklering of the tenant floors in the WTC towers was completed by October 1999, while sprinklering of the skylobbies was still underway at that time. The sprinkler system was installed in three phases. Phase 1 was completed during initial building construction and included the sub-grade areas. Phase 2 was completed in 1976, in compliance with Local Law 5, and included sprinklering the corridors, storage rooms, lobbies, and certain tenant spaces. Phase 3 was begun in 1983 and completed in 2001 and resulted in fully sprinklering the buildings.

Finding 25: Modern building codes allow a lower fire rating for structural elements when a building is sprinklered. This trade-off provides an economic incentive to encourage installation of sprinklers. Sprinklers provide better intervention against small and medium fires, fires which are more likely to occur than a WTC disaster, as long as the water supply is not compromised and there is redundant technology in place. The required technical basis is not available to establish whether the "sprinkler trade-off" in current codes adequately considers fire safety risk factors such as: (1) the complementary functions of sprinklers and fire-protected structural elements, (2) the different fire scenarios for which each system is designed to provide protection, and (3) the need for redundancy should one system fail. It is noteworthy that the British Standards Institution has established a group to review all the sprinkler trade-offs contained in their standards. No such formal review has yet been initiated in the United States. Although the classification and fire rating of the WTC towers did not take advantage of the sprinkler-tradeoff since such provisions were not contained in the 1968 NYC Building Code, had such provisions existed, they would have permitted a lower fire rating for many WTC building elements.

Use of Elevators in Emergencies

Finding 26: With a few special exceptions, building codes in the United States do not permit the use of fire-protected elevators for routine emergency access by first responders or as a secondary method (after stairwells) for emergency evacuation of building occupants. The use of elevators by first responders would additionally mitigate counterflow problems in stairwells. While the United States conducted research on specially protected elevators in the late 1970s, the United Kingdom along with several other countries that typically utilize British standards have required such "firefighter lifts," located in protected shafts, for a number of years. Without functioning elevators (e.g., due to a power failure or major water leakage), first responders carrying gear typically require about a minute per floor to reach an incident using the stairs. While it is difficult to maintain this pace for more than about the first 20 stories, it would take a first responder about an hour to reach, for example, the 60th floor of a tall building if that pace could be maintained. Such a delay, combined with the resulting fatigue and physical effects on first responders that were reported on September 11, 2001, would make firefighting and rescue efforts difficult even in tall building emergencies not involving a terrorist attack. Each of the WTC towers had 106 elevators, and WTC 7 had 38 elevators. By code, the elevators could not be used for fire service access or

occupant egress during an emergency since they were not fire-protected, nor were they located in protected shafts. The elevators were equipped through normal modernization with fire service recall. Most were damaged by the aircraft impacts; though prior to the impact in WTC 2 the elevators were functioning and contributed greatly to the much faster initial evacuation rate in WTC 2.

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Chapter 1
INTRODUCTION

1.1 BACKGROUND

On September 11, 2001, the 110-story twin towers of the World Trade Center (WTC) complex[1] (WTC 1 and WTC 2) were each attacked by a hijacked Boeing 767 airplane. The first airplane struck WTC 1 at 8:46 a.m. Eastern Daylight Time, and the second airplane struck WTC 2 at 9:03 a.m. Eastern Daylight Time. The impact of the airplanes caused severe damage to the buildings and significant fire. WTC 1 collapsed at 10:29 a.m. and WTC 2 at 9:59 a.m. Debris from the collapse of the towers caused severe damage to surrounding buildings of the WTC complex (WTC 3 through WTC 7). WTC 7, a 47-story office building, burned unattended for about 7 h before collapsing at 5:20 p.m.

As stated in the Preface, the National Institute of Standards and Technology (NIST) Investigation is comprised of eight interdependent projects (refer to Table P–1). This report presents the results of Project 1 "Analysis of Building and Fire Codes and Practices." The project was carried out to support one of the four primary objectives of the NIST Investigation, which is to determine the procedures and practices that were used in the design, construction, operation, and maintenance of the WTC 1, 2, and 7 (for other objectives, see the Preface). This report documents criteria used to design and construct the buildings and maintenance of the structural and fire safety systems. It also addresses innovative systems and materials that were incorporated into the design and construction process. Based on this information, NIST has identified procedures and practices for which improvements are recommended.

1.2 SCOPE OF REPORT

The assessment of the criteria, procedures, and practices that were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7 involved reviewing the design and construction documents of these buildings, including design drawings, specifications, and design calculations. In addition, since the 1968 New York City (NYC) Building Code was adopted by the Port of New York Authority (whose name was changed to the Port Authority of New York and New Jersey [PANYNJ or Port Authority] in 1972, and is subsequently referred to as the Port Authority herein) for design and construction of the WTC 1, 2, and 7, review of relevant provisions of that code and similar provisions of other contemporaneous codes was necessary to place in context the design and construction practices that were used for WTC 1, 2, and 7.

Traditionally, owners and designers of major construction projects maintain the design and construction documents. In the case of the WTC buildings, the design and construction documents that were kept at the Port Authority office in WTC 1 were destroyed when the tower collapsed. Thus, available copies of design and construction documents of WTC 1, 2, and 7 had to be assembled from various sources that were associated with the WTC projects.

[1] The WTC complex was composed of seven buildings. They are referred to as WTC 1 through WTC 7 in this report. For specific details, see Sec. 2.1.

NIST obtained a considerable amount of information (design drawings, shop drawings, specifications, project correspondence, and inspection reports) related to WTC 1 and WTC 2 from the structural engineering firm involved in the original design and subsequent modifications to WTC 1 and WTC 2. The Port Authority provided construction related files for WTC 1, 2, and 7, mostly pertaining to tenant alteration projects, wherein tenants modified parts of the buildings to meet their needs. No document was obtained from the general contractor of WTC 1, 2, and 7 who had discarded the construction documents after retaining them for about 7 years. As a result, records were not available from the general contractor pertaining to changes to the structural and fire safety systems that were made during construction.

The information collected enabled NIST to document the following:

- Factors related to the design and construction of structural systems:
  - Provisions used to design and construct the buildings.
  - Criteria used to proportion structural members and other components of the buildings, including structural connections.
  - Innovative systems, technologies, and materials that were incorporated in the design and construction.
  - Tests performed to support the design, such as wind tunnel tests and tests of structural assemblies.
  - Deviations granted by the Port Authority, including the justification for those deviations.
  - Special fabrication and inspection requirements.
  - Inspection protocols used during construction.
  - Technical problems that occurred during construction of the buildings and their resolution.
- Comparison of the structural provisions in the 1968 New York City (NYC) Building Code with other contemporaneous code provisions:
  - Differences between the 1968 NYC Building Code and the contemporaneous building codes of New York State, Chicago, and Building Officials and Code Administrators, International (BOCA), and the 2001 NYC Building Code.
- Maintenance of and modifications to the structural system:
  - Guidelines used by the Port Authority for inspection, repair, and modifications.
  - Structural integrity inspection programs during the occupancy of the buildings.
  - Any significant modifications to and/or repairs of the original structural framing system by the owner or tenants during original construction and occupancy.

- Factors related to the design and construction of the fire protection and egress systems:
  - Provisions used to design and construct the fire protection and egress systems of the buildings.
  - Building regulations adopted after the issuance of the certificates of occupancy that were applied to the buildings retroactively, including any provisions of New York City Local Laws, and any permits issued or special inspections required resulting from the installation of special hazards or equipment in the buildings.
- Comparison of the fire safety provisions in the 1968 NYC Building Code with other contemporaneous code provisions:
  - Differences between the 1968 NYC Building Code and the contemporaneous building codes of New York State, Chicago, and Building Officials Conference of America (BOCA), and the 2001 NYC Building Code.
  - Evolution of the life safety provisions in the NYC Building Code since the design of WTC 1 and WTC 2.
- Maintenance of and modifications to the fire protection and egress systems:
  - Guidelines used by the Port Authority for inspection, repair, and modifications to fire protection and egress systems.
  - Any repairs and modifications made to the passive and active fire protection systems from initial occupancy to September 11, 2001.
- The fuel system for emergency power in WTC 7 to determine:
  - Locations of emergency power generating systems.
  - Size and locations of the fuel storage tanks and distribution systems.
  - Specific fire protection systems used for the fuel storage and distribution systems.
  - Normal and emergency operating procedures.
  - Maintenance history.

This report provides an overview and comparison of building codes in use at the time when WTC 1, 2, and 7 were designed and constructed. It includes a description of the buildings as designed and relates features of the buildings to the code requirements and accepted practices of the time. Also presented is the evolution of codes during the time the buildings were in use and a description of how the buildings were modified and upgraded over the same period. Even though many of the new code requirements did not apply to existing buildings, in several instances these new approaches were incorporated and systems upgraded accordingly. Also identified were some issues that were not consistent with code requirements, such as the sprayed fire-resistive materials and tenant separation walls that were eventually addressed by

upgrade projects. The upgrades were performed on change of tenancy over many years. The reader should note that the documentation of certain systems and their condition and arrangement on September 11, 2001 are included in other reports. Specifically, the elevators and egress stairs are discussed in NIST NCSTAR 1-7, and the fire alarm, sprinkler, and smoke management systems in NIST NCSTAR 1-4. These references are to the companion documents from this Investigation. A list of these documents appears in the Preface to this report.

1.3 DESIGN AND CONSTRUCTION REQUIREMENTS FOR WTC 1, 2, AND 7

For most buildings constructed in the United States, building codes adopted by local jurisdictions establish minimum requirements for design and construction. However, because the Port Authority is an interstate entity, which was established in 1921 under a clause in the U.S. Constitution, its construction projects are not required to comply with any state or local building code. For the design of the WTC towers, which began in 1962, the Port Authority in May 1963 instructed the architect and engineers to prepare their designs of WTC 1 and WTC 2 to comply with the NYC Building Code.[2] While not specifically stated in the 1963 letter to the architect, the 1938 edition of the Code was in effect at that time. In areas where the Code was not explicit or where technological advances made portions of the 1938 Code obsolete, the Port Authority also directed the architect and engineers to propose designs "based on acceptable engineering practice." When such situations occurred, the Port Authority required the architect and engineers to inform the Planning Division of the WTC. The Port Authority established a special WTC office that reviewed and approved plans and specifications, issued deviations, and conducted inspections during construction instead of the city agencies that would normally perform these duties.

In September 1965, the Port Authority instructed the architect and engineers to revise their designs for WTC 1 and WTC 2 to comply with the second and third drafts of the NYC Building Code that was under development and to undertake any design modifications necessary to comply with the new code provisions.[3] Prior to issuance of this instruction, the Port Authority recognized that the draft version of the new NYC Building Code had incorporated advanced techniques, and the Port Authority favored the use of advanced techniques in the design of the WTC towers.[4] By adopting the draft versions of the new NYC Building Code, the Port Authority had an option of classifying WTC 1 and WTC 2 as Type 1-B Construction instead of Type 1-A Construction (see Sec. 9.1.3 for definition and fire protection requirements of Construction Type), and several architectural features related to egress were modified in the final design (see Sec. 10.1). This relaxation of code requirements allowed the Port Authority to gain economic advantage.[5] The new NYC Building Code (NYC BC 1968) was enacted by the City Council on October 22, 1968, approved by the Mayor on November 6, 1968, and became effective on December 6, 1968.

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[2] Letter dated May 15, 1963 from Malcolm P. Levy (Chief, Planning Division, World Trade Department, PANYNJ) to Minoru Yamasaki (architect, Minoru Yamasaki & Associates) (See Appendix A).

[3] Letter dated September 29, 1965 from Malcolm P. Levy (Chief, Planning Division, World Trade Department, PANYNJ) to Minoru Yamasaki (architect, Minoru Yamasaki & Associates) (See Appendix A).

[4] Memorandum dated June 22, 1965 from John M. Kyle (Chief Engineer, PANYNJ) to Malcolm P. Levy (Chief, Planning Division, World Trade Department, PANYNJ) (See Appendix A).

[5] Memorandum dated January 15, 1987 fromLester S. Feld (Chief Structural Engineer, World Trade Department) to Robert J. Linn (Deputy Director, Physical Facilities, World Trade Department) (See Appendix A).

The Port Authority also required that all design concepts were to be reviewed before the final design by the Chief Engineer of the Port Authority and by the appropriate New York City agencies. A letter in 1975 from the architect-of-record for the WTC project to the Port Authority indicates that the New York City Building Department reviewed the design drawings of WTC 1 and WTC 2 in February 1968.[6]

Unlike WTC 1 and WTC 2, which were developed and owned by the Port Authority, WTC 7 was developed on land owned by the Port Authority, but the building was owned by Seven World Trade Company and Silverstein Development Corporation, General Partners. It was designed and constructed as a "Tenant Alteration Project" of the Port Authority. When WTC 7 was designed in the mid-1980s, the 1968 NYC Building Code with amendments was in effect. The Project Specifications for WTC 7, issued in 1984, required that the structural steel be designed in accordance with the then current NYC Building Code.

The Port Authority developed a tenant alteration process for any modifications to leased spaces in WTC 1 and WTC 2 to maintain structural integrity and fire safety. In 1971, the Port Authority issued the first edition of a set of requirements, *Tenant Construction Review Manual* (see NIST NCSTAR 1-1C, Appendix A), shortly after the first tenants occupied WTC 1 in December 1970 and before initial occupancy of WTC 2 in 1972. The manual contained the technical criteria to be used in planning alterations (architectural, structural, mechanical, electrical, and fire protection) to suit the needs of tenants. The manual included applicable standards to be used by tenants and their agents and review criteria to be used by the Engineering Department of the Port Authority. Alteration designs were to be completed by registered design professionals, and at the completion of the work, as-built drawings were to be submitted to the Port Authority. The 1968 NYC Building Code was referenced, and specific code provisions were referenced in various checklists. The review manual was updated in 1979, 1984, 1990, and 1997, at which times changes that had been made to the NYC Building Code were incorporated. In 1998, the manual was complemented by *Architectural and Structural Design Guidelines, Specifications, and Standard Details* (see NIST NCSTAR 1-1C, Appendix F), which dealt specifically with alterations to WTC 1 and WTC 2. Since WTC 7 was built as a "tenant alteration project," its design and construction followed the requirements in the 1984 edition of the *Tenant Construction Review Manual*. Any modifications to the building after initial occupancy were carried out in accordance with the manual.

1.4 ORGANIZATION OF REPORT

This report is organized in fourteen chapters:

- Chapter 1 covers the background and the scope of the report.
- Chapter 2 presents architectural and structural descriptions of WTC 1, 2, and 7.
- Chapter 3 presents the evolution of building codes in the United States, the development of the building code of New York City, and design requirements and policies of the Port Authority of New York and New Jersey.

[6] Letter dated February 18, 1975 from Joseph H. Solomon (Architect, Emory Roth & Sons) to Malcolm P. Levy (General Manager, World Trade Center Operations) (See Appendix A).

- Chapter 4 provides an overview and comparison of building codes in use at the time WTC 1, 2, and 7 were designed and constructed. Also presented is the evolution of codes during the time the buildings were in use and how the buildings were modified and upgraded over the same period. The structural code provisions compared include the 1964 New York State Building Construction Code, the 1965 BOCA model building code, and the 1967 Municipal Code of Chicago. A comparison was also made between the 1968 NYC Building Code and the current (2001) NYC Building Code.

- Chapter 5 presents the criteria for structures used to design WTC 1, 2, and 7.

- Chapter 6 presents innovative features incorporated in the structural design of WTC 1 and WTC 2.

- Chapter 7 presents the protocols for inspection of steel members during fabrication and erection, and deviations that were requested by fabricators and the erector and granted by the Port Authority.

- Chapter 8 covers structural maintenance and modifications to WTC 1, 2, and 7 during occupancy.

- Chapter 9 compares the fire safety provisions in the 1964 New York State Building Construction Code (NYSBC 1964), the 1965 BOCA model building code (Basic Building Code), and the 1967 Municipal Code of Chicago (MCC 1967). A comparison was also made between the 1968 NYC Building Code and the current (2001) NYC Building Code. This chapter also describes various construction classifications of buildings.

- Chapter 10 describes passive and active fire protection systems used in WTC 1, 2, and 7, and egress provisions in the WTC towers.

- Chapter 11 presents maintenance of and modifications to fire safety systems in WTC 1, 2, and 7 during occupancy.

- Chapter 12 presents the fuel system distribution for emergency power generators in WTC 7.

- Chapter 13 presents the findings of this report.

- Chapter 14 covers the reference cited in this report.

Chapter 2
DESCRIPTION OF WTC 1, 2, AND 7

2.1 SITE PLAN OF WTC COMPLEX

The World Trade Center (WTC) complex was located in Manhattan, New York City, near the Hudson River. The complex was comprised of seven buildings (referred to in this report as WTC 1 through WTC 7). Figure 2–1 depicts the locations of these buildings relative to the surrounding streets. The two towers, WTC 1 (North Tower) and WTC 2 (South Tower), were each 110 stories high. WTC 3 (Marriott Hotel) was 22 stories. WTC 4 (South Plaza Building) and WTC 5 (South Plaza Building) were both nine-story office buildings. WTC 6 (U.S. Customs House) was an eight-story office building. These six buildings were built around a 5-acre WTC Plaza. WTC 7 was a 47-story office building which was built just north of the six-building WTC site. There was a six-story subterranean structure below a large portion of the WTC Plaza and WTC 1, 2, 3, and 6. In order to build this subterranean structure, a bentonite slurry wall was built surrounding the perimeter of the subterranean structure prior to excavation. The slurry wall was replaced section by section with reinforced concrete wall which served as a continuous foundation wall for the subterranean structure. The reinforced concrete wall was temporarily supported by rock anchors to provide lateral stability. The permanent lateral support was provided by the subterranean floor slabs. The application of slurry wall technology was considered to be an innovative idea (ENR 1964).

The first six buildings on the site were developed by the Port Authority. Groundbreaking for WTC 1 and WTC 2 was in 1966, and the first tenant began to occupy WTC 1 in December 1970 and WTC 2 in January 1972. Construction of other buildings continued during the 1970s and the 1980s.[7] Construction of the last building, WTC 7, was completed in 1987. It was developed by a consortium of Seven World Trade Company and Silverstein Development Corporation.

2.2 DESCRIPTION OF WTC 1 AND WTC 2

2.2.1 Building Description

WTC 1 and WTC 2 (also known as North Tower and South Tower) each consisted of a 110-story structure above the Concourse level (109-story above the Plaza level) and 6-story structure below the Concourse level.[8] Although the towers were similar, they were not identical. The height of WTC 1 at the roof level was 1,368 ft above the Concourse level, 6 ft taller than WTC 2, and WTC 1 supported a 360 ft tall antenna for television and radio transmission. Figure 2–2 shows the west elevation of WTC 1, and Fig. 2–3 shows a typical exterior wall from the foundation to floor 9.

[7] A brochure entitled "The World Trade Center" published by the Port of New York Authority, New York, NY and "World Trade Center Fact Sheet" published by the Port Authority of New York and New Jersey, New York, NY, April 1994.

[8] The architectural and structural descriptions and dimensions of the WTC buildings in this report are based on the design drawings of these buildings obtained from the Port Authority of New York and New Jersey.

Each tower had a square plan with the side dimension of approximately 207 ft. The exterior columns (perimeter columns) were placed with respect to the column reference lines, wherein the geometric centers of the exterior columns were offset from the column reference lines (see Sec. A-A, Fig. 2–9). The four reference lines surrounding the base of the tower established the footprint of the building. The column reference lines were spaced at 207 ft 2 in. The corners of the tower were chamfered 6 ft 11 in.

Each tower had a core service area of approximately 135 ft by 87 ft. All elevators were located within the core. Three stairs were also located within the core except at the mechanical floors where the stairs were located outside the structural core area (the area enclosed by the four corner columns of the core). For detailed descriptions of the stair locations, see Table 2–1, NIST NCSTAR 1-7. A typical architectural floor plan in the tower is shown in Fig. 2–4. As can be seen in this figure, placing all service systems within the core provided nearly a column-free floor space of approximately 31,000 ft^2 per floor outside the core. The long axis of the core in WTC 1 was oriented in the east-west direction, while the long axis of the core in WTC 2 was oriented in the north-south direction. Design wind forces were different for the two towers (the presence of one tower had an effect on the wind pressures on the other tower, see NIST NCSTAR 1-2), and that resulted in somewhat different lateral-force resisting system design. Thus, the two towers appear similar, but they were structurally different.

The exterior walls were composed of steel columns and spandrel beams. Above the 7th floor level, the columns were welded steel plate box columns of an approximately 14 in. square section. Each building face consisted of 59 columns spaced at 3 ft 4 in. on center. Adjacent columns were interconnected at each floor level by deep spandrel plates, typically 52 in. deep. As seen in Fig. 2–3, below floor 7, the columns are combined in groups of three to form single base columns which are spaced 10 ft on center. The external cladding, which covers the columns and spandrel beams, consisted of aluminum sheets. The window openings were infilled with glass fitted into aluminum frames and sealed with neoprene gaskets.

Fire protection of structural steel members in the WTC towers was provided by fire resistive materials, either sprayed fire-resistive materials (SFRMs), gypsum wallboards, or a combination of the two, depending upon the type of structural members. All floor trusses and beams were protected with SFRM. The columns inside the core were either covered with gypsum wall board or a combination of gypsum wall board and SFRM. For the exterior columns, vermiculite plaster was applied to the side of the column facing the interior of the building, whereas SFRM was applied to the other three faces. No fire resistive material was applied to the underside of the metal deck, which was in contact with the concrete slab above. For a detailed discussion of the passive fire protection of steel members, see NIST NCSTAR 1-6A.

For typical tenant floors, the ceiling was suspended from the steel trusses. The space between the ceiling and the floor above was used for the mechanical and electrical systems.

Elevators were the primary mode of routine ingress and egress from the towers for tens of thousands of people on a daily basis. In order to minimize the total floor space needed for elevators, each tower was divided into three zones by the skylobbies, which served to distribute passengers among express and local elevators (for details, see NIST NCSTAR 1-7). In this way, the local elevators within a zone were placed on top of one another within a common shaft. Figure 2–5 shows the elevator riser diagram for WTC 1 and WTC 2. People transferred from express elevators to local elevators at the skylobbies which were located on the 44th and 78th floors in the both towers. Each tower had 99 elevators within the core of the building, including seven freight elevators, most serving a particular zone, and dedicated express

elevators that served the restaurant, bars, and ballrooms on floors 106 and 107 of WTC 1, as well as the observation deck in WTC 2. The concept of multiple elevators in a common shaft was first used in the WTC towers and has since become the norm for buildings taller than about 50 stories. This approach allowed an increase of useable space in WTC 1 and WTC 2 from 62 percent to 75 percent per floor (Sullivan 1964).

The architectural design was performed by Minoru Yamasaki & Associates, with Emory Roth & Sons, P.C. serving as the architect of record. The structural engineer of record was the firm of Skilling, Helle, Christiansen, Robertson (SHCR). Jaros, Baum & Bolles were the mechanical engineers, and Joseph R. Loring & Associates were the electrical engineers. Tishman Construction Corporation was the general contractor. The foundation of the towers was designed by the Engineering Department of the Port of New York Authority (see footnote 6).

2.2.2 Structural Description

As described above (Sec. 2.2.1), both WTC 1 and WTC 2 were 116 stories above the foundation (110 stories above grade and 6 stories below grade). The buildings were square in plan, 207 ft 2 in. by 207 ft 2 in. (based on column centerline dimensions).

(see NIST NCSTAR 1-2A), and the WTC towers behaved more like a framed tube than a moment-resisting frame.

The floor inside the core and the mechanical floors were framed with structural steel shapes with welded shear studs, acting compositely with normal-weight concrete slabs. The thickness of concrete slab in these floors varied from 4.5 in. to 8 in. depending upon the design load requirements. The area outside the core (typically tenant floors) was framed with steel trusses, acting compositely with 4 in. thick lightweight concrete slabs cast on 1½ in., 22 gauge fluted metal deck. The trusses consisted of double angle top and bottom chords with round bar webs. The composite action was achieved by the shear connection provided by the web bar extending above the top chord and into the slab in the form of a "knuckle" (see Fig. 2–14). Pared trusses, spaced at 6 ft 8 in. on center, were supported at every other exterior column. The metal deck which spanned parallel to the main trusses was directly supported by transverse bridging trusses spaced at 13 ft 4 in. and intermediate deck support angles spaced at 6 ft 8 in. from the transverse bridging trusses. The typical floor consisted of three truss zones; a long-span zone, a short-span zone, and a two-way zone (see Fig. 2–15). The span of the trusses was about 35 ft in the short-span zone and 60 ft in the long-span zone.

The floor trusses were pre-assembled into floor panels. The prefabricated floor panels were typically 20 ft wide, containing two sets of double trusses in the interior and a single truss along each edge. In addition, the bottom chord of each pair of trusses was attached to perimeter spandrels with viscoelastic dampers (see Fig. 2–16). The main purpose of these dampers was to supplement the steel frame in limiting wind-induced building oscillations.

Pairs of flat bars (straps) extended diagonally from the top chord of the floor trusses to the perimeter columns (see Fig. 2–13). Once in place, 4 in. of lightweight concrete was placed on the steel deck. Figure 2–17 shows an assembled floor panel before the concrete was placed.

The minimum yield strengths of the steel for the design of the floor trusses were specified to be 36 ksi and 50 ksi for different parts of the trusses. According to the fabrication drawings prepared by Laclede Steel Company, both 36 ksi and 50 ksi steels were specified.

Hat Trusses

At the top of each tower (floor 107 to the roof), an assembly of hat trusses interconnected the core columns and the exterior wall panels (see Fig. 2–18). Diagonals of the hat truss were typically W12 or W14 wide flange members. In addition, four diagonal braces (18 in. by 26 in. box beams spanning the 35 ft gap, and 18 in. by 30 in. box beams spanning the 60 ft gap) and four horizontal floor beams connected the hat truss to each perimeter wall at the floor 108 spandrel. The hat truss was designed primarily to provide a base for antennae atop both towers, although only the WTC 1 antenna was actually built. The hat truss also controlled the expansion and contraction of the tower due to unequal column temperatures, although not specifically designed for this purpose.

2.3 DESCRIPTION OF WTC 7

2.3.1 Building Description

WTC 7 was a 47-story commercial office building, completed in 1987. Its location relative to the WTC Plaza is shown in Fig. 2–1. It contained approximately 2 million ft^2 of floor area. A typical floor plan above floor 7 is shown in Fig. 2–19. WTC 7 was connected to the WTC complex with a 120 ft wide elevated plaza at floor 3, and a 22 ft wide pedestrian bridge, also at floor 3.

The overall dimensions of WTC 7 were approximately 330 ft long, 140 ft wide, and 610 ft high. The building was constructed over a pre-existing electrical substation owned by Consolidated Edison (Con Edison). The original plans for the Con Ed Substation included supporting a high-rise building, and the foundation was sized for the planned structure. However, the final design for WTC 7 had a larger footprint than originally planned. The building elevations are shown in Fig. 2–20. Over the years, numerous structural modifications were made throughout the building, mainly to suit its largest tenant, Salomon Brothers Inc. (later to become Salomon Smith Barney, now CitiGroup), who leased 25 of the 47 floors. One of the more substantial modifications was the addition of a penthouse that was used to house the chiller plant and the cooling towers for Salomon Brothers. Also, large portions of the 41st and 43rd floor slabs and the floor framing were removed on the east side of the building to accommodate trading floors for Salomon Brothers. The removed floor areas were subsequently restored after the trading activity was moved to another venue.

Above floor 7, the building had typical steel framing for high-rise construction. The floor systems had composite construction with steel beams supporting concrete slabs on metal decks, with a floor thickness of 5.5 in. The core and perimeter columns supported the floor system and carried their loads to the foundation. The perimeter moment frame also resisted wind forces. Columns above floor 7 did not align with the foundation columns, so braced frames, transfer trusses, and transfer girders were used to transfer loads between these column systems, primarily between floors 5 and 7. Floors 5 and 7 were heavily reinforced concrete slabs on metal decks, with thicknesses of 14 in. and 8 in., respectively.

The architectural design was performed by Emory Roth & Sons, P.C. The structural engineer of record was the Office of Irwin G. Cantor, P.C. Syska & Hennessy, P.C. was the mechanical engineer. Tishman Construction Corporation was the general contractor.

Consolidated Edison Substation

The Con Edison Substation was constructed in 1967 and consisted of a steel framed structure with cast-in-place concrete floors and walls. It was placed on the northern portion of the site and extended approximately 40 ft north of the north facade of WTC 7, as shown in Fig. 2–21. Its southern boundary was irregular, but extended approximately one-third to two-thirds of the width of WTC 7. The Con Edison Substation was three stories high.

The substation's lateral system consisted of a moment frame along the northern row of interior columns. Along the south edge of the substation there was a braced frame. This braced frame was coincident with the north side of the WTC 7 core. Lateral loads from WTC 7 were passed directly from the core above to the Con Edison braced frame below. There were also two moment frames within the substation, oriented in the north-south direction, one on each end of the WTC 7 core.

The WTC 7 columns**,** which were within the perimeter of the substation**,** were supported by substation columns. During the construction of WTC 7, heavy plates were welded to the tops of the existing substation columns, which then supported the new building columns.

The exterior columns above the Con Edison structure that did not align with the columns of the Con Edison structure were supported by a series of transfer girders. The arrangements of the transfer girders are described in detail in Sec. 2.3.2.

2.3.2 Structural Description

Typical Floor Systems above Floor 7[9]

The typical floor framing system, shown in Fig. 2–22, was composed of rolled steel wide-flange beams with composite metal decking and concrete slabs. Floors 8 through 45 had essentially the same framing plan, but the core layout varied over the height of the building.

Floors 8 through 45 had floor slabs with a total thickness of 5.5 in. that were composed of 3 in., 20 gauge metal deck with 2.5 in., normal weight concrete of 3,500 psi. There was one layer of 6x6 W1.4xW1.4 welded wire fabric within the concrete. The structural design drawings show a second layer of welded wire fabric placed over girders at the slab edges. The fastening requirements for the metal deck are not shown on the drawings. The drawings contain a note calling for 1.5 in., 20 gauge deck with 4 in. concrete topping (5.5 in. total) in the elevator lobbies, where there was a 3 in. floor finish specified by the architect.

Typical floor framing for floors 8 through 20 and floors 24 through 45 consisted of 50 ksi wide-flange beams and girders. A grid of beams and girders spanned between the core columns. Core girders ranged in size from W16x31 to W36x135, depending on the span and load. (W16x31 describes a steel wide-flange beam, sometimes referred to as an 'I' beam; the nomenclature indicates the cross section is nominally 16 in. deep and weighs 31 lb per lineal foot.) Beams spanned directly between the core and the exterior of the building, at approximately 9 ft on center. On the north and east sides, the typical beam was a W24x55 with 28 shear studs, spanning 53 ft. On the south side, the typical beam was a W16x26 with 24 shear studs spanning 36 ft. Between the exterior columns were moment connected girders that formed part of the lateral-load-resisting system of the building. On floors 10, 19, and 20, a portion of the floor framing was reinforced with plates attached to the bottom flange. Certain connections at these floors were also reinforced.

Floors 21 to 23 had slightly heavier steel framing than the typical floors. Core girders were generally one size class larger than the typical floor; the beams between the core and the south facade were W16x31 instead of W16x26. There were additional studs on the W24x55 beams on the north and west sides.

Most of the beams and girders were made composite with the slabs through the use of shear studs. Typically, the shear studs were 0.75 in. in diameter by 5 in. long, spaced 1 ft to 2 ft on center.

[9] Structural descriptions are determined from the design drawings.

Floor Framing of Other Floors

The remaining floors, floors 1 to 7 and floors 46 to 47, were atypical. Floor 1 was built adjacent to the Con Edison substation and included the truck ramp for the WTC complex (see Fig. 2–21). The floor was framed with steel beams that were encased in a formed concrete slab. The floor slab was 14 in. The southeast portion of the floor above the WTC truck ramp had a 6 in. formed concrete slab. The floor slabs for floors 2, 3, 4, and 6 had a 3 in., 20 gauge metal deck with 3 in. normal weight concrete, for a total thickness of 6 in. Floors 2 and 3 were also partial floors adjacent to the substation. In addition, they had a floor opening on the south side to form the atrium above the ground level lobby. Floor 4 was above the substation and had a large opening over most of the south side of the building to form a double-height space above the 3rd floor lobby. Floor 5 had an 11 in. thick slab of normal weight concrete on top of 3 in., 18 gauge steel deck for a total slab thickness of 14 in. The slab was heavily reinforced with #7 reinforcing bars spaced at 12 in. on center in both directions on top and #9 reinforcing bars spaced at 12 in. on center on bottom. This floor also had steel WT sections embedded in the 11 in. concrete slab above the steel deck. The WT sections were designed to act as a horizontal truss within the plane of the floor between the perimeter and core columns (see Fig. 2–23). Floor 6 had two openings on the floor to form a double-height mechanical space, one at the east side and the other at the southeast corner. Floor 7 had 5 in. normal weight concrete on top of 3 in., 18 gauge metal deck, which made a total thickness of 8 in. The slab was reinforced with #5 reinforcing bars spaced at 6 in. on center in both directions.

Columns

Core columns were primarily rolled wide-flange shapes of grade 36 or 50 steel. As the loads increased toward the base of the building, many of these column sizes were increased through the use of built-up shapes. These built-up columns had a W14x730 core with cover plates welded to the flanges (to form a box) or web plates welded between the flanges as shown in Fig. 2–24. The reinforcing plate welds were specified to be continuous 0.5 in. fillet welds at the cover plates and 0.313 in. minimum at the web plates. Plate thickness ranged from 1.5 in to 8 in. Steel used for reinforcing plates were specified as follows:

Plate thickness t (in.):

$2 < t < 4$	ASTM A 588 Grade 50
$4 < t < 6$	ASTM A 572 Grade 42
$t > 6$	ASTM A 588 Grade 42

Typical core column splices were specified to be milled. The splice plates were welded or bolted to the outsides of the column web and flanges. Built-up columns were also milled at their bearing ends, but the splice plates were fillet welded to the cover plates.

Perimeter columns were nominally 14 in. wide-flange shapes (W14) of ASTM A 36 steel. Perimeter column splices were similar to the core column splices.

Column Transfer Trusses and Girders

Because the layout of the substructure and Con Edison columns did not align with the column layout in the upper portion of WTC 7, a series of column transfers were constructed. These transfers occurred

primarily between floors 5 and 7. See Fig. 2–25 for a schematic rendering of the transfer trusses and girders.

Columns 47 through 54, at the north facade, were transferred at floor 7 by cantilever girders to bring them in line with the substation columns, offset 6 ft to 9 ft to the south. The back-span of these cantilevers was supported by the north side core columns. The eastern most cantilever girder was connected to truss #1, and the western most cantilever girder was connected to truss #3.

Column 76 was supported at floor 7 by truss #1. The west side of truss #1 was supported by column 73, while the east side was supported by a transfer girder running north-south which was, in turn, supported by columns E3 and E4 at floor 5.

Columns 58, 59, and 78 were transferred by simply supported girders at floor 7. Column 78 was supported at floor 7 by a transfer girder that was supported at its north end by truss #2. Column 77 was also supported by truss #2. Truss #2 was supported by column 74 at its west end and by column 80 at its east end.

Column 61 was supported by truss #3. Truss #3 runs north-south and was supported by columns 62 and 61A. Truss #3 has a 10 ft cantilever span between column 61 and column 61A and an 18 ft back-span to column 62.

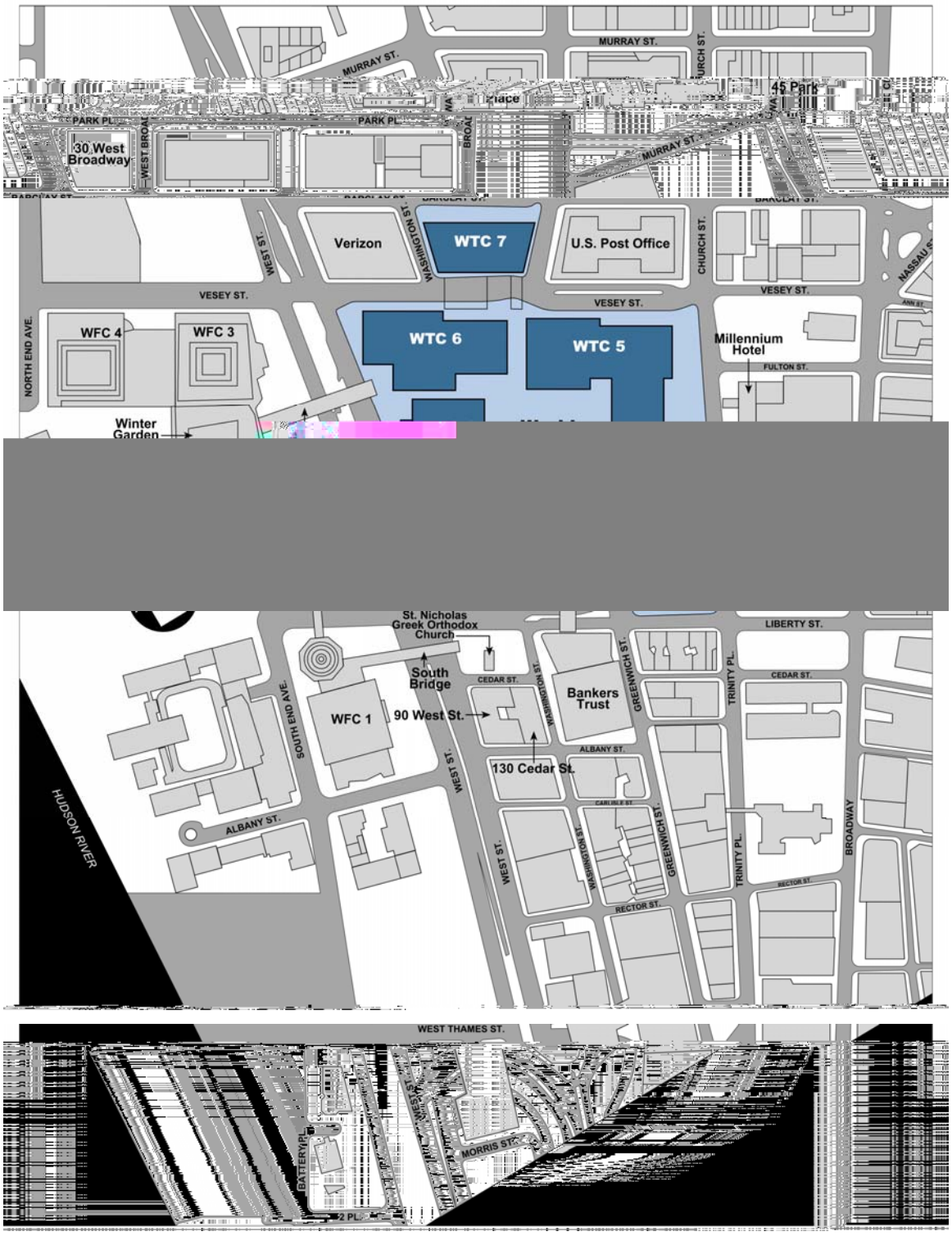


Figure 2–1. WTC site plan.

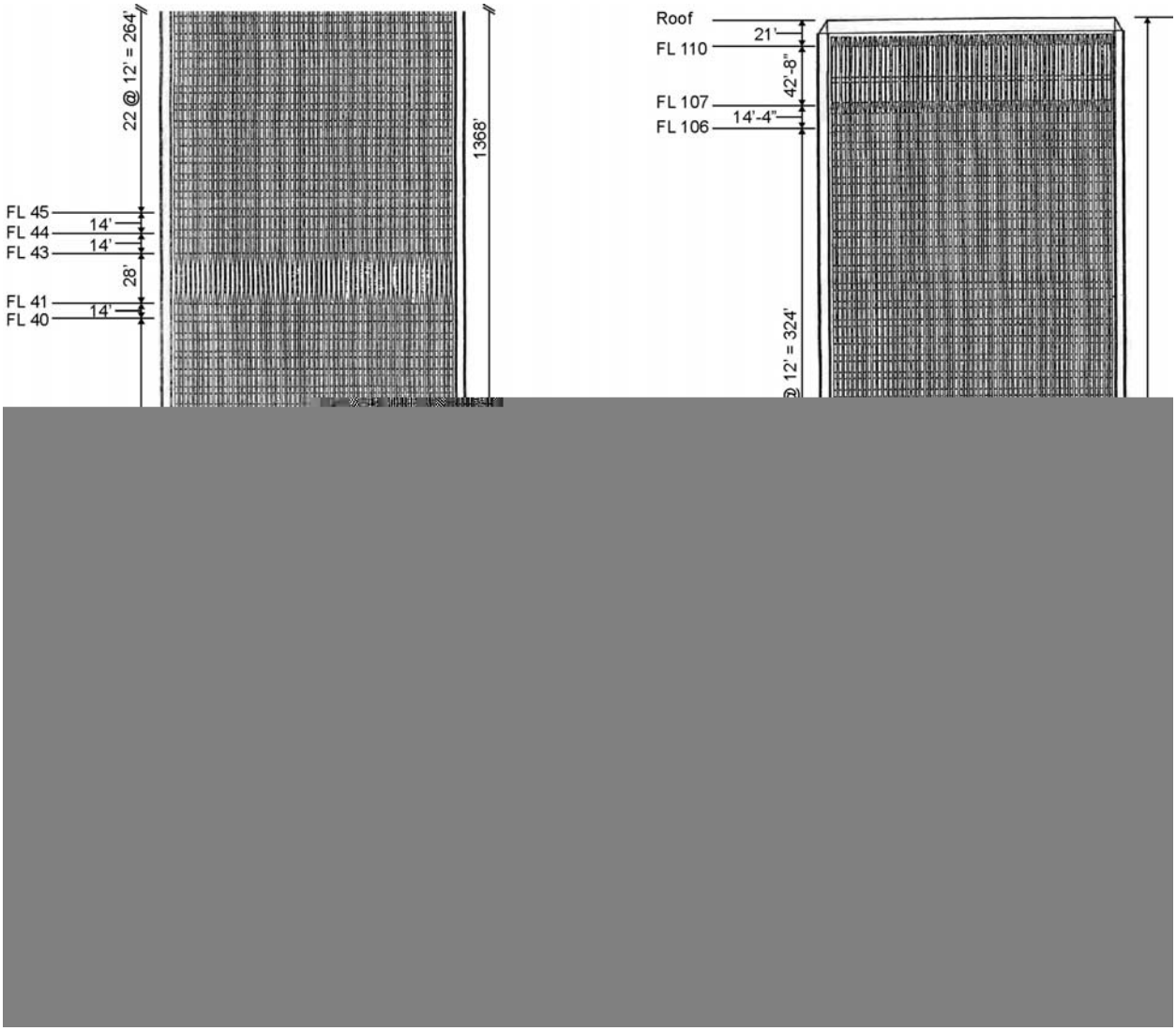


Figure 2–2. West elevation of WTC 1.

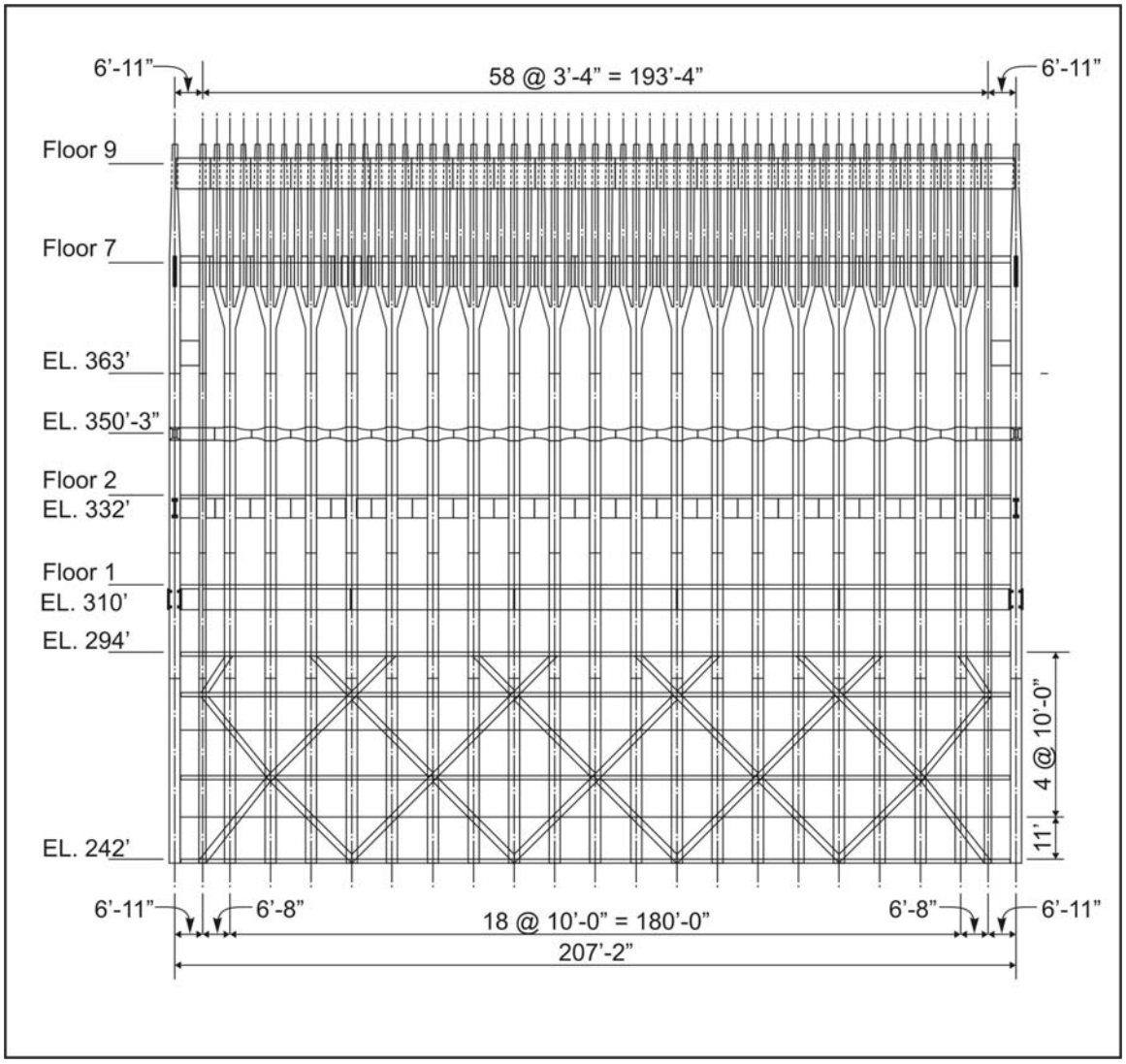
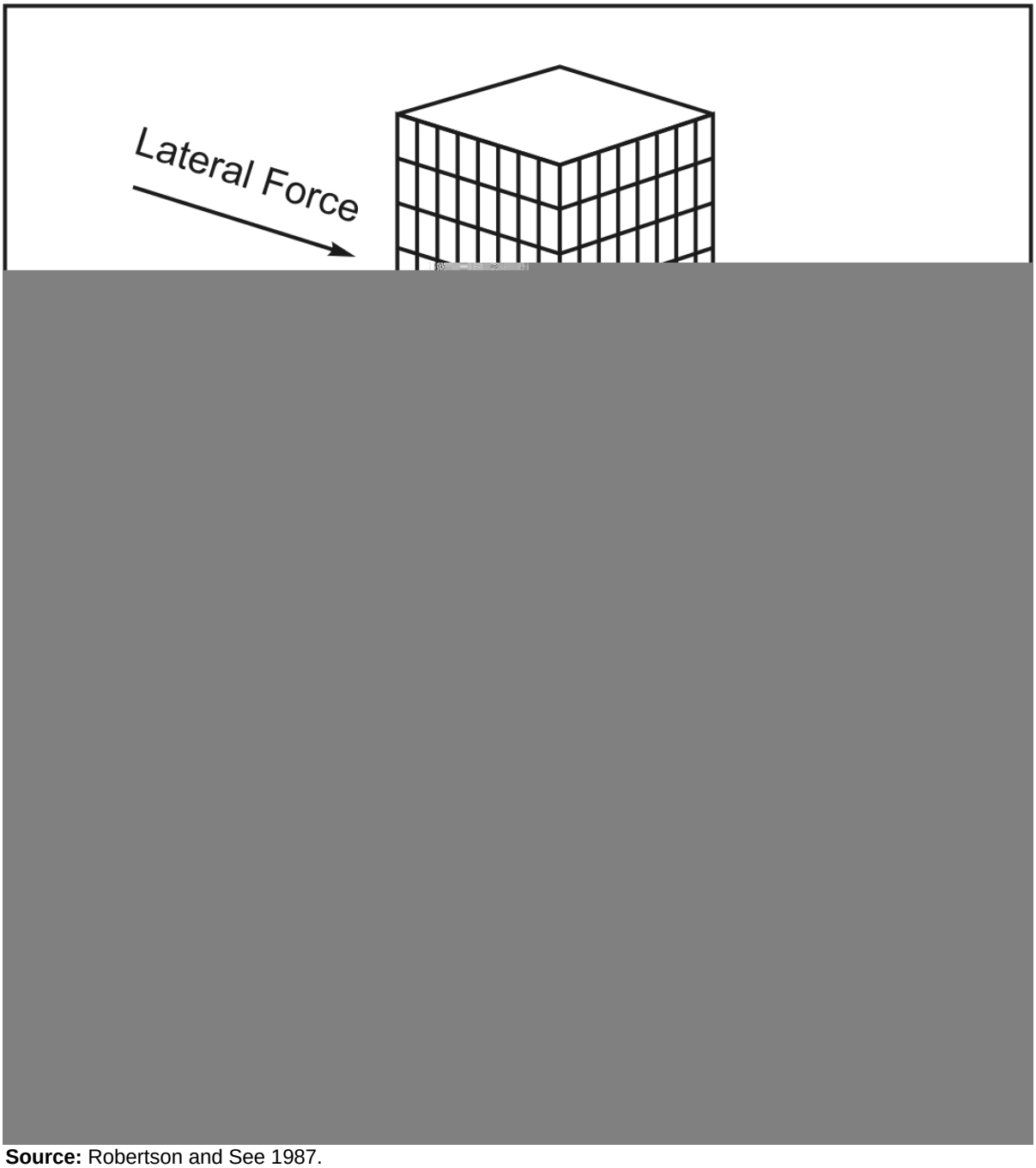


Figure 2–3. Elevation of exterior wall from foundation to floor 9.

Figure 2–4. Typical WTC tower architectural floor plan.



Source: Robertson and See 1987.

Figure 2–6. Framed tube system.

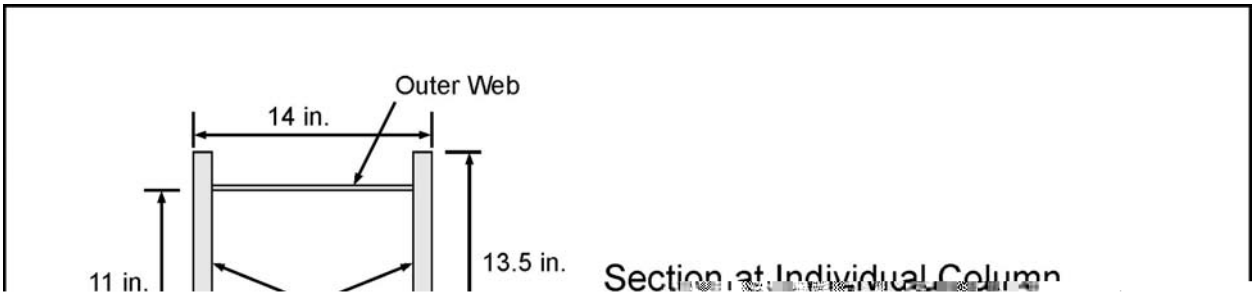


Figure 2–7. Cross section of perimeter columns.

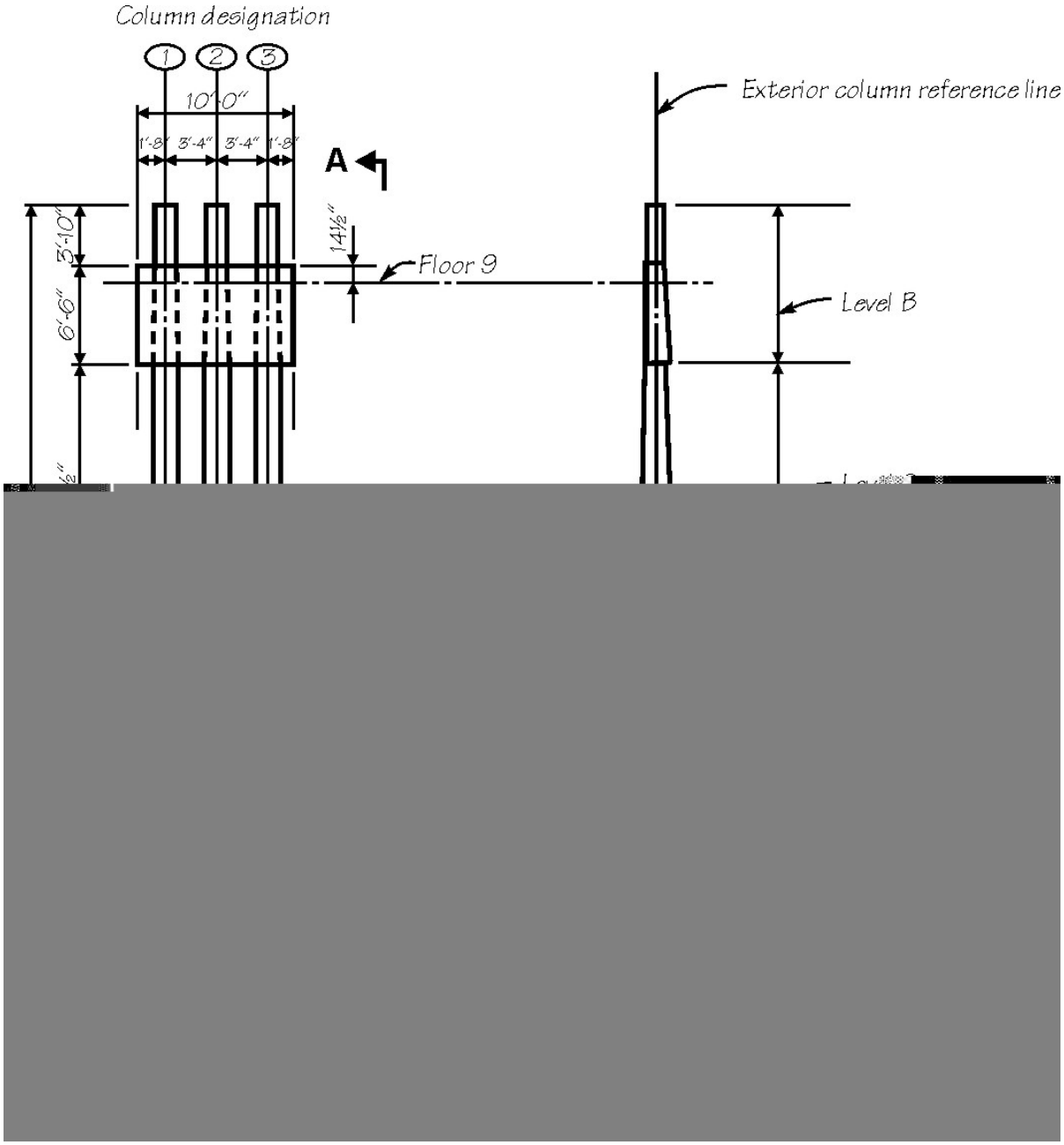


Figure 2–8. Typical WTC tower exterior wall tree panel.

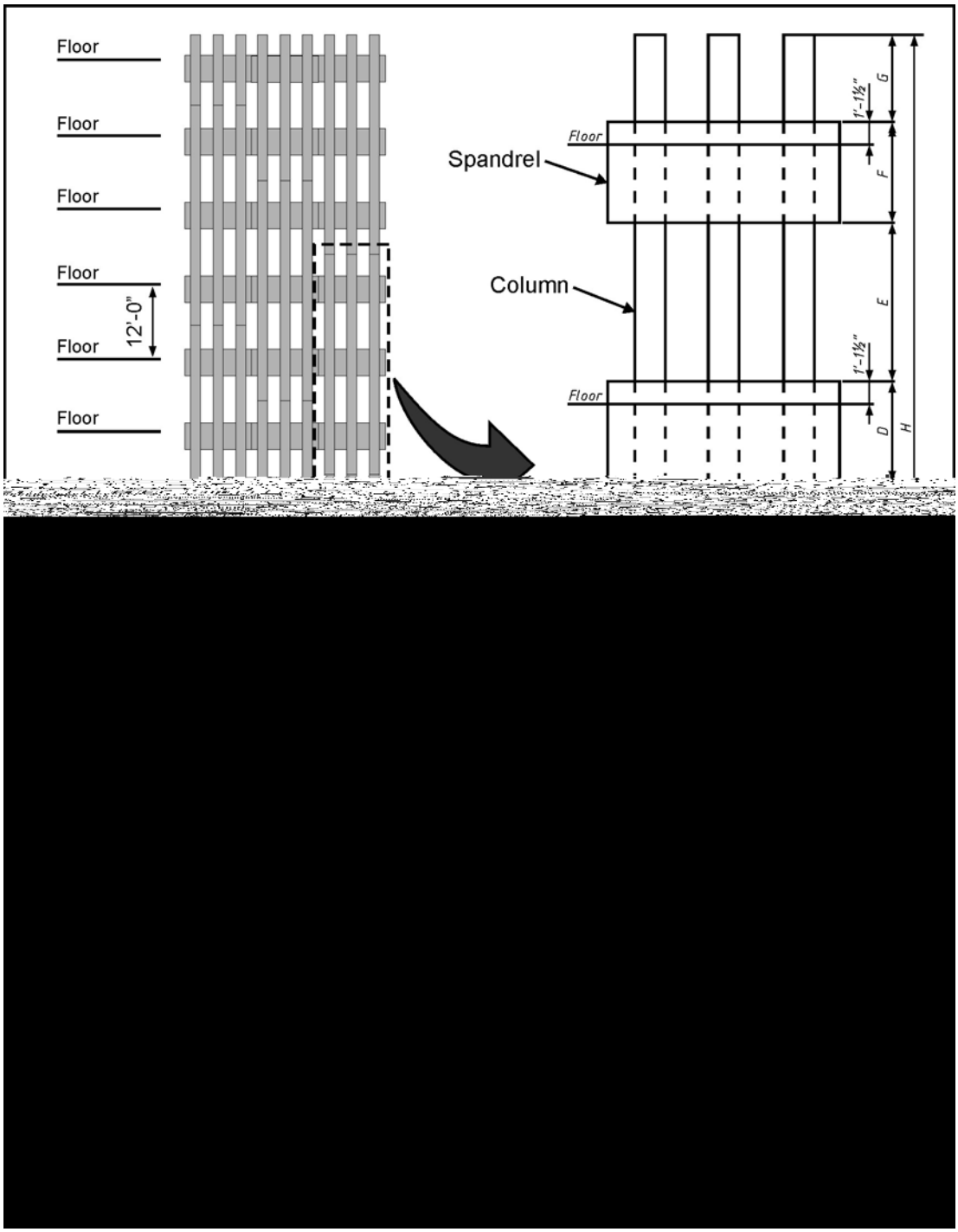


Figure 2–9. Typical WTC tower exterior wall panel.

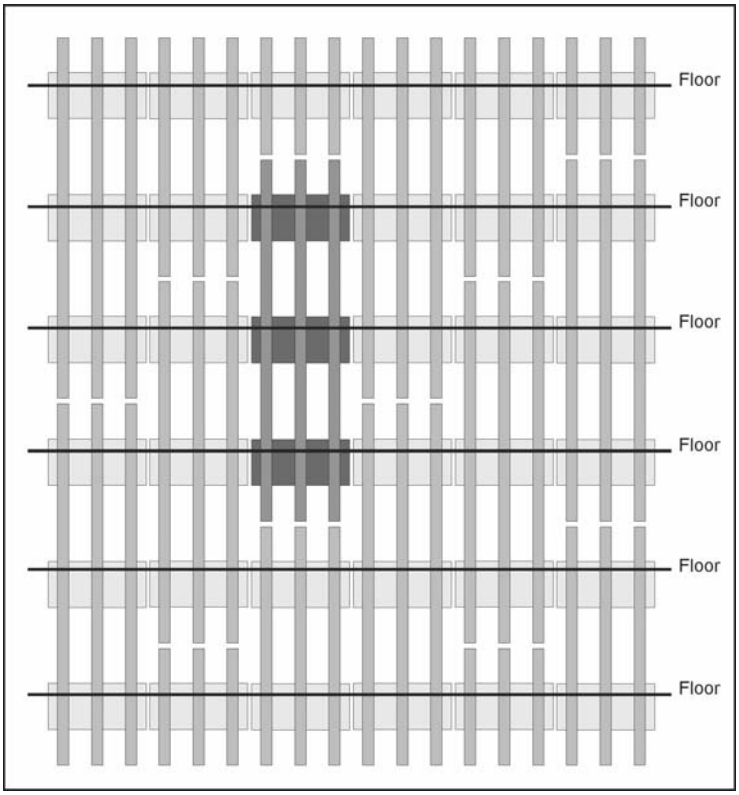


Figure 2–10. Elevation of exterior wall frame illustrating staggered panel construction.

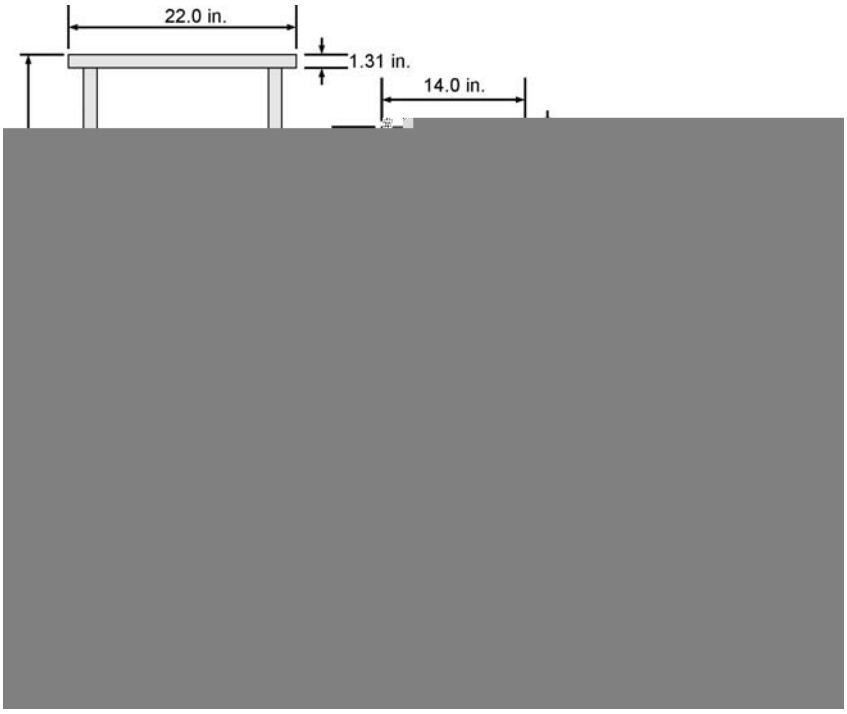


Figure 2–11. Typical welded box members and rolled shapes between floor 83 and floor 86.

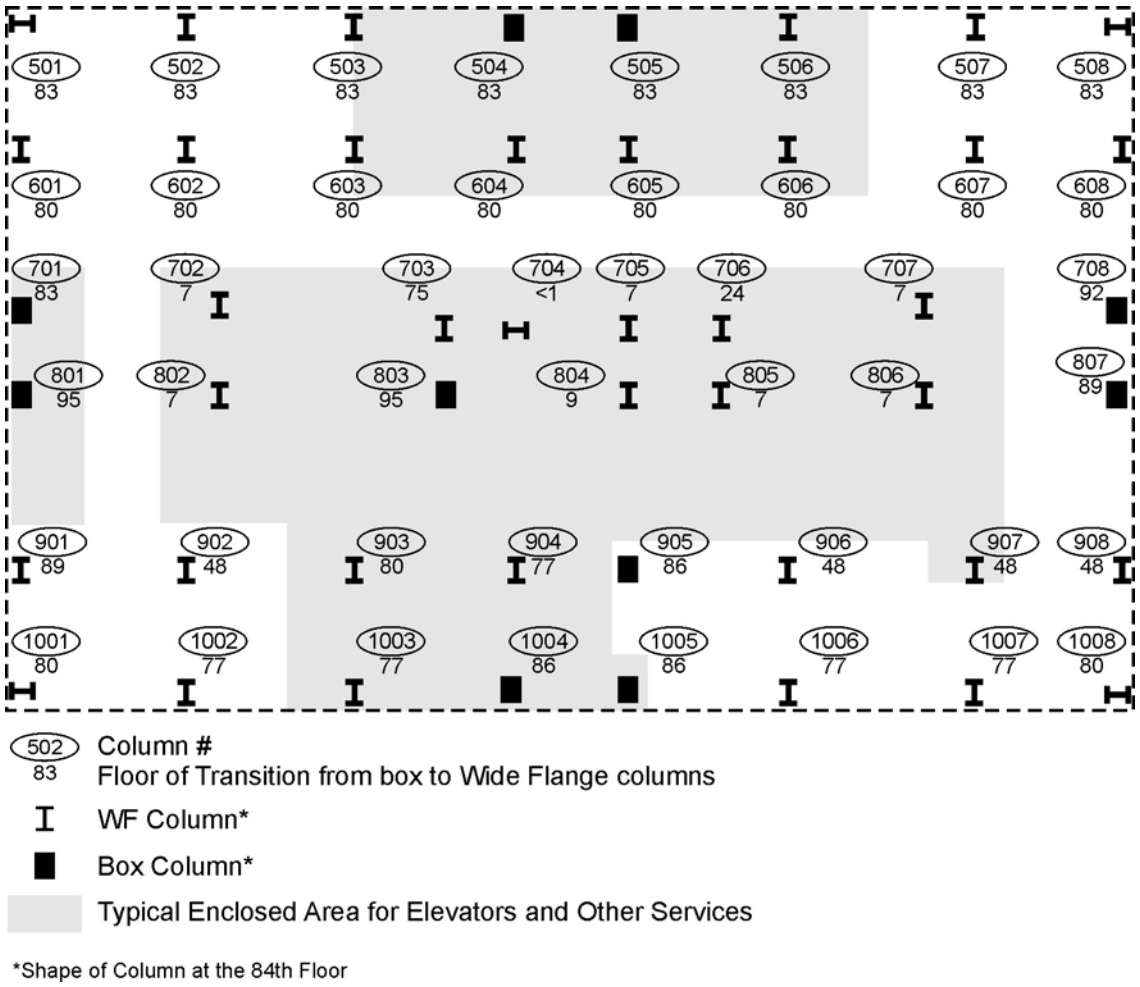


Figure 2–12. Core column layout in WTC towers.

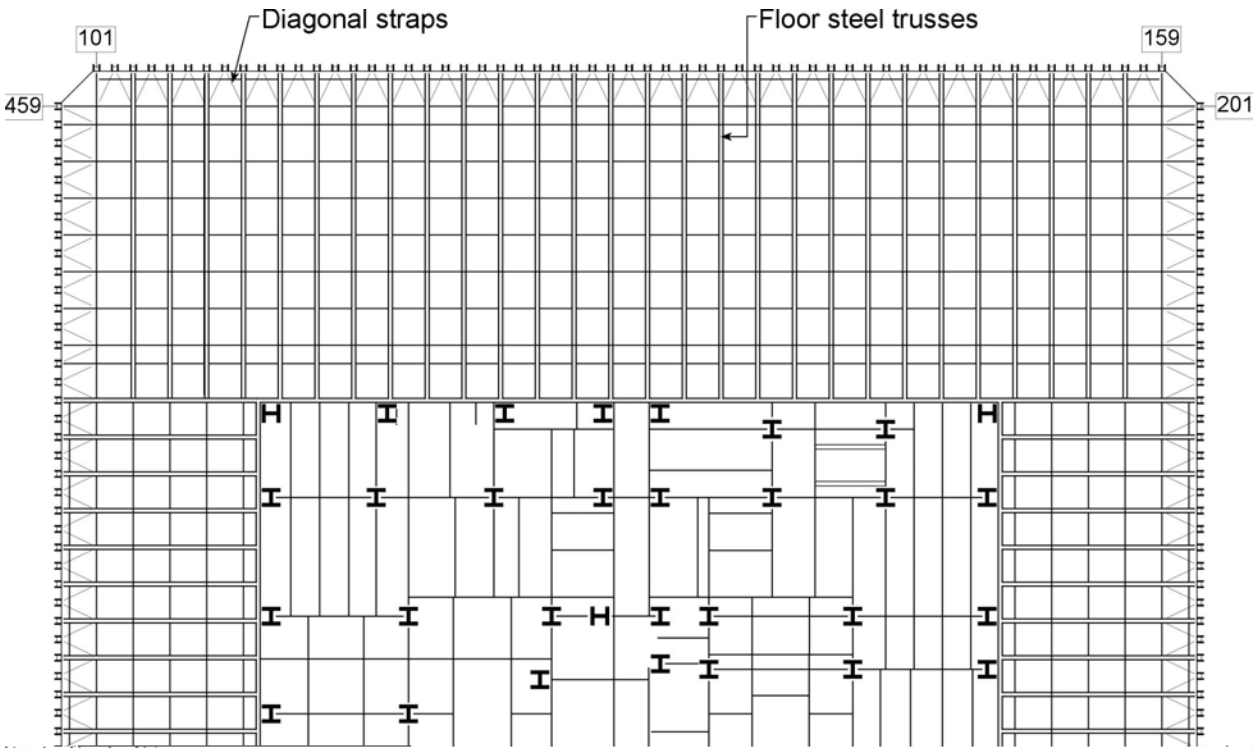
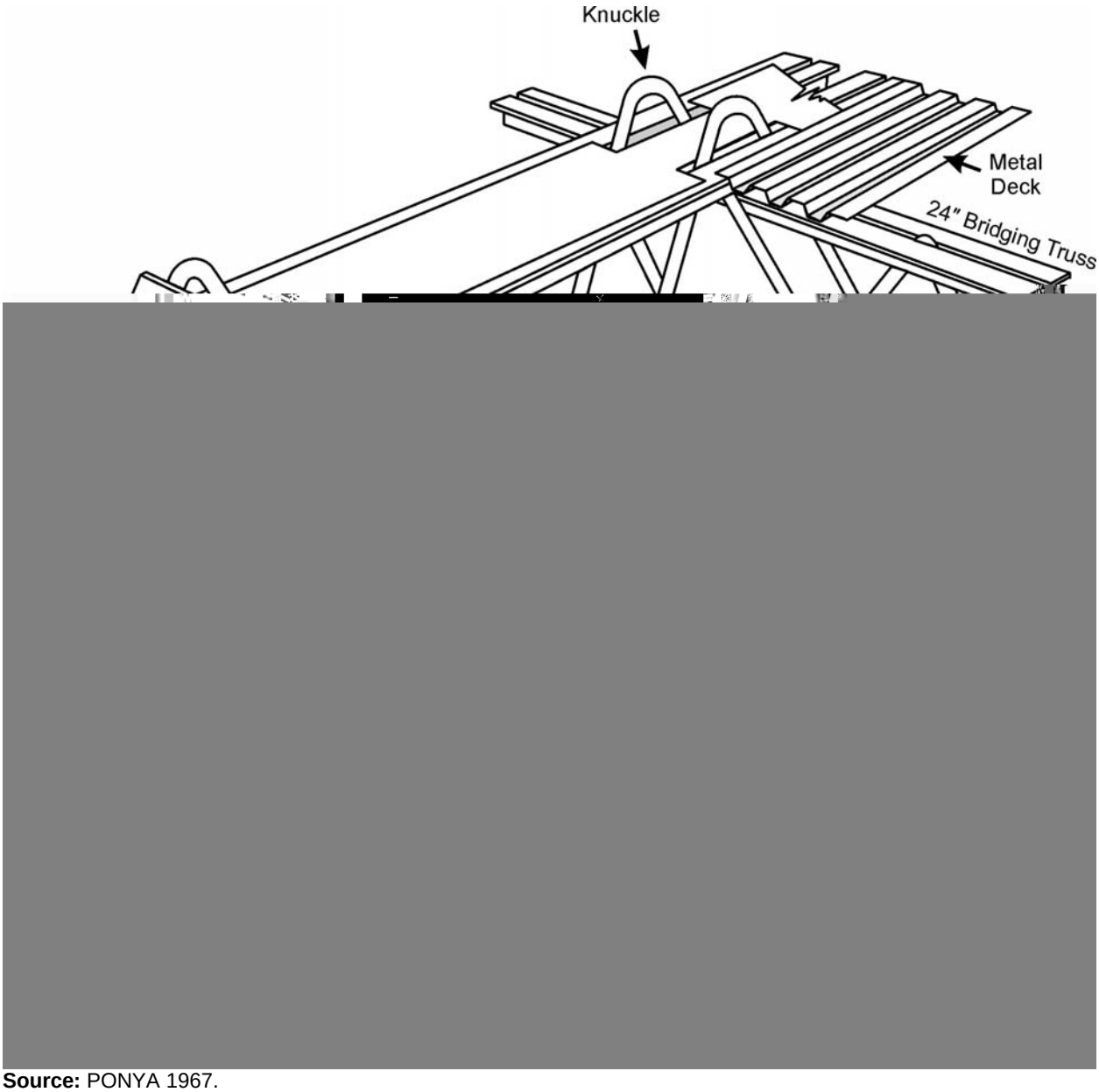


Figure 2–13. Typical floor-framing plan.



Source: PONYA 1967.

Figure 2–14. Prefabricated floor panel used in WTC 1 and WTC 2.

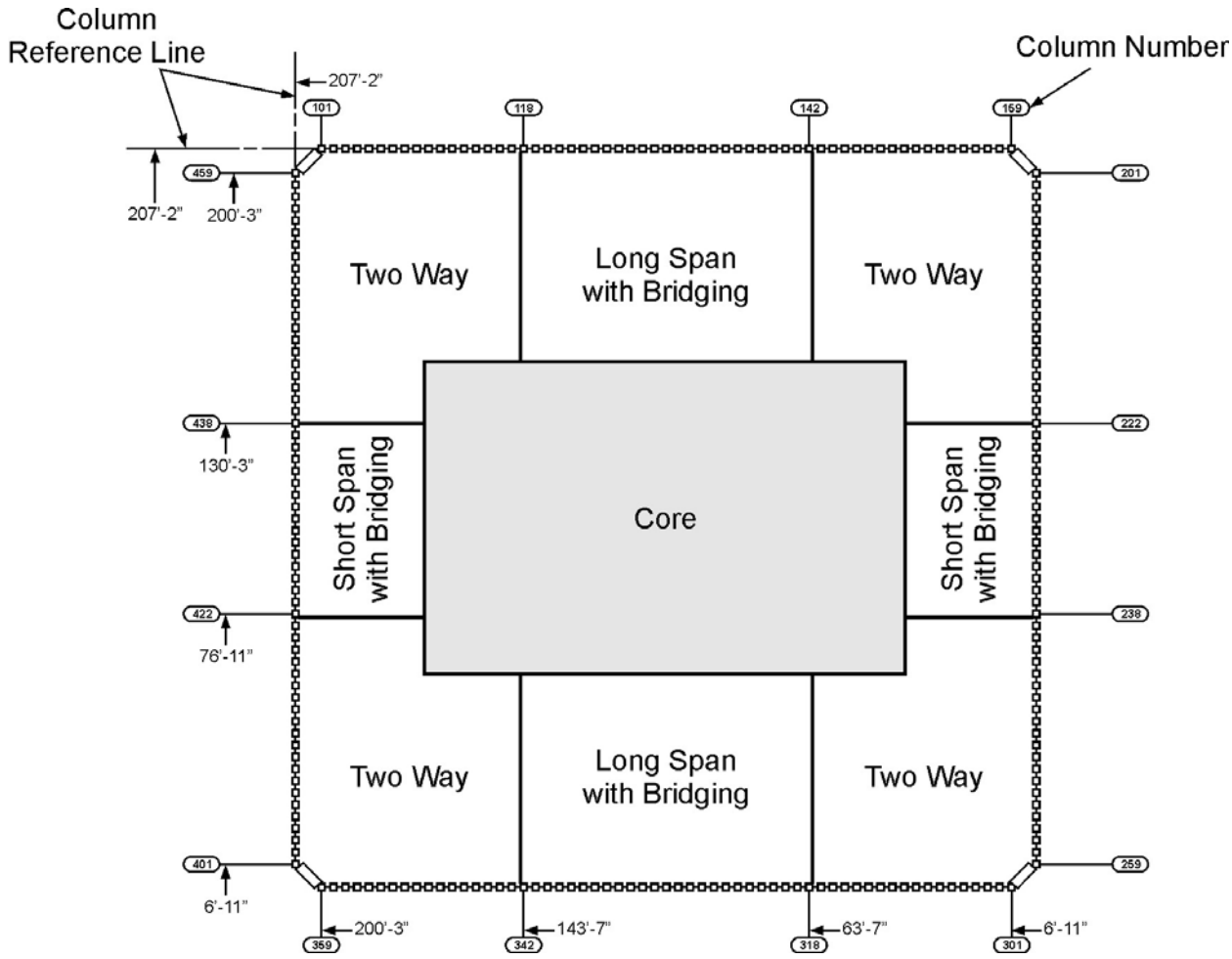


Figure 2–15. Typical WTC floor truss framing zone.

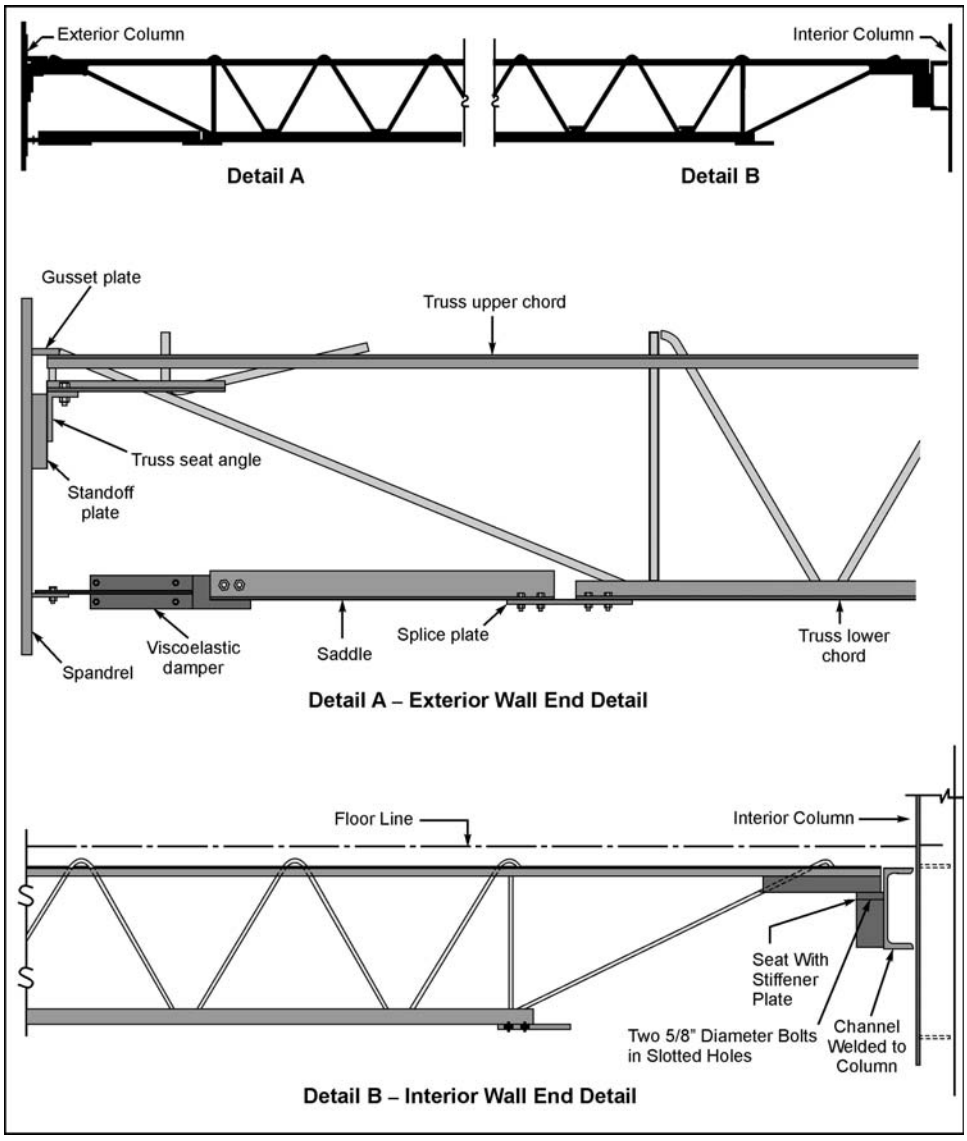
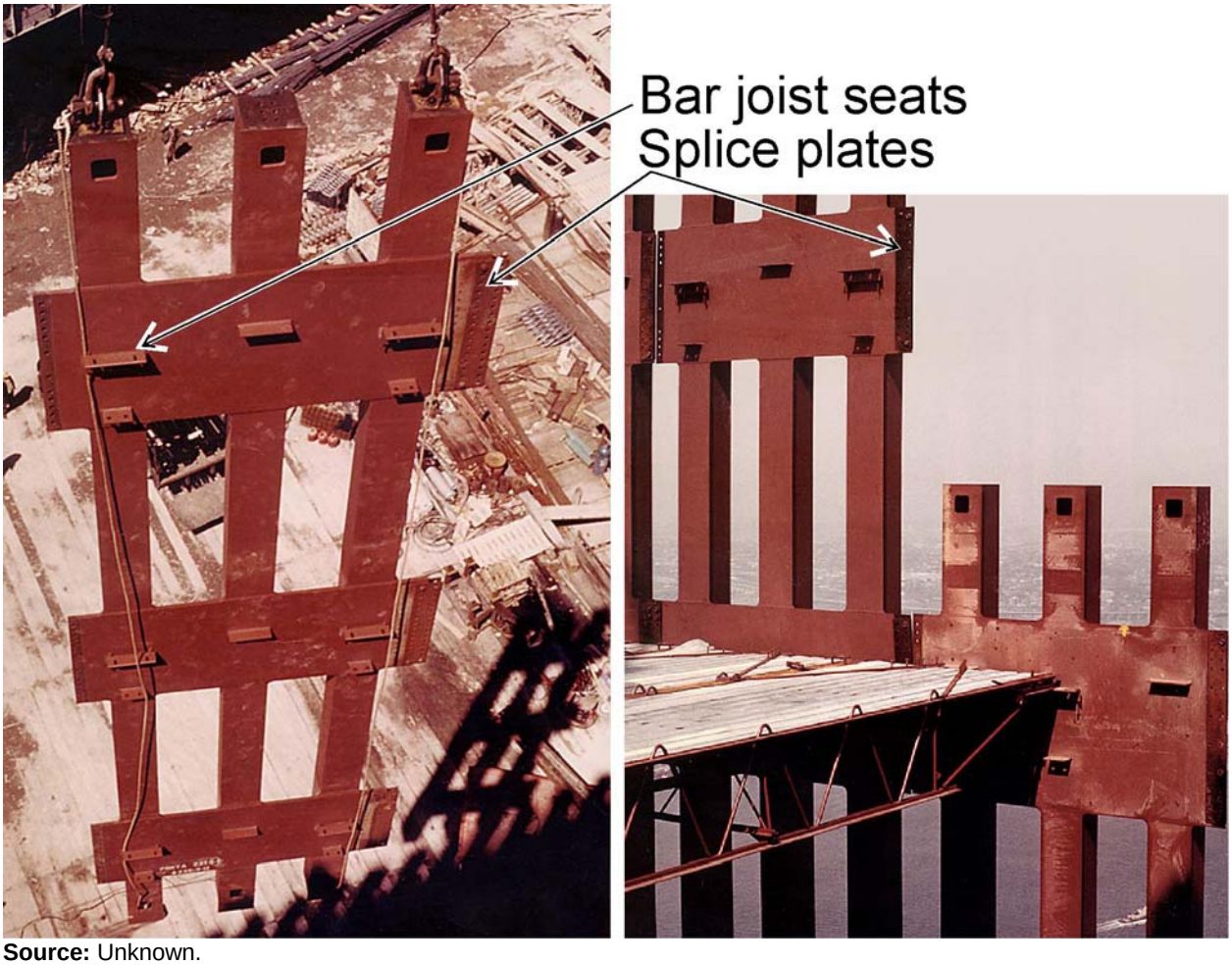


Figure 2–16. Position of viscoelastic damper.



Source: Unknown.

Figure 2–17. Perimeter column wall panel and steel truss floor modules.

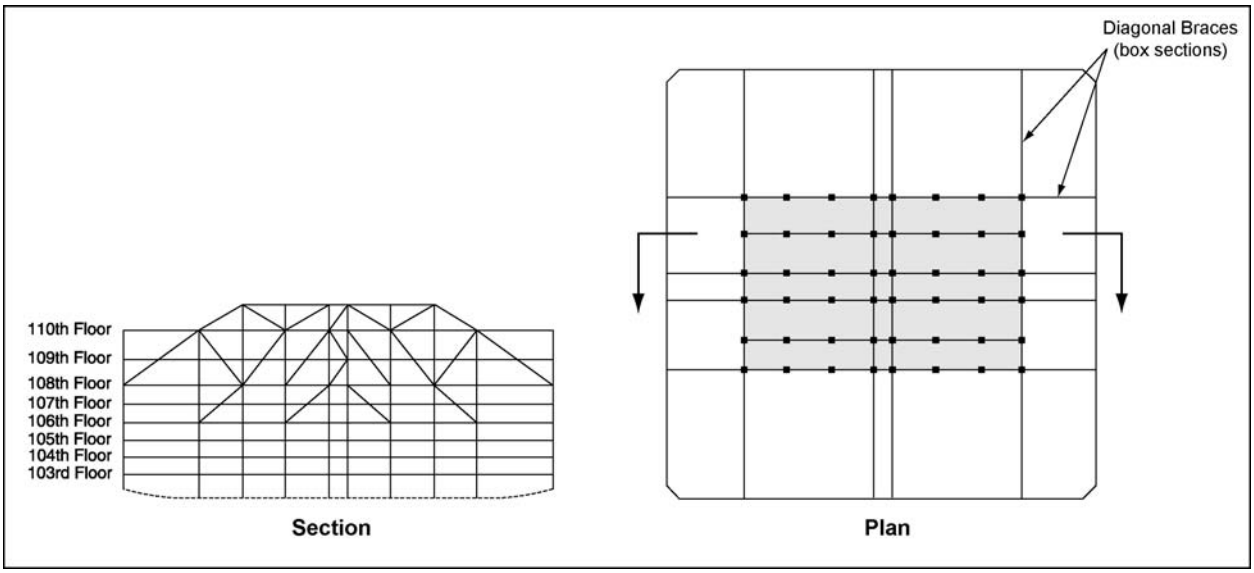


Figure 2–18. Hat truss.

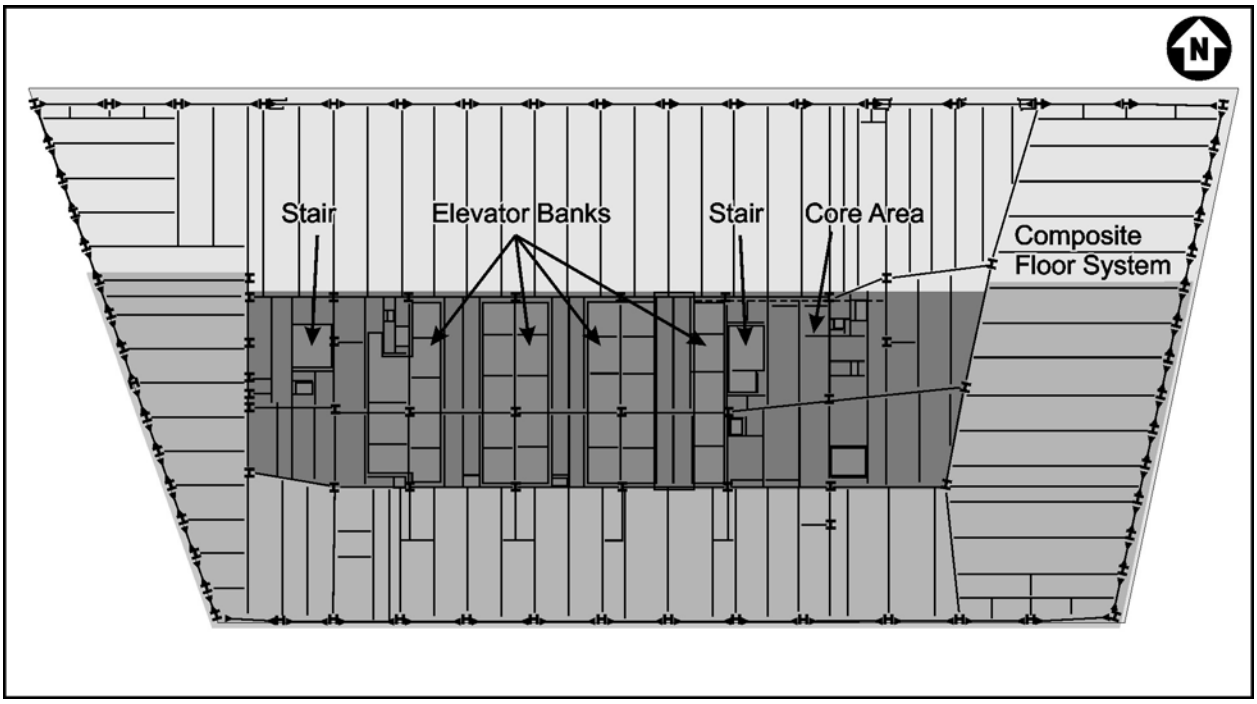


Figure 2–19. Typical floor plan above floor 7.

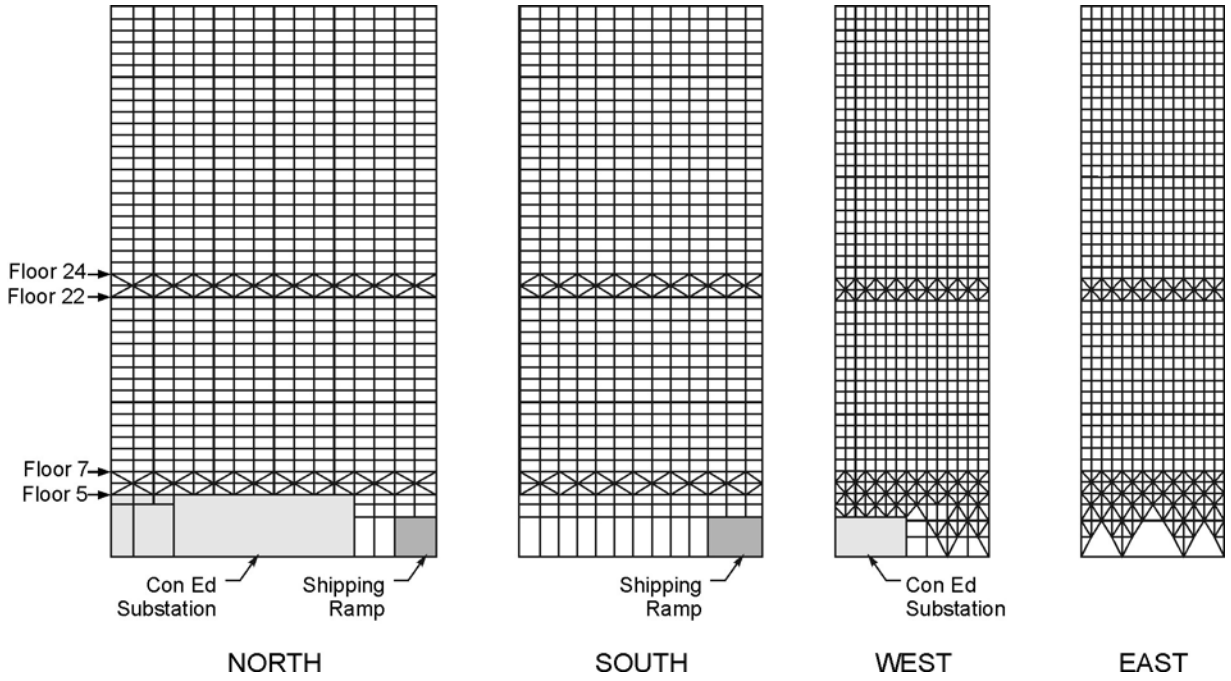


Figure 2–20. Perimeter elevations of WTC 7.

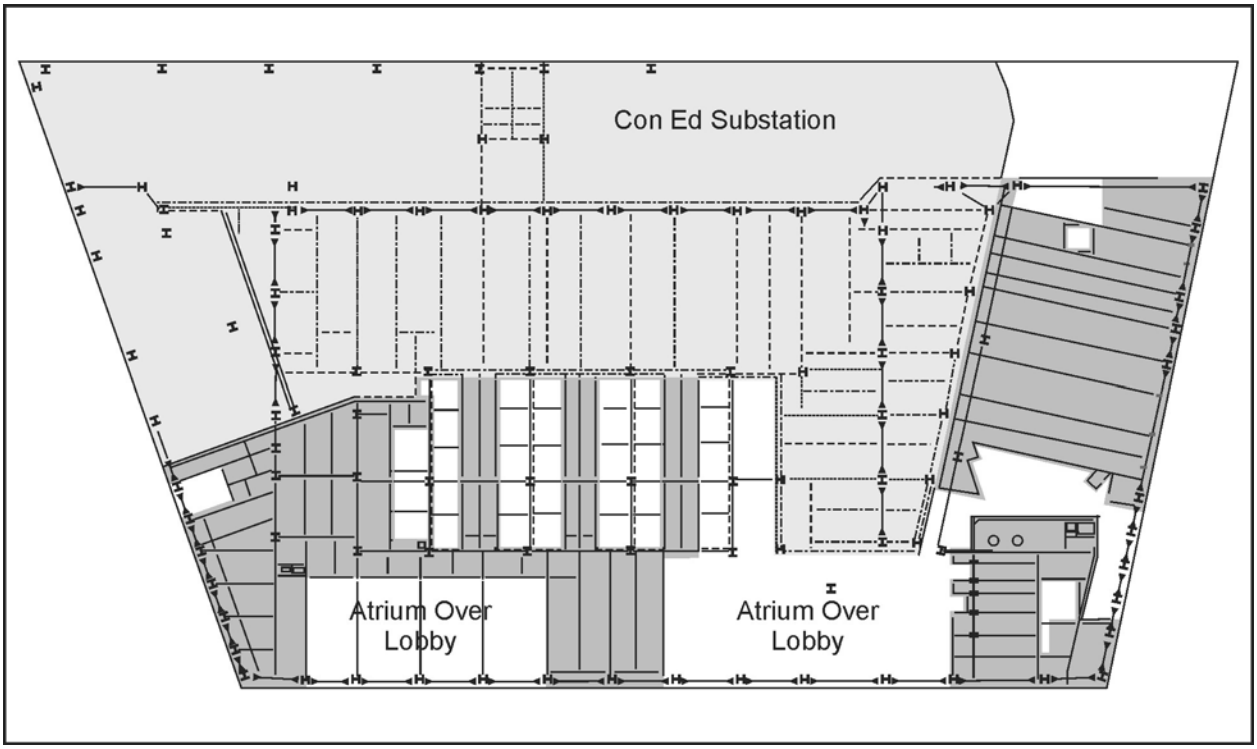


Figure 2–21. Floor 1 plan of WTC 7.

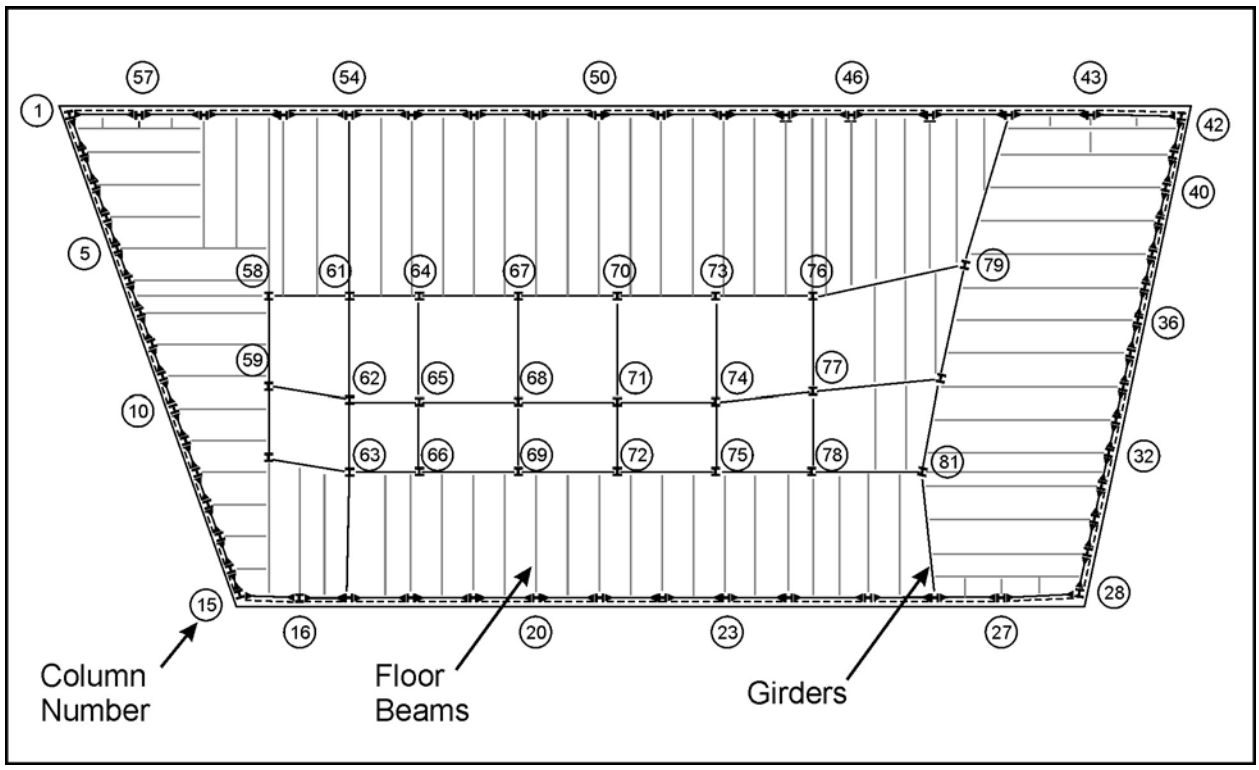


Figure 2–22. Framing plan for floor 8 through floor 45.

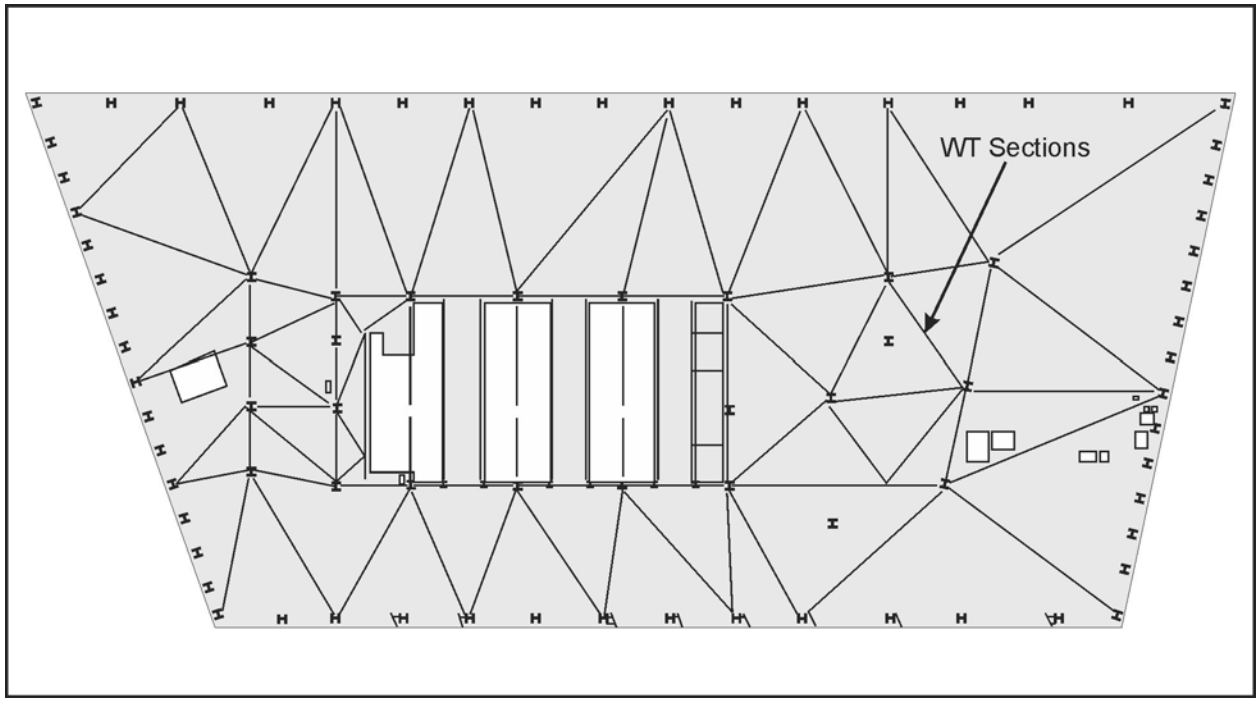


Figure 2–23. Floor 5 diaphragm plan.

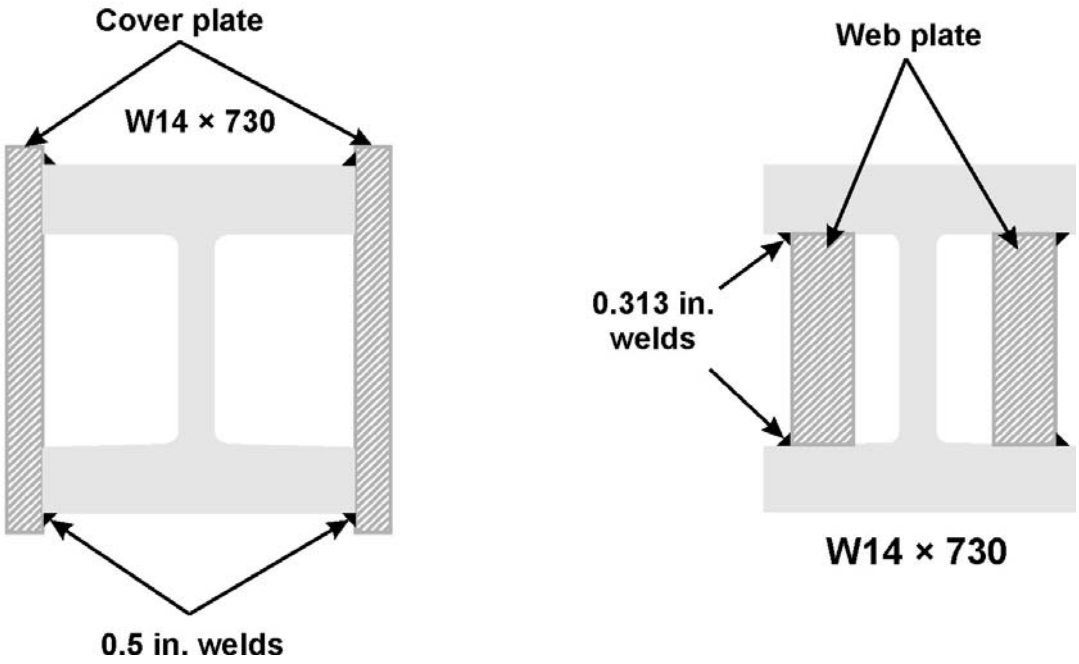


Figure 2–24. Typical built-up column details.

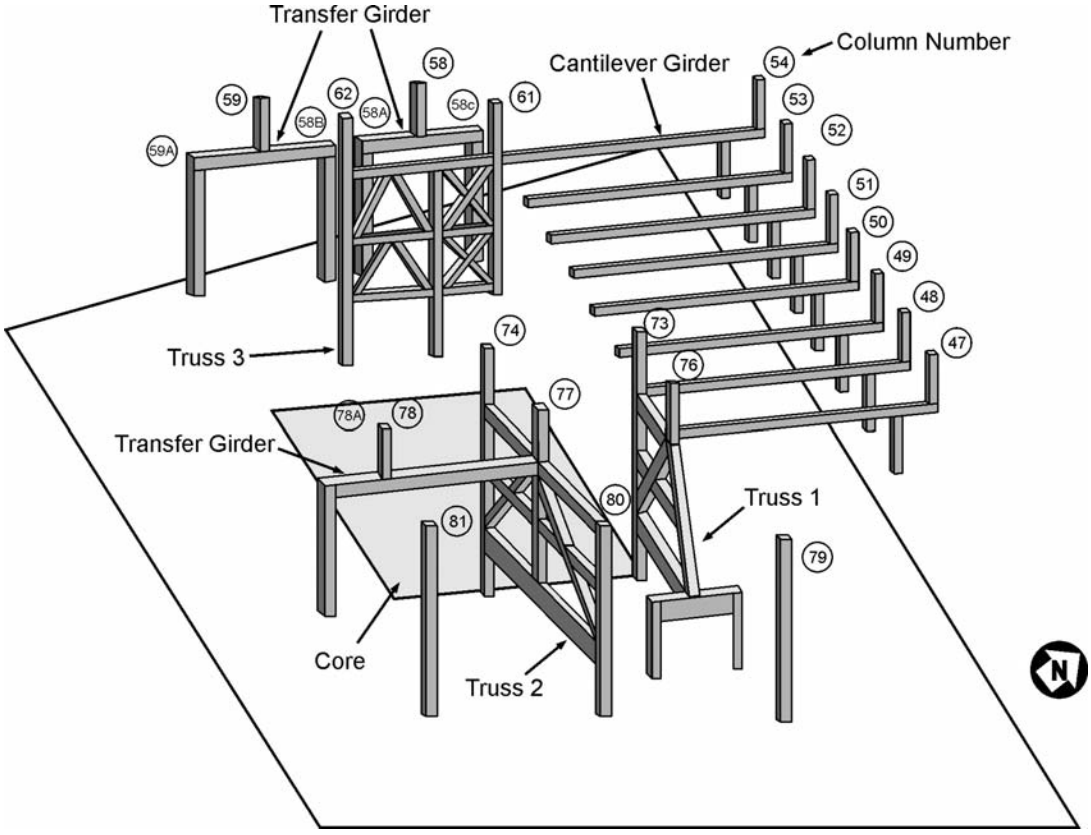


Figure 2–25. Schematic view of transfer trusses and girders between floors 5 and 7.

Chapter 3
DEVELOPMENT OF BUILDING CODES

Since World Trade Center (WTC) 1, 2, and 7 were designed according to the New York City (NYC) Building Code, it is important to understand the evolution of this building code. This chapter presents the historical background of the development of the NYC Building Code. This chapter also summarizes the Port Authority policies for design and construction of its buildings.

3.1 BUILDING CODE DEVELOPMENT IN THE UNITED STATES

In the United States, building codes were introduced to minimize losses from fire. Following large fires in major cities such as Boston, New York, Chicago, and Baltimore in the late 1800s, the first model building code was developed by the fire insurance industry. The National Board of Fire Underwriters (predecessor of the American Insurance Association) published the *National Building Code* in 1905. Subsequently, the Pacific Coast Building Officials Conference (predecessor of the International Conference of Building Officials) issued the *Uniform Building Code* (UBC) in 1927, the Southern Building Code Congress International Inc. (SBCCI) published its *Southern Standard Building Code* in 1946, and the Building Officials and Code Administrators, Inc. (BOCA) published the *Basic Building Code* in 1950. In the mid-1980s, the Basic Building Code was changed to the *BOCA National Building Code* (NBC). The three model building codes, namely the BOCA National Building Code, the Southern Standard Building Code, and the Uniform Building Code, were revised annually to incorporate developments in new materials, construction methods, and practices, and new editions were published every three years.

Before the issuance of the *International Building Code* (IBC) in 2000, which was published by the International Code Council (consolidation of the three model code organizations), most local and state jurisdictions in the United States adopted one of the three model building codes. The model codes were sometimes adopted by these jurisdictions in their entirety and other times with significant modifications. The version adopted is law in that jurisdiction. In early 1900s the National Fire Protection Association (NFPA) initiated the development of a "life safety code" for safety of building occupants. This code, while not a building code, is frequently used as a supplement to the building codes. In 2002, NFPA also published a model building code known as the *NFPA Building Construction and Safety Code* (NFPA 5000). A number of major cities in the United States have developed their own building codes to meet their specific needs, such as San Francisco for earthquake resistant design and New York City for high-rise buildings. At the present time, 44 states have adopted IBC with some modifications,[10] and it is being considered for adoption by New York City.

These model building codes establish minimum requirements to safeguard life, health, property, and public welfare through provisions pertaining to the design, construction, and quality of materials, use and occupancy, and maintenance of buildings. When buildings are designed, constructed, and maintained according to building code requirements, they are considered to have met minimum requirements. While

[10] The International Code Council updates the number of local jurisdictions that have adopted IBC (www.iccsafe.org).

building code regulations address a number of objectives demanded by society, the primary objectives of building codes are structural stability and fire safety.

3.2 NEW YORK CITY BUILDING CODE

The New York City (NYC) Building Code is part of the Administrative Code of New York City.[11] Although New York City had laws governing construction as early as 1674, after a tenement fire in 1860 took 20 lives, New York City modified and strengthened building safety laws extensively. New York City building laws are amended from time to time by Local Laws to improve safety requirements or to incorporate technological advances.

Local Laws are enacted by the NYC Council. Any member can introduce a bill to the Council for the purpose of amending the Building Code requirements. When passed by the Council and approved by the Mayor, the bill becomes a Local Law. The current Building Code was enacted on December 6, 1968. Through 2002, 79 Local Laws were adopted that modified the 1968 Building Code.

To aid the implementation of and to clarify Building Code requirements, New York City issues "rules." Typically these rules are initiated by City Government offices such as the Department of Buildings and the Department of Environment, and issued by the Building Commissioner. The rules do not require enactment by the City Council, and new rules issued by the Building Commissioner can be put into effect expeditiously. The rules, although are not part of the Building code, are required to be complied with for design, construction, and maintenance of buildings.

The 1968 NYC Building Code includes "Reference Standards," including standard test methods published by the American Society for Testing and Materials (ASTM), and design standards published by other organizations such as the American Concrete Institute and the American Institute of Steel Construction. These reference standards may include modifications to the provisions in the published standards, or they may be stand-alone requirements developed by New York City.

At the time the WTC project was begun (early 1960s), the 1938 NYC Building Code, which was first adopted on January 1, 1938, was in effect and enforced throughout the five boroughs. In the late 1950s, it was noted that "great changes have occurred in all facets of the building industry" and that "As a result of these developments, and the failure in many instances, of the Code to keep pace, there had been a growing dissatisfaction with it" (Schaffner 1964). Thus, in 1960, the Building Commissioner requested the New York Building Congress to form a working committee to study the problem. The committee recommended that the Code should not be rewritten by a group of volunteers and that a local educational institution should conduct a study to develop an approach to solve the problem. The Polytechnic Institute of Brooklyn conducted the study, and in July 1961, the Institute made the following recommendations (Schaffner 1964):

1. The NYC Building Code should be completely rewritten. The new Code should provide for frequent periodic revision through a committee or board appointed solely for this purpose.

[11] The historical information about the development the New York City Building Code may be found at the New York City/the Buildings Department web site (www.nyc.gov).

2. The new Code should be a combination of performance and specification types with heavy emphasis on performance, wherever possible, and with liberal reference to accepted national standards.

3. The BOCA Basic Building Code should be used as a guide for the development of the NYC Building Code.

4. The Code should be rewritten by a private professional group such as an engineering company, architectural firm, educational institution, or any combination of the three. Those rewriting the Code should work closely with the NYC Building Department. They should be supported, for review purposes, by volunteer committees composed of representatives of professional, trade, and industry associations.

In April 1962, New York City signed an agreement with the Polytechnic Institute of Brooklyn for the writing of a new Code to be completed in 3 years. The first draft was completed in 1964. A public relations document highlighted the "major advantages to be gained from recommendations in the proposed new Building Code" (Bell and Stanton 1964). One of these related to "area and height limitations," and it was stated that:

> Area and height limitations will be liberalized and present unrealistically high construction requirements for fire protection in structures of low combustible content such as auditoriums, halls, schools, institutions and residences will be significantly reduced and considerable economy will result.

On December 6, 1968, Local Law 76 repealed the 1938 code and replaced it with the 1968 Code, which itself has been subsequently amended by Local Laws. As is the general custom with changes to building codes, the new provisions generally are not applied to existing buildings (those approved under the prior code) provided they do not represent a danger to public safety and welfare.

Between 1969 and 2002, there were 79 Local Laws adopted that modified the 1968 code. Of particular importance with regard to fire protection and life safety are Local Law 5, adopted in 1973, and Local Law 16, adopted in 1984 (see NIST NCSTAR 1-1D). Local Law 5, among other things, added requirements on compartmentation of large floor areas, and Local Law 16 added requirements for sprinklers in high-rise buildings (greater than 100 ft). Local Law 5 is particularly significant because its provisions, which are reviewed in Sec. 11.1, applied retroactively to existing office buildings taller than 100 ft in height. Local Law 84, which was passed in 1979, revised the compliance dates of Local Law 5 so that full compliance was required by February 7, 1988.

3.3 PORT AUTHORITY POLICIES FOR DESIGN AND MODIFICATIONS TO BUILDINGS

3.3.1 Procedures for PANYNJ Owned Projects

Established in 1921, the Port of New York Authority (PONYA)[12] was a self-supporting, public interstate agency and is not subject to the local laws of jurisdictions where its properties are constructed. This means that for the construction of the WTC buildings, the PONYA was not bound by the NYC Building Code or any regulations requiring inspection or approval of the building construction or operation. The PONYA could establish its own requirements, conduct its own inspections, and enforce its own rules without independent oversight.

The PONYA established an office to act as the Authority Having Jurisdiction for their facilities generally, and there was a special office for the towers. The PONYA staff reviewed and approved plans, monitored construction, and developed specifications. They developed a series of manuals that described the building infrastructure (sprinkler systems, fire alarm systems, smoke control systems) and how tenants would interface systems in their space to the building. Large tenants were generally permitted to contract for their own systems as long as they were compatible and complied with the manuals. Smaller tenants could use the PONYA office for this purpose. In either case approvals and inspections were performed by the PONYA and did not involve the City services (Department of Buildings or Fire Department).

To reaffirm and formally state the Port Authority's "long standing policy" that its facilities meet or exceed New York Building Code requirements, a memorandum of understanding between the Port Authority and the New York City Department of Buildings was established in 1993.[13] Specific commitments were made by the Port Authority to the Department of that would ensure that any building construction project undertaken by the Port Authority or by any of its tenants at the buildings owned and operated by the Port Authority that were located within the Department of Buildings' jurisdiction conform to the NYC Building Code.

A summary of the 1993 agreement follows:

- The Port Authority was to thoroughly review and examine all plans for conformance with the requirements of the then current NYC Building Code. Such reviews were to be conducted by New York State licensed professional engineers or architects retained or employed by the Port Authority. Plans for projects undertaken by Port Authority tenants were to be prepared and sealed by a New York State licensed professional engineer or architect retained or employed by the tenant. Similarly, for projects undertaken by the Port Authority, plans were to be prepared and sealed by a New York State licensed professional engineer or architect retained or employed by the Port Authority.

- The Port Authority was to maintain a file containing the most recent drawings, plans, and other documents required in connection with the review of the project for code conformance.

[12] In 1972, PONYA's name was changed to the Port Authority of New York and New Jersey (PANYNJ).

[13] Memorandum of Understanding between the New York City Department of Buildings and PANYNJ, 1993 (WTCI-160-P, see Appendix A).

- The Port Authority was required to obtain the certification of a New York State licensed professional engineer or architect that any tenant projects undertaken at any of its facilities was constructed in accordance with the approved plans and specifications for the project. Such certification was to be kept in the project file described in item 2 above.

- The Port Authority was required to provide copies of any project files to the Department of Buildings at any time.

- The Port Authority was to promptly advise the Department of Buildings of any deviations from code requirements that were proposed on a project. In cases where the Department of Buildings believed that such deviations were unacceptable, further review by the Port Authority Board of Commissioners was required.

- The Port Authority was required to perform building inspections and structural integrity inspections on a cyclical basis for all of its structures located in New York City.

- The Port Authority was responsible for life safety in buildings at its facilities. The Department of Buildings was not responsible for any type of inspection or review.

- Personnel from the Port Authority and the Department of Buildings were not to be held personally responsible under any provision of this agreement.

A supplement to the 1993 agreement was executed in 1995.[14] The supplement added that the design professional responsible for performing the review and certification of plans for WTC tenants must not be the same design professional providing certification that the project had been constructed in accordance with the plans and specifications. But the plans were to be approved by the Port Authority and held for possible inspection by the City if the Port Authority so chose.

3.3.2 Review of Tower Plans by New York City Department of Buildings

While the Port Authority facilities, including the WTC buildings, were not required to undergo review or approval by the NYC Department of Buildings, a letter dated February 18, 1975, from Joseph Solomon of Emory Roth & Sons (the architect of record for the towers) to Malcolm Levy, General Manager, World Trade Center Operations states, "The Building Department reviewed the tower drawings in 1968 and made six comments concerning the plans in relation to the old code. Specific answers noting how the drawings conformed to the new code with regard to these points were submitted to the Port Authority on March 21, 1968."

NIST has attempted to locate the March 21, 1968, letter without success. NIST hoped to gain information about the six points and the level of review provided by the NYC Department of Buildings because they were under no obligation to conduct any review. However, NIST located a letter dated January 25, 1968, from Mr. Solomon to Mr. Levy that appears to list the six items questioned in the NYC Department of Buildings' review (note that the letter states five points and contains five numbered paragraphs, which are

[14] Supplement to Memorandum of Understanding between the New York City Department of Buildings and PANYNJ (1995) (WTCI-113-P; see Appendix A).

followed by an additional point in an unnumbered paragraph).[15] The copy of this letter provided by PANYNJ is illegible. Both the original and the NIST reconstructed copies are shown in Appendix B.

It is interesting to note that all six points raised deal with egress issues. They do not address innovative features of the building, and egress from Windows on the World is not mentioned even though the restaurant was a part of the design from the beginning.

3.3.3 Procedures for Tenant Alteration Projects

To maintain structural integrity and fire safety, the Port Authority developed a tenant alteration process for any modifications to leased spaces in WTC 1 and WTC 2 for tenants who would adapt their spaces to their own needs. In 1971, shortly after the first tenants occupied WTC 1 in December 1970 and before initial occupancy of WTC 2 in 1972, the Port Authority issued the first edition of a set of requirements the *Tenant Construction Review Manual*. The manual contained the technical criteria to be used in planning alterations (architectural, structural, mechanical, electrical, fire protection, and others). Applicable standards to be used by tenants and their agents and review criteria to be used by the Engineering Department of the Port Authority were included. Registered design professionals were to complete alteration design, and at the completion of the work, as-built drawings were to be submitted to the Port Authority. The manual referenced the 1968 NYC Building Code, and specific code provisions were referenced in various checklists. The review manual was updated in 1979, 1984, 1990, and 1997, at which times changes that had been made to the NYC Building Code were incorporated. In 1998, the manual was replaced by the *Architectural and Structural Design Guidelines, Specifications, and Standard Details*, which dealt specifically with alterations to WTC 1 and WTC 2.

Since WTC 7 was built as a "tenant alteration project," its design and construction followed the requirements of the 1984 edition of the *Tenant Construction Review Manual*. Any modifications to the building after initial occupancy were carried out in accordance with the Manual.

[15] Letter dated January 25, 1968 from Joseph H. Solomon (Emery Roth & Son) to Malcolm P. Levy (General Manager, World Trade Center Operations) (see Appendix B).

Chapter 4
CODE PROVISIONS FOR STRUCTURAL DESIGN

This chapter presents a summary of the provisions for structural design in the 1968 edition of the New York City (NYC) Building Code, and comparison of structural provisions of this code with similar provisions of other contemporaneous codes. As previously noted in Chapter 1, the design of the World Trade Center (WTC) towers was based on the 1968 Code, and so was the design for WTC 7. The contemporaneous codes compared include the 1964 New York State Building Construction Code (NYSBC 1964), the 1965 Building Officials and Code Administrators (BOCA) model building code (Basic Building Code [BBC]), and the 1967 Municipal Code of Chicago (MCC 1967). A comparison was also made between the 1968 NYC Building Code and the current (2001) NYC Building Code. The current NYC Building Code (NYCBC 2001) consists of the code adopted in 1968 with modifications made over the years by adoption of Local Laws.

This chapter also provides a summary of the criteria used for the design of WTC 1, 2, and 7. Only those provisions that relate to the design of WTC 1, 2, and 7 are discussed here. Unless otherwise noted, referenced article and section numbers are from the 1968 edition of the NYC Building Code.

4.1 CONTEMPORANEOUS CODES

Three contemporaneous codes were selected for code comparison. The 1964 New York State Building Construction Code was selected, as it would have been a governing building code outside the New York City limits. The 1965 BOCA Basic Building Code was selected as it was typically adopted by local jurisdictions in the northeastern region of the United States. The 1968 NYC Building Code is compared with the 1967 Municipal Code of Chicago to note any substantial differences in the structural and fire safety requirements of the two codes. In the late 1960s and early 1970s, several tall buildings were built in Chicago including the Sears Tower (110 stories) and the John Hancock Tower (100 stories). In addition, the 2001 edition of the NYC Building Code is compared with the 1968 version to examine the extent to which Local Laws have modified the code provisions, and in most cases, is only addressed in areas where changes have occurred between the two versions.

A provision by provision comparison was made between the 1968 NYC Building Code and these four codes and documented in NIST NCSTAR 1-1B, *Comparison of Building Regulatory and Code Requirements for WTC 1, 2 and 7*. The only code provisions compared were the requirements related to structural stability. This chapter presents a summary of substantial differences noted in the comparison. This summary focuses on the following topics:

- Loads to be considered in the design of buildings.
- Requirements for materials, design, and construction.

With respect to structural stability, no Local Law other than Local Law 17 (seismic provisions for new construction) has been adopted that modified the structural requirements of the 1968 NYC Building Code.

Hence, comparison between the structural requirements of the 1968 and 2001 NYC Building Code is not discussed here, with the exception of earthquake loads.

4.2 LOADS

A key aspect of any structural design is the loading that the structure is intended to support. Building codes provide minimum values for the different types of loads that are considered in typical building designs. The designer is permitted to use larger values for these loads but is not permitted to use smaller values without approval by the building official. This section compares the specified loads in the selected codes. Similarities and differences are noted.

4.2.1 Dead Loads

Dead loads refer to loads that are permanently present in a building. They include, for example, the weight of the structural components, the weights of permanent partitions, the weights of floor and wall finishes, and the weights of service equipment that is part of the building (elevator equipment, plumbing, electrical, heating, air conditioning, and ventilation systems). Weights of the structural components are computed from the sizes of the members and the densities of the materials, and codes typically provide default density values for different materials. The dead loads of partitions and walls are typically prescribed in terms of weight per unit area of wall, and the weight per unit length of wall or partition is determined from these prescribed values and the heights of the partitions or walls. Floor finishes and ceilings are typically specified in terms of a uniform load per unit area of floor or ceiling. Table 4–1 gives examples of the minimum values of dead load prescribed in Reference Standard RS 9-1 in the 1968 New York City (NYC) Building Code and in Appendix J of the 1965 BOCA Basic Building Code. There are no corresponding provisions in the 1964 New York State Building Construction Code or the 1967 Municipal Code of Chicago. All building codes permit the designer to use weights based on available data that are greater than the specified minimum values in the code, but the designer is not permitted to use lower values without approval of the Code Official.

According to the 1968 NYC Building Code, weights from service equipment (plumbing stacks, piping, heating, ventilating, and air conditioning [HVAC], etc.) are to be included in the dead load (C26-901.2).[16] The weight of equipment that is part of the occupancy of a given area is to be considered as live load (see next section). The 1964 New York State Building Construction Code and the 1967 Municipal Code of Chicago do not have a provision in this regard. The 1965 BOCA Basic Building Code has a similar provision but does not cite specific types of service equipment as the NYC Building Code.

The 1968 NYC Building Code requires that weights of partitions be considered in two ways: (1) using line loads at locations shown on plans or (2) using the equivalent uniform load given in Reference Standard RS 9-1. The stipulated equivalent uniform load depends on the partition weight, for example, if a partition weighs 201 plf to 350 plf, it may be taken into account by designing for a uniform load of 20 psf. The uniform loading approach, however, is not permitted in certain situations for which actual partition weights must be used. Equivalent uniform loads must be used in areas where the locations of partitions are not shown on plans, or in areas where partitions can be relocated. The 1964 New York

[16] Refers to section number in the 1968 New York City Building Code.

Table 4–1. Examples of dead loads given in NYC Building Code and BOCA Code.

	NYC	BOCA
Walls and Partitions		
Hollow concrete block – 8 in. thick	53 psf	50 psf
Clay tile, nonload bearing – 8 in. thick	34 psf	36 psf
Plaster partition, metal studs and lath, gypsum plaster both sides	18 psf	18 psf
Floor Finishes		
Resilient flooring	2 psf	2 psf
Hardwood flooring 7/8 in. thick (1 in. for BOCA)	4 psf	4 psf
Cement, 1 in. thick	12 psf	12 psf
Ceilings		
Suspended acoustical tile	2 psf	–
Suspended metal lath and gypsum plaster	9 psf	10 psf
Miscellaneous Materials		
Marble	168 pcf [a]	168 pcf
Concrete (normal density stone or gravel)	144 pcf	144 pcf
Reinforced concrete (normal density)	150 pcf	150 pcf

a. Note that the units in the 1968 NYC Building Code are given incorrectly as "psf."

State Building Construction Code does not have a specific provision in this regard. The 1967 Municipal Code of Chicago prescribes a minimum partition load of 20 psf. The BOCA Basic Building Code requires consideration of the actual weight of the partitions or an equivalent uniform load of at least 20 psf.

4.2.2 Live Loads

Live loads are those resulting from the use and occupancy of the building, and include loads such as weights of occupants, furniture, filing cabinets, safes, mechanical equipment, and other items that the structure is called upon to support. Live loads are specified in terms of weight per unit of floor (or roof) area or in terms of concentrated loads. The values specified in codes are based largely on load survey data, experience, and judgment.

Floor Live Loads

In general, values of minimum uniformly distributed live loads specified in codes are organized on the basis of use or occupancy of spaces, and there is no consistency in the names of these use categories. Thus, comparison between codes is not straightforward. Table 4–2 gives some examples of minimum uniformly distributed live loads for floors. It is seen that there is general agreement in the values of these selected minimum uniform live loads specified by the four codes.

Table 4–2. Comparison of uniform live load values. Examples of minimum uniformly distributed live loads.

	1968 NYC	1964 NYS	1967 Chicago	1965 BOCA
Office space	50 psf	50 psf	50 psf	50 psf
Restaurant	100 psf	100 psf	–	100 psf
Lobbies	100 psf	100 psf	100 psf	100 psf
Stairways	100 psf	100 psf	75–100 psf [a]	100 psf
Rest rooms	40 psf	60 psf	–	–
Hospital operating room	60 psf	60 psf	40 psf	60 psf
School classroom	40 psf	60 psf	40 psf	–

a. Depends on occupancy, for example, 75 psf for business, 100 psf for schools.

The codes also specify concentrated live loads placed so as to result in maximum stresses.

Live-Load Reduction

There is a low likelihood that the full design floor live loads will be present on all floors of a building at the same time. In addition, the likelihood that the complete area any one floor is loaded with the design live load decreases as the floor area increases. To account for these factors, building codes permit "live-load reductions" in calculating the design loads for primary members (columns and girders) that support the roof and floors. The codes use several methods for live-load reduction (CTB&UH 1980):

1. *Percentage Method*—In this method, the live-load reduction increases by a certain percentage with increasing numbers of floors, with a limit on the maximum value of reduction (typically 50 percent).

2. *Tributary Area Method*—The live load is reduced as the accumulated tributary area that a member supports is increased. The limiting value depends on the ratio of live load to dead load. The type of occupancy affects whether a reduction is permitted.

3. *Live Load to Dead Load Ratio*—The permitted reduction depends on the ratio of live load to dead load, provided that the dead load is greater than the live load.

The 1968 NYC Building Code uses the tributary area method and permits the percentage method as an alternative for columns, piers, and walls. The 1964 New York State Building Construction Code and the 1967 Municipal Code of Chicago use the tributary area method for beams and girders and the percentage method for columns and walls. The 1965 BOCA Basic Building Code uses a tributary method that is similar to the New York State Code.

Figure 4–1 compares the reduced live load for columns, walls, and piers on the basis of the percentage method for three of the codes. The permitted reductions are similar with the exception of the roof and top floor, where the 1968 NYC Building Code and the 1967 Municipal Code of Chicago are more conservative (less reduction permitted) than the 1964 New York State Building Construction Code.

Table 4–3 compares the reduced live loads for beams and girders for the selected codes. For the 1968 NYC Building Code, the reduced value of live load for a given contributory area depends on the live load

to dead load ratio, with lower values permitted for lower live load to dead load ratios. For the 1964 New York State Building Construction Code and the 1965 BOCA Basic Building Code, the values shown in the table are based on a reduction factor of 0.08 percent/ft^2. The lowest reduced value, however, is limited to 40 percent or

$$100\ \% \frac{3.33\frac{L}{D} - 1}{4.33\frac{L}{D}} \tag{4–1}$$

whichever is larger, where *L/D* is the live load to dead load ratio. As the ratio of live load to dead load increases, less live-load reduction is permitted. A comparison of the values in Table 4–3 shows that the 1967 Municipal Code of Chicago did not permit as large a reduction in live load for the same contributory area as the other codes.

4.2.3 Wind Load

The effect of wind on buildings is accounted for in the building codes by specifying a uniform pressure to be applied horizontally to a building. These pressures are to be applied in any direction so as to obtain the most critical loading condition.

The pressure due to wind varies with the square of the wind speed, and wind speed increases with height. Thus building codes specify minimum design wind pressures that increase with elevation. The variations of pressure with height, however, are not the same among the building codes compared. Figure 4–2 compares the specified wind pressure versus height relationships for the four selected codes. Several observations are noted:

- For buildings up to 600 ft in height, the 1964 New York State Building Construction Code prescribes the largest wind pressures.
- The 1967 Municipal Code of Chicago prescribes the lowest wind pressures for buildings up to 900 ft in height.
- The 1968 NYC Building Code and the 1965 BOCA Basic Building Code provide similar wind pressures for buildings up to 700 ft in height; for taller buildings the BOCA Code specifies larger pressures.

For a building height of 1,370 ft (the approximate heights of WTC 1 and WTC 2), the wind pressure distribution specified by the 1965 BOCA Basic Building Code would result in the largest shear force and overturning moment at the base of the building.

Table 4–3. Reduced live load for beams and girders.

Contributary Area (ft^2)	1968 NYC Building Code (%)	1967 Chicago Municipal Code (%)	1956 NY State and 1965 BOCA Codes (%)
100 or less	100	100	100
100–149	100	95	100
150–199	80 to 85[a]	95	84 to 88[b]
200–299	80 to 85[a]	90	76 to 84[b]
300–449	60 to 75[a]	85	64 to 76[b]
450–599	50 to 70[a]	85	52 to 64[b]
600 and more	40 to 65[a]	85	40 to 52[b]

a. Permitted value depends on live load to dead load ratio; less reduction permitted with higher ratio.
b. The lowest value is limited to 40 percent, or 100 percent of (3.33 L/D –1)/(4.33 L/D), whichever is greater.

Assuming wind is blowing in the direction perpendicular to the face of the tower, a comparison using the specified wind pressures from the aforementioned codes reveals that the largest shear force at the base of a building the height of the WTC towers is obtained from the BOCA Basic Building Code. Similarly, the largest overturning moment at the base of a building the height of the WTC towers is also obtained from the BOCA Basic Building Code. The lowest base shear and moment are obtained from the 1968 and 2001 New York City Codes. The base shear from the New York City Codes is approximately 8 percent less than that from the BOCA code, while the base moment is approximately 11 percent less (see Table 4–4).

Table 4–4. Base shears and overturning moments from reviewed codes for a building the height of WTC towers (1,368 ft).

	1968 NYC Building Code	2001 NYC Building Code	1964 NY State Code	1967 Chicago Municipal Code	1965 BOCA/BBC
Base Shear (kip)	9,250	9,250	9,460	8,610	9,970
Overturning Moment (ft kip x 10^3 at footing)	7,621	7,621	7,572	7,446	8,470

The 1968 NYC Building Code permits the designer to use wind pressure values, other than specified minimums, on the basis of wind tunnel tests and with approval of the building official.[17] The following wording is provided in Sec. 6 of Reference Standard RS 9-5, "Minimum Design Wind Pressures."

> In lieu of the design wind pressures established in sections 1 and 2 of this reference standard, and subject to review and approval of the commissioner, design wind pressures may be approximated from suitably conducted model tests. The tests shall be predicated on a basic wind velocity of 80 mph at the 30 ft level, and shall simulate and include all factors involved in considerations of wind pressure, including pressure and suction effects, shape factors, functional effects, gusts, and internal pressures and suctions.

[17] See Sub-article 904.0, the1968 New York City Building Code.

The other three contemporaneous codes do not have a similar provision for conducting model tests to determine the design wind pressure.

Thus the 1968 NYC Building Code presumes a wind with a speed of 80 mph measured 30 ft above the ground. The 1964 New York State Building Construction Code, on the other hand, states that the prescribed wind loads "are based on a design wind speed of 75 mph at a height of 30 ft above grade level." Both the 1965 BOCA Basic Building Code and the 1967 Municipal Code of Chicago do not specify the design wind speed.

4.2.4 Earthquake Load

The 1968 NYC Building Code did not have provisions for earthquake loads. Among the selected contemporaneous codes, only the 1965 BOCA Basic Building Code had earthquake load provisions. These are contained in Appendix K-11 of that Code and were adapted from the 1962 edition of the Uniform Building Code.

The 2001 edition of the NYC Building Code contains seismic design provisions from the 1988 edition of the Uniform Building Code (UBC 1988), including the 1990 Accumulative Supplement. These provisions were put into effect in 1996 as a result of Local Law 17 (1995). Significant modifications to the 1988 Uniform Building Code were made, and described in Reference Standard RS 9-6.

For example, the paragraph on "Minimum Seismic Design," is modified to read:

> The following types of construction shall, at a minimum, be designed and constructed to resist the effects of seismic ground motions as provided in this section:
>
> > new structures on new foundations;
> >
> > new structures on existing foundations; and
> >
> > enlargements in and of themselves on new foundations.
> >
> > Buildings classified in New York City occupancy group J-3 and not more than three stories in height need not conform to the provisions of this section. The Commissioner may require that the following types of construction be designed and constructed to incorporate safety measures as necessary to provide safety against the effects of seismic ground motions at least equivalent to that provided in a structure to which the provisions of the section are applicable:
> >
> > new buildings classified in occupancy group J-3 and which are three stories or less in height; and
> >
> > enlargements in and of themselves where the costs of such enlargement exceeds sixty percent of the value of the building.

In the subdivision on "Criteria Selection" the following paragraph was added:

> Seismic Zone. The seismic zone factor, Z, for buildings, structures and portions thereof in New York City shall be 0.15. The seismic zone factor is the effective zero period acceleration for S_1 type rock.

Another significant amendment is the addition of consideration of soil liquefaction that was not found in the Uniform Building Code.

4.2.5 Other Loads

Temperature and Shrinkage

The 1968 NYC Building Code included provisions dealing with types of loadings not considered in the other codes that were compared. Two examples are "thermal forces" and "shrinkage." Section C26-905.7 deals with thermal forces and includes the following requirement:

> …For exterior exposed frames, arches, or shells regardless of plan dimensions, the design shall provide for the forces and/or movements resulting from an assumed expansion and contraction corresponding to an increase or decrease in temperature of forty degrees F for concrete or masonry construction and sixty degrees F for metal construction…

Section C26-905.8 on shrinkage includes the following requirement:

> The design of reinforced concrete components shall provide for the forces and/or movements resulting from shrinkage of the concrete in the amount of 0.0002 times the length between contraction joints for standard weight concrete, and 0.0003 times the length between contraction joints for lightweight concrete….

Abnormal loads (Progressive collapse consideration)

The 1968 NYC Building Code did not have provisions for design against progressive collapse of buildings due to abnormal loads. Abnormal loads would include explosions resulting from ignition of gas or industrial liquids, vehicle impacts, gross construction errors, and the like. In response to the collapse of a concrete panel building in Ronant Point, England in 1968, the NYC Building Code by rule[18] adopted the progressive collapse provisions in August 2, 1973. However, on August 7, 1973, the Department of Buildings issued a memorandum to clarify the type of structures to which the new progressive collapse provisions apply. These include structures with connections that rely on friction due to gravity loads to transfer tension, compression and shear forces in the structural members. Thus, for cast-in-place concrete construction having adequate joint reinforcement, the new progressive collapse provisions would not apply. Similarly, for structural steel construction with bolted, riveted or welded connections to transfer tension, compression and shear forces, the provisions would not apply. In practical sense, the new provisions would apply to precast construction wherein joint forces are transferred by friction developed by gravity loads.

[18] The rules intrepret the code to clarify the intent of the code.

4.2.6 Distribution of Loads

Another topic that is addressed only in the 1968 (and 2001) NYC Building Code is the distribution of loads, which is covered in Article 7 of Sub-chapter 9. Section C26-906.1 deals with vertical loads and states:

> Distribution of vertical loads to supporting members shall be determined on the basis of a recognized method of elastic analysis or system of coefficients of approximation. Elastic or inelastic displacements of supports shall be considered and, for the distribution of dead loads, the modulus of elasticity of concrete or composition [composite] sections shall be reduced to consider plastic flow. Secondary effects due to warping of the floors shall be considered.

Section C26-906.2 deals with distribution of horizontal forces. Because this section provides important information in the design assumptions to be used in the design of high-rise buildings, several key sections are repeated here:

> The following provisions shall apply to superstructure framing only, and shall not apply to structures wherein horizontal loads are transmitted to the foundation by staycables, arches, non-rectangular frames, or by frames, trusses, or shear walls not oriented in vertical planes.
>
> **(a) Distribution of horizontal loads to vertical frames, trusses and shear walls.** - Horizontal loads on the superstructure shall be assumed to be distributed to vertical frames, trusses, and shear walls by floor and roof systems acting as horizontal diaphragms. The proportion of the total horizontal load to be resisted by any given vertical frame, truss, or shear wall shall be determined on the basis of relative rigidity, considering the eccentricity of the applied load with respect to the center of resistance of the frames, trusses, or shear walls. For vertical trusses, web deformations shall be considered in evaluating the rigidity.
>
> **(b) Distribution of horizontal loads within rigid frames of tier buildings.** -
> (1) ASSUMPTIONS. - The distribution of horizontal loads within rigid frames of tier buildings may be determined on the basis of a recognized method of elastic analysis or, subject to limitations in paragraph two of this subdivision, may be predicated on one or more of the following simplifying assumptions:
>
> a. Points of inflection in beams or columns are at their midspan and midheight, respectively. The story shear is distributed to the columns in proportion to their stiffnesses.
>
> b. The change in length of columns due to axial effects of the horizontal loads may be neglected.
>
> c. Vertical column loads due to horizontal forces are taken by the exterior columns only, or are resisted by the columns in proportion to the column distances from the neutral axis of the bent.

(2) LIMITATIONS. -

a. For buildings over 300 ft in height, the change in length of the columns, due to the effects of the horizontal loads, shall be evaluated or the framing proportioned to produce regular movements of the successive joints at each floor so that warping of the floor system may be neglected.

b. Simplifying assumptions used in design shall be subject to approval by the commissioner for any of the following conditions or circumstances:

1. For buildings over 300 ft in height or for buildings with a height-width ratio greater than five.

2. At two-story entrances or intermediate floors.

3. Where offsets in the building occur.

4. Where transfer columns occur.

5. In any similar circumstances of irregularities or discontinuities in the framing.

4.3 DESIGN STANDARDS

Article 10 of the 1968 NYC Building Code is entitled "Structural Work," and it provides minimum requirements for materials, design, and construction of all structural elements in buildings. Section 4.3.1 compares design standards in the selected building codes. Section 4.3.2 discusses design load combinations that were specified in the selected building codes.

4.3.1 Design Standards

Design standards are those documents that are used to proportion the structural elements and their connections. The principal structural materials in the WTC buildings were concrete and steel, and the design standards were those produced by the American Concrete Institute (ACI) and the American Institute of Steel Construction (AISC). The ACI produced the standard known as ACI 318, *Building Code Requirements for Reinforced Concrete*,[19] and the AISC produced the following:

- Specification for the Design, Fabrication and Erection of Structural Steel for Buildings (AISC 1963)
- Specifications for Structural Steel Buildings–ASD and Plastic Design (AISC 1989)
- Load and Resistance Factor Design Specifications for Structural Steel Buildings (AISC 1993)

[19] In 1999, the title was changed to *Building Code Requirements for Structural Concrete.*

Table 4–5 summarizes the concrete and steel design standards adopted by the codes that were compared. The 1964 New York State Building Construction Code was a performance standard and did not adopt design standards by reference. Thus, at the time the WTC towers were being designed, the other two codes (Chicago and BOCA) referenced the same concrete and steel design standards as the New York City code.

Table 4–5. Design standards for concrete and steel.

Material	1968 NYC Code	2001 NYC Code	1967 Chicago Code	1965 BOCA Code
Concrete	ACI 318-63	ACI 318-89	ACI 318-63	ACI 318-63
Steel	AISC 1963	AISC 1989 AISC 1993	AISC 1963	AISC 1963

The 1963 edition of ACI 318 permits reinforced concrete members to be designed by either the working stress (or allowable stress) method or by the ultimate strength method. The 1963 AISC specification, on the other hand, is based on allowable stress design. The design method affects the loads used in the design calculations.

4.3.2 Load Combinations

The loads prescribed by the codes are used in different combinations to assess the governing design condition. The codes distinguish between sustained loads and loads of short duration or infrequent occurrence. For allowable stress design, two approaches are used for dealing with these two categories of loads, as will be discussed. For ultimate strength design, the prescribed loads are multiplied by specified load factors. In either case, the designer considers all applicable load combinations and determines the most critical condition, which becomes the design basis for a particular element.

Allowable Stress Design

The 1968 NYC Building Code defines two categories of loads:

- Basic loads, which include dead load, live load, and reduced live load where applicable; and
- Loads of infrequent occurrence, which include wind load, thermally induced load, shrinkage induced load, and unreduced live load where live load reduction is permitted.

Under the 1968 NYC Building Code, stresses in structural elements may not exceed the allowable values specified in the referenced design standards under the following load combinations[20]:

- The sum of the basic loads multiplied by a factor equal to 1.
- The factored sum of one or more basic loads and one load of infrequent occurrence, where the load factor equals 0.75.

[20] See Section C26-1001.4 of the 1968 NYC Building Code.

- The factored sum of one or more basic loads plus two or more loads of infrequent occurrence, where the load factor equals 0.6.

The 2001 NYC Building Code is similar with the exception that it includes earthquake load as another load of infrequent occurrence.

The other Codes that were compared use a different approach for dealing with loads of infrequent occurrence. The 1964 New York State Building Construction Code states that stress due to wind load may be ignored if it is less than one-third of the stress due to dead load plus imposed load excluding wind load. If the stress due to wind load exceeds this limit, the allowable stress for the material is permitted to be increased by 1/3.

The 1967 Municipal Code of Chicago uses a similar approach and states: "For combined stresses due to dead, live, and wind load, the allowable stresses in materials may be increased 1/3, provided the section thus determined is at least as strong as that required for dead and live load alone. Snow load shall be considered a live load."

The 1965 BOCA Basic Building Code is similar except that wind load or earthquake load is considered along with dead load and live load (including snow load). The same 1/3 increase in allowable stress is permitted under wind or earthquake load. The BOCA Code also explicitly states that wind load is permitted to be neglected if it results in stress less than one-third the stress due to dead load plus live load.

Ultimate Strength Design

In the 1960s, ultimate strength design was standardized only for reinforced concrete. As shown in Table 4-5, the three codes from the 1960s referenced ACI 318-63, which includes the following load combinations to establish the design loads (U) for structural members:

1. For structures where wind and earthquake loads may be neglected, U = 1.5 D + 1.8 L.

2. For structures where wind load must be included, U = 1.25 (D + L) or U = 0.9 D+ 1.1 W, whichever produces the most unfavorable condition for the member.

3. For structures where earthquake loading is included, E shall be substituted for W in condition 2.

4. In structures where effects of shrinkage and temperature are included, the effects of such items shall be considered on the same basis as the effects of dead load.

The 2001 NYC Building Code refers to ACI 318-99, which includes many more load combinations to be considered. These are as follows:

1. For all structures, U = 1.4 D + 1.7 L.

2. For structures where wind load must be included, U = 0.75[1.4 D + 1.7 L + 1.7 W)] or U = 0.9 D + 1.3 W, whichever produces the most unfavorable condition for the member.

3. For structures where resistance to earthquakes must be included, the load combinations of condition 2 are used with 1.1 E substituted for W.

4. For structures where resistance to earth pressure (H) must be included, U = 1.4 D + 1.7 L + 1.7 H or 0.9 D + 1.7 H, whichever produces the most unfavorable condition.

5. For structures where resistance to fluid pressure (F) must be included, U = 1.4 D + 1.7 L + 1.4 F or 0.9 D + 1.7 F, whichever produces the most unfavorable condition.

6. For structures where resistance shrinkage and temperature (T) must be included, U = 0.75 (1.4 D + 1.4 T + 1.7 L) > 1.4 (D + T).

7. For structures where resistance to impact must be taken into account, such effects shall be included with live load L.

4.4 ALTERATION OF EXISTING BUILDINGS

The compared codes have provisions to address code compliance when existing buildings are altered. The provisions of all codes, other than the 1964 New York State Building Construction Code, are broadly similar. In general, whether the altered building or only the alternations need to comply with code requirements depends on the ratio of alterations to the total building expressed either in terms of cost or dimensions. When the ratio is low, even the alterations may not have to be in compliance with the code, provided stipulated conditions are met. The 1964 New York State Building Construction Code, however, requires that any addition or alteration, regardless of building value, shall be made in conformity with that code. It is silent as to the structure being altered. Table 4–6 summarizes code provisions related to alterations.

Table 4–6. Compliance requirements for alterations.

Code	Provisions
1968 New York City Building Code	**Alterations exceeding 60 percent of building value (in any 12 month period):** The entire building shall be made to comply with the requirement of the code. **Alterations between 30 percent and 60 percent of building value (in any 12 month period):** Only those portions of the building altered shall be made to comply with the requirements of the code. **Alteration under 30 percent of building value (in any 12 month period):** Those portions altered may, at the option of the owner, be altered in accordance with the requirement of the code, or altered in compliance with their previously required condition and with the same or equivalent materials and equipment, provided the general safety and public welfare are not thereby endangered.
2001 New York City Building Code	Same as 1968 Code, except that wording for alterations **less than 30 percent** of building values was changed to: "those portions of the building altered may, at the option of the owner, be altered in accordance with the requirements of this code, or altered in compliance with the applicable laws in existence prior to December sixth, nineteen hundred sixty-eight, provided the general safety and public welfare are not thereby endangered." In addition, certain alterations are required to conform to the code regardless of

Code	Provisions
	magnitude or cost. These include, among others: Alterations to standpipes, sprinklers, or interior fire alarm and signal systems; Alterations to equipment for heating or storing water; Sprinkler, alarm protection, and emergency lighting requirements for places of assembly.
1964 New York State Building Construction Code	**Addition or alteration:** Any addition or alteration, regardless of cost, made to a building shall be made in conformity with applicable regulations of the code.
1967 Municipal Code of Chicago	**More than 50 percent:** Such buildings and structures shall be made to conform to all requirements of the code that are applicable to new buildings and structures. **25 percent to 50 percent:** All new constructions shall conform to the requirements of the code for new buildings or structures of like area, height and occupancy. **25 percent or less:** Certain exceptions can be made that allow the use of materials that conform to the strength and fire resistance for the materials with which the building is constructed. Otherwise, all new construction shall conform to the requirements of this code for a new building.
1965 BOCA Basic Building Code	"In the reconstruction, repair, extension or alteration of existing buildings, the allowable working stresses used in design shall be as follows: 1. **Building extended:** If altered by an extension in height or area, all existing structural parts affected by the addition shall be strengthened where necessary and all new structural parts shall be designed to meet the requirements for buildings hereafter erected. 2. **Building repaired:** When the uncovered structural parts are found unsound, such parts shall be made to conform to the requirements for buildings hereafter erected. 3. **Existing live load:** When an existing building heretofore approved is altered or repaired within the limitation prescribed in Sec. 106.3 (alteration under 50 percent) and 106.4 (alteration under 25 percent), the structure may be designed for the loads and stresses applicable at the time of erection, provided that public safety is not endangered. 4. **Posted live load:** May be posted for original approved live loads."

4.5 MATERIALS AND METHODS OF CONSTRUCTION

The compared codes have requirements for the materials and construction methods. Each code makes distinctions in materials and methods that depend on the nature of inspection and conformance with standards.

The 1968 NYC Building Code prescribes testing and inspection requirements for all materials, assemblies, forms, and methods of construction. A distinction is made between materials and methods subject to "controlled inspection" and those that are not subject to controlled inspection. Materials and methods subject to controlled inspections "shall be inspected and/or tested to verify compliance with code requirements." In general, activities related to controlled inspections "shall be made and witnessed by or under the direct supervision of an architect or engineer retained by or on behalf of the owner or lessee, who shall be, or shall be acceptable to, the architect or engineer who prepared or supervised the preparation of the plans." On the other hand, materials and methods not designated for controlled inspection "shall be inspected and/or tested to verify compliance with code requirements by the person superintending the use of the material or its incorporation into the work…"

The 1968 NYC Building Code provides tables to indicate which materials and methods are subject to controlled inspections and which are not. Table 4–7 includes excerpts from the requirements for inspection of materials and assemblies. A footnote to the table in the code states that "All structural materials and assemblies subject to controlled inspection shall be tested and/or inspected at their place of manufacture and evidence of compliance with the provisions of this subchapter shall be provided as stipulated in sub-articles 1003.0 through 1011.0." Table 4–8 is an excerpt of the inspection requirements for methods of construction. A footnote to the companion table in the code states that "All construction operations designated for controlled inspection shall be inspected by the architect or engineer designated for controlled inspection during the performance of such operation."

Table 4–7. Excerpts of inspection requirements for materials and assemblies in Article 10 of 1968 NYC Building Code.

Material	Elements Subject to Controlled Inspection	Elements Not Subject to Controlled Inspection
Steel	None	All structural elements and connections
Concrete	Materials for all structural elements proportioned on the basis of calculated stresses 70 percent or greater, of basic allowable stresses. See Sec. 1004.0 for specific requirements relating to "quality control of materials and batching."	(1) All materials for all structural elements proportioned on the basis of calculated stresses less than 70 percent or greater of basic allowable values. (2) Concrete materials for: (a) Short span floor and roof construction proportioned as per Sec. 1004.8. (b) Walls and footings for buildings in Occupancy Group J-3. (3) Metal reinforcement.

The 1968 NYC Building Code required that the installation of "sprayed-on fire protection" of structural members (except those encased in concrete) be subjected to controlled inspection requirements, as defined above. There were, however, no specific provisions on what testing was required.

The 1964 New York State Building Construction Code and the 1965 BOCA BBC make distinctions between "controlled" and "ordinary" materials in reference to establishing allowable stresses. For example BOCA defines "controlled materials" as those that are "certified by an accredited authoritative agency as meeting accepted engineering standards for quality." Ordinary materials are those that do not conform to the requirements for controlled materials.

The 1967 Municipal Code of Chicago specifies that all materials and methods used in the design and construction of buildings shall be classified as "controlled materials" or "ordinary materials." According to the Chicago Code, "controlled materials" means a building, structure, or part thereof, which has been designed or constructed under the following conditions: (a) All controlled materials must be selected or tested to meet the special strength, durability and fire resistance requirements upon which the design is based. (b) The design, preparation of working drawings, including details and connections, the checking and approval of all shop and field details and the inspection of the work during construction shall be under the supervision of a registered architect or structural engineer (Sec. 69-3.1).

Table 4–8. Excerpts of inspection requirements for methods of construction in Article 10 of 1968 NYC Building Code.

Material	Operations Subject to Controlled Inspection	Operations Not Subject to Controlled Inspection
Steel	(1) Welding operations and the tensioning of high strength bolts in connections where the calculated stresses in the welds or bolts are 50 percent or more of basic allowable values. (2) Connection of fittings to wire cables for suspended structures, except where cables together with their attached fittings are proof-loaded to not less than 50 percent of ultimate capacity.	(1) Welding operations and the tensioning of high strength bolts in connections where the calculated stresses in the welds or bolts are less than 50 percent of basic allowable values. (2) All other fabrication and erection operations not designated for controlled inspection.
Concrete	Except for those operations specifically designated in this table as not subject to controlled inspection, for all concrete, the operations described in Sec. 1004.5(a) shall be subject to controlled inspection."	(1) All operations relating to the constriction of members and assemblies (other than prestressed concrete) which involve the placement of a total of less than 50 cubic yards of concrete and wherein said concrete is used at levels of calculated stress 70 percent or less of basic allowable values. (2) placing and curing of concrete for all: (a) short span floor and roof construction as per Sec. 1004.8. (b) Walls and footings for buildings in Occupancy Group J-3. (3) Size and location of reinforcement for walls and footings in Occupancy Group J-3. (4) All other operations not described in Secs. C26-1004.5(a).

4.6 STABILITY, BRACING, AND SECONDARY STRESSES

The 1968 and 2001 NYC Building Codes are the only codes of those compared that include provisions for *stability*, *bracing*, and *secondary stresses*. The provisions are the same in the two editions of the code. Stability, in this case, refers to resistance to sliding or overturning of the building on its foundation. The NYC Building Code requires a factor of safety of 1.5 against failure by sliding or overturning. The required stability is to be provided solely by the dead load plus any permanent anchorage that is provided. Bracing refers to lateral support to prevent buckling of compression members (columns and walls). The NYC Building Code requires that the bracing be proportioned to resist a load of at least 2 percent of the total design compression load in the braced member plus any transverse shear load on the bracing member. Secondary stresses refer to stresses associated with transverse deflection of a member. In trusses, for example, secondary stresses arise because joints are not true pins, and some bending is introduced, which results in transverse displacements of the individual elements. The NYC Building Code requires that secondary stresses in trusses be considered in designing the size of the individual elements.

4.7 DEFLECTION LIMITATIONS

All five codes contain limits on vertical deflections of floor and roof assemblies. Except for the NYC Building Codes (both the 1968 and 2001 versions), the deflection limits relate to crack formation of plastered building components. The deflection is limited to 1/360 of the span for plastered members and 1/240 of the span for non-plastered members. The NYC Building Codes refer to the reference standards for deflection limits in addition to the 1/360 of the span limit. For concrete members, ACI 318-63 specifies limits for both short- and long-term deflections of beams and one-way slabs. For steel members, the 1963 AISC Specification specifies deflection limits to avoid damage to plastered ceilings and to limit deflections of flat roofs.

4.8 LOAD TESTS

Building codes generally allow load tests to ascertain the adequacy of load carrying capacity of structural members. Specifically, building codes allow load tests or tests of in-place materials:

- To verify adequacy of structural design for a member or an assembly;
- To verify adequacy of partially completed construction;
- To prequalify structural members or assemblies before used in service;
- To verify adequacy of questionable completed structure; and
- To determine concrete strength by means of core tests.

The NYC Building Codes have provisions to cover all five categories. The New York State Code had provisions for (1) and (4). The Chicago Municipal Code had provisions for (1), (4) and (5). The BOCA/Basic Building Code had provisions for (1) and (2).

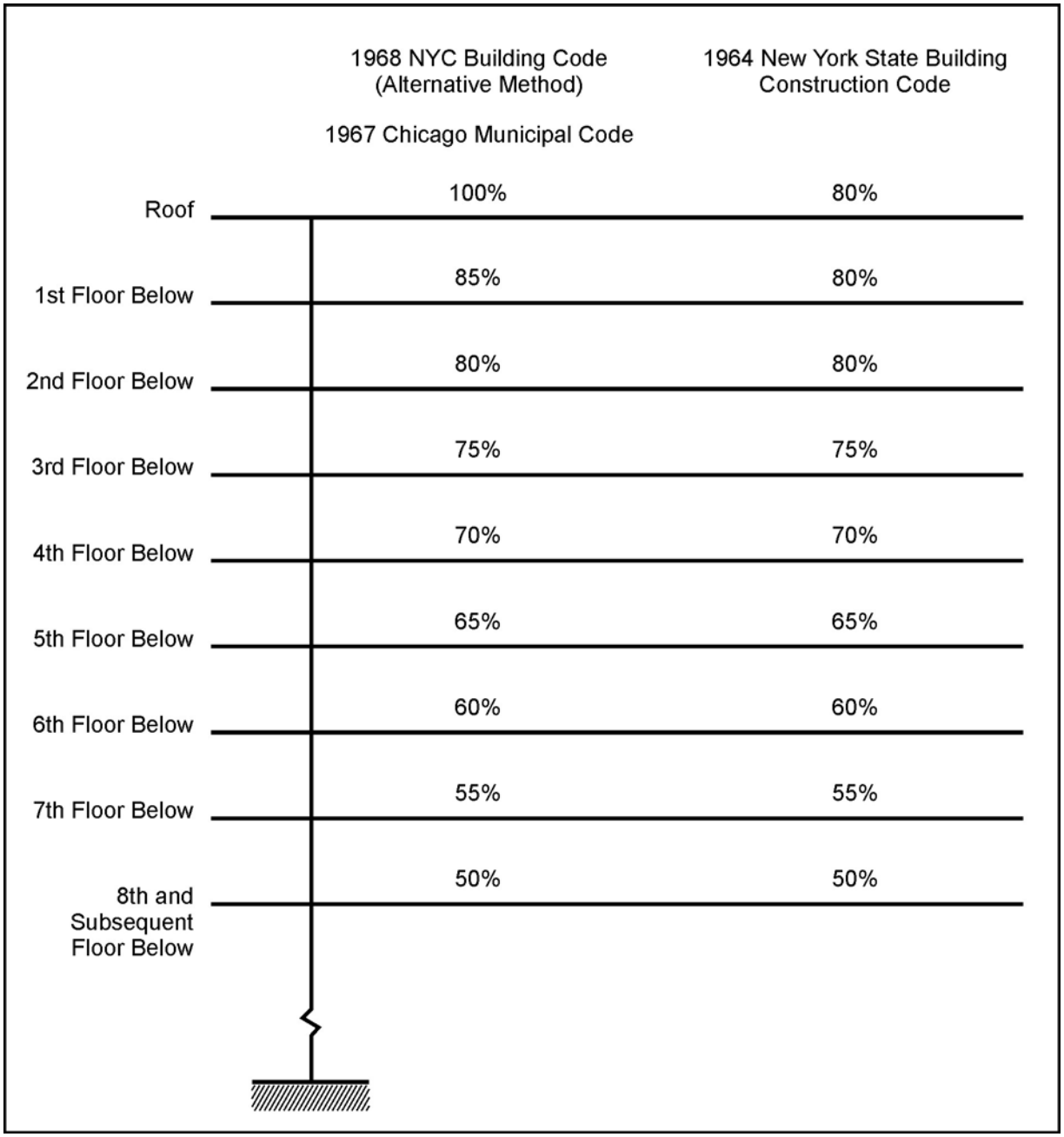


Figure 4–1. Reduced live load as a function of floor location based on the percentage method (for columns, walls, and piers).

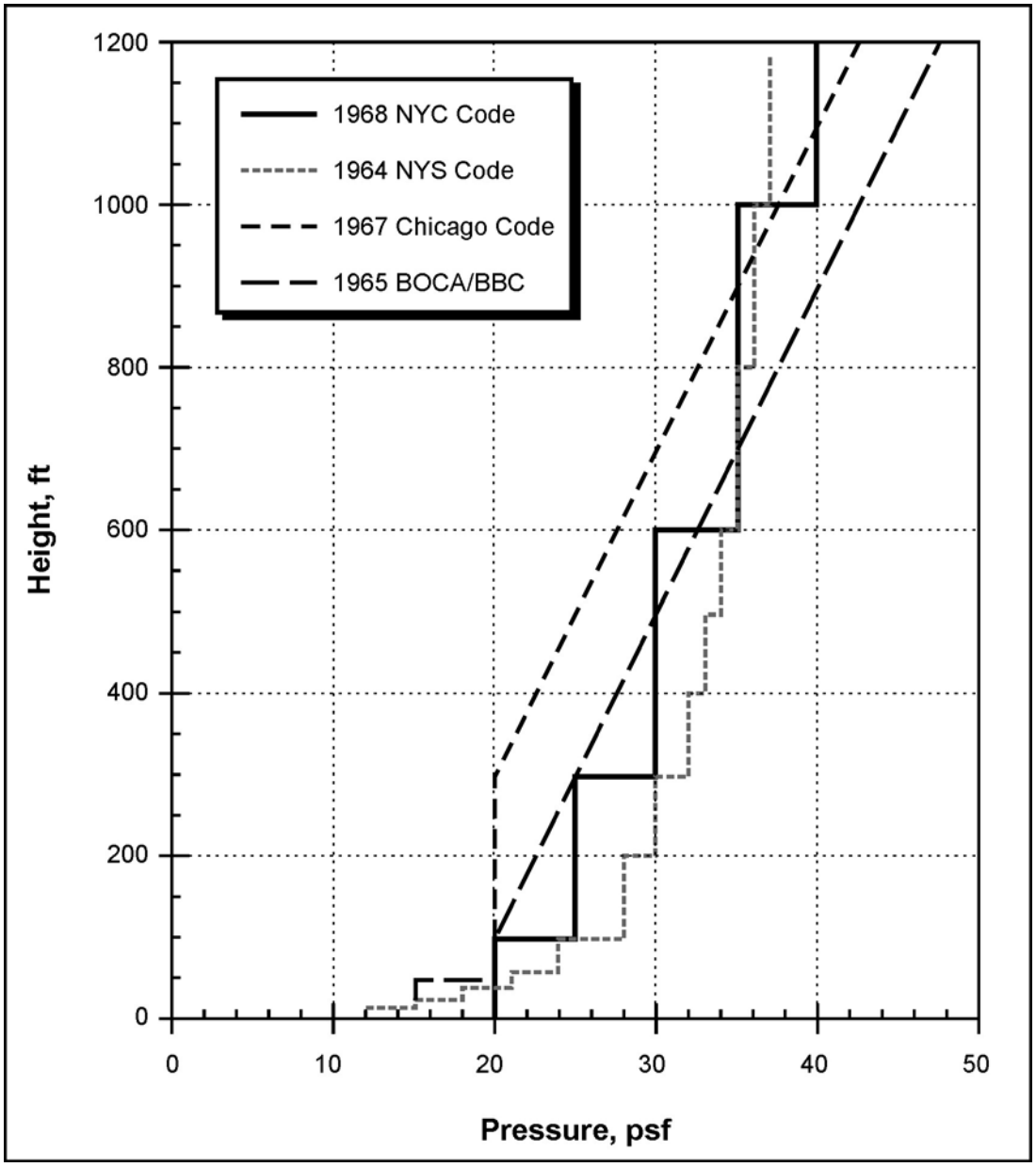


Figure 4–2. Wind load pressure versus elevation.

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Chapter 5
STRUCTURAL DESIGN OF WTC 1, 2, AND 7

5.1 DESIGN CRITERIA

As stated in Sec. 1.1, the design of World Trade Center (WTC) 1 and WTC 2 was governed by the second and third drafts of the 1968 New York City (NYC) Building Code. The 1968 Code also governed the design of WTC 7. However, different design values were allowed by the Building Code if they were more conservative than minimum design requirements specified in the Building Code.

In a number of cases, the design of the WTC 1 and WTC 2 were based on values that were more conservative than those specified in the 1968 NYC Building Code, such as live loads for the tenant spaces outside the central core area and wind loads for the towers. These will be presented in further detail below. No design calculations are available for review of the actual design criteria used for the design of WTC 7. The materials presented in this chapter pertain mainly to WTC 1 and WTC 2.

5.1.1 Loads

As presented in Chapter 4, the building codes specify minimum design values for vertical and lateral loads. In the NYC Building Code, Chapter 26, Article 9 prescribes the minimum loads to be used in the design of buildings and their parts. Section C26-900.2, Standards, refers to Reference Standard RS-9 for the minimum dead, live, and wind loads, which are incorporated by reference into Article 9. In no case does the Code allow for the loads used in design to be less than the minimum values contained in that article. In this section, actual design loads used for design are presented and compared with the New York City Code requirements.

Dead Loads

The unit dead loads specified for the various structural members are contained in the Design Criteria for WTC 1 and WTC 2 (WSHJ 1965a). Different criteria were established for members located inside the core and outside the core.

Floor Inside of Core

The core area in a representative upper floor of WTC 1 and WTC 2 is illustrated in Fig. 2–13. Unit design dead loads for the beams, columns, and slabs within the core area of the towers are summarized in Fig. 5–1.[21] In all cases, the dead loads in the design criteria were greater than or equal to the corresponding dead loads prescribed in the Code. Examples of design dead loads in the 1968 NYC Building Code are listed in Table 4–1. A comprehensive list of the dead loads prescribed in the Code is given in Annex A1 of the report entitled *Comparison of Building Code Structural Requirements* (NIST NCSTAR 1-1B). For equivalent uniform loads for partitions (according to C26-901.3(b) of the NYC

[21] In Fig. 5–1, "contact" fireproofing is listed. This is a type of fireproofing that is sprayed on to steel members.

Building Code), the equivalent uniform partition loads in Reference Standard RS 9-1 may be used in lieu of actual partition weights when partitions are not shown on the plans. The actual values for design are given in the design criteria shown in Fig. 5–2. As allowed by the Code, the actual partition loads, which were less than specified 20 psf in the Code for a partition of 201 plf to 350 plf, were used in the design of WTC 1 and WTC 2.

Floor Outside of Core

Unit dead loads for areas outside of the core are specified in the design criteria for the following structural members: one-way long-span floor trusses, one-way short-span floor trusses, two-way floor trusses, beams on framed floors, bridging, columns, steel deck, and reinforced concrete slabs. The design criteria vary depending upon the floor level. Figure 5–3 contains sample design criteria for the long-span floor trusses at typical floor levels. For a further description of dead loads used in design, see NIST NCSTAR 1-2. The dead loads in the design criteria for all of the structural members were greater than or equal to the corresponding dead loads prescribed in the Code.

Design Criteria for WTC 7

Design load criteria for WTC 7 are summarized in Fig. 5–4. These criteria appear on Sheet S-24, Typical Superstructure Sections and Details, in the structural drawings (The Office of Irwin G. Cantor 1983). Because the actual materials used for the partitions, flooring, and ductwork were not specified, the reasonableness of these design values cannot be ascertained.

Live Loads

Design Criteria for WTC 1 and WTC 2

Specified live loads are given in the Design Criteria for WTC 1 and WTC 2 (WSHJ 1965a). As in the case of dead loads, different live-load criteria were established for members located inside the core and outside the core.

- **Floor inside of core.** Live loads to be used in the design of the beams and columns within the core area are summarized in Fig. 5–5, Fig. 5–6, and Fig. 5–7. As can be seen from the figures, except for floor 109 and areas occupied by equipment, the design live load varied from 40 psf to 100 psf. For all occupancies or use of spaces common to the design criteria and the Code, the live loads in the design criteria were equal to the corresponding live loads prescribed in the Code (which are given in Annex A1 of NIST NCSTAR 1-1B/*Comparison of Building Code Structural Requirements*).

- **Floor outside of core.** Like the unit dead loads, design live loads outside of the core area varied with the floor level. At most floor levels, a design live load of 100 psf was specified for the slabs (see Fig. 5–8 from the Design Criteria). At mechanical floors 7, 41, 75, and 108, a 75 psf live load was used. Figure 5–9 shows sample design criteria for the columns at the floor levels noted in the figure. Live loads specified in the design criteria were equal to or greater than the corresponding live loads prescribed in the Code. It should be noted that the 100 psf live load used is twice the design live load specified in the NYC Building Code.

Table 5–1 compares live loads used for the design of floors with corresponding values specified in the 1968 NYC Building Code. In most cases, they are the same. Major differences are noted for the design live loads for corridors within the core, tenant spaces outside of the core, and passenger elevator lobbies on the tenant floors. Note that the design live load for the tenant spaces are twice the code specified value.

Table 5–1. Live loads used in design of WTC 1 and WTC 2.

Use of Spaces	1968 NYC Code (psf)	WTC Design Criteria (psf)
Cafeteria	100	100
Closets (tenant floors)	100	100
Concourse	100	100
Corridors within core (mechanical equipment floor)	**75**	**100**
Corridors within core (skylobby floor)	100	100
Corridors within core (typical office floor)	75	75
Duct offset space	75	75
Electric closet	75	75
Electric substation & transformer room	75	75
Expansion tank room	75	75
Janitor's closets	100	100
Kitchen	100	100
Local passenger elevator lobbies (skylobby floors)	100	100
Main shuttle elevator lobbies (skylobby floors)	100	100
Mechanical equipment rooms	75	75
Men's toilets	40	40
Observation lobby	100	100
Tenant space outside core	**50**	**100**
Passenger elevator lobbies (tenant floors)	**100**	**75**
Powder rooms	40	40
Restaurant	100	100
Roof	30	40
Secondary motor rooms	75	75
Service room (mechanical equipment floor)	75	100
Service room (tenant floor)	75	100
Sprinkler tank room	75	75
Stairs	75	100
Telephone closets	80	75
Tenant spaces within core	50	56
Woman's toilets	40	40

Design Criteria for WTC 7

As noted previously, design criteria for WTC 7 are summarized in Fig. 5–4. These criteria appear on Sheet S-24, Typical Superstructure Sections and Details, in the structural drawings (The Office of Irwin G. Cantor 1983). For the floor levels where the type of occupancy was noted on Sheet S-24, the live loads in the design criteria were equal to those given in the Code.

5.1.2 Live Load Reduction

Code Requirements

Provisions for live-load reduction in the 1968 NYC Building Code are contained in Sub-article 903.0, Live Load Reduction. According to C26-903.1, live load reduction is not permitted on roofs. The allowable reduced live load for floor members is determined by multiplying the basic live load value from Reference Standard RS 9-2 (see above) by the percentages given in Table 9-1 of the Code, which is reproduced in Table 5–2. These percentages are a function of the contributory floor area, which is defined in C26-903.3, and the ratio of live load to dead load.

Table 5–2. Percentage of live load per the 1968 NYC Building Code.

Contributory Area (ft^2)	Ratio of Live Load to Dead Load[a]		
	0.625 or less	1	2 or more
149 or less	100	100	100
150–299	80	85	85
300–449	60	70	75
450–599	50	60	70
600 or more	40	55	65

a. For intermediate values of live load/dead load, the applicable percentages of live load may be interpolated.

Contributory floor areas are computed as follows (C26-903.3):

- For one-way and two-way slabs: product of the shorter span length and a width equal to one-half the shorter span length. Ribbed slabs shall be considered as though the slabs were solid.
- For flat plate or flat slab construction: one-half the area of the panel.
- For columns, girders, or trusses framing into columns: the loaded area directly supported by the column, girder, or truss. For columns supporting more than one floor, the loaded area shall be the cumulative total area of all the floors that are supported.
- For joists and similar multiple members framing into girders or trusses, or minor framing around openings: twice the loaded area directly supported but not more than the area of the panel in which the framing occurs.

No live load reduction is permitted (C26-903.2(b)) for members and connections (other than columns, piers, and walls) supporting:

- Floor areas used for storage (including warehouses, library stacks, and record storage);
- Areas for parking of vehicles;
- Areas for places of assembly, for manufacturing; and
- Areas for retail or wholesale sales.

The maximum live load reduction is 20 percent for columns, piers, and walls supporting such areas.

Live-load reduction is also not permitted for calculating shear stresses at the heads of columns in flat slab or flat plate construction (C26-903.2).

As an alternative procedure, live load reduction for columns, piers, and walls may be taken as 15 percent on the top floor, increased successively at the rate of 5 percent on each successive lower floor, with a maximum reduction of 50 percent. For girders supporting 200 ft^2 or more of floor area, the live-load reduction is 15 percent.

Design Criteria for WTC 1 and WTC 2

Live-load reduction criteria from the Design Criteria for WTC 1 and WTC 2 are given in Fig. 5–9 (WSHJ 1965a). The figure shows the percentage of design live load from the Design Criteria that was used in the design of structural members. For floor members, these percentages were the same as those from the 1968 Code, except in the case where the live load to dead load ratio was 2 or more and the loaded area tributary to the floor member was between 150 ft^2 and 299 ft^2; in this case, the code-prescribed percentage is 85 percent, while the value in the Design Criteria was 90 percent, which is more stringent than the code requirement (see Fig. 5–10).

Figure 5–11 shows the design live loads from the Design Criteria for the tenant areas inside of the core. The solid line represents the reduced live load that was used in the design of the beams; these values were computed in accordance with the live-load reduction provisions in the Design Criteria (see Fig. 5–10). The unreduced live load specified in the Design Criteria for tenant spaces inside the core was 100 psf, which matches the design live load shown in Fig. 5–12 for tributary areas up to 200 ft^2. Also included in this figure are two other sets of data points: one set represents the reduced live load computed in accordance with the 1968 Code provisions with a live load to dead load ratio equal to one and the other set is the Code equivalent uniform load for partitions, which is a constant 6 psf for partition weights up to 100 plf. The Code requires a 50 psf live load in tenant areas (office areas without storage) per Reference Standard RS 9-2. The 50 psf live load plus the 6 psf partition load is shown in the figure for tributary areas up to 150 ft^2. Figure 5–12 clearly shows that the design live loads specified in the Design Criteria, including live load reduction, were greater than those required by the Code for office areas without storage.

Figure 5–13 contains the design criteria for live load reduction for the floor areas outside of the core for the floor levels that are noted in the figure. These criteria are the same as those for the tenant space inside

of the core (see Fig. 5–12). Similar criteria were also provided in the Design Criteria for other floor levels.

5.1.3 Wind Load

In lieu of using its prescribed pressures, the 1968 NYC Building Code allows "suitably conducted model tests" to establish design wind pressures, subject to review and approval of the Building Commissioner (Item 6 in Reference Standard RS 9-5). The tests are to be based on a basic (fastest-mile) wind velocity of 80 mph at 30 ft above ground and are to simulate and include all factors involved in consideration of wind pressure, including pressure and suction effects, shape factors, functional effects, gusts, and internal pressures and suctions.

Design Criteria for WTC 1 and WTC 2

Design wind forces on the towers were determined based on a series of wind tunnel tests that were conducted at the Colorado State University (CSU) and the National Physical Laboratory (NPL) in the United Kingdom. Specific details on these tests can be found in NIST NCSTAR 1-1A.

The design wind loadings of the exterior walls of WTC 1 and WTC 2 consisted of shear forces and overturning moments that were computed at each floor level in the two principal directions of the towers due to the equivalent design wind velocity of 98 mph from 24 wind directions equally spaced at 15 degrees intervals around the tower. The equivalent design wind velocity was defined as the mean wind velocity averaged over a 20 min period at a height of 1,500 ft above the ground and was based on a 50 year return period.

The shear forces S and overturning moments M at each floor level were comprised of static and dynamic components:

$$S = \overline{S} \pm S' \qquad M = \overline{M} \pm M' \tag{5–1}$$

where the first and second terms indicate, respectively, the mean or steady-state components and the dynamic components. The static components of the shear and moments were calculated from the following equations.

$$\overline{S}(z) = \frac{1}{2}\rho \overline{V}_o^2 DHC_S(z) \qquad \overline{M}(z) = \frac{1}{2}\rho \overline{V}_o^2 DH^2 C_M(z) \tag{5–2}$$

where:

ρ = design air density = 0.0023 slugs per cubic foot

$\overline{V}_o$ = mean design wind velocity = 98 mph averaged over 20 min at a height of 1,500 ft above ground

C_S = shear force coefficients from wind tunnel tests

C_M = overturning moment coefficients from wind tunnel tests

D = plan dimension of building

H = height of building

The dynamic components of the shear forces and overturning moments at any height z were calculated from the following equations.

$$S'(z) = 4\pi^2 n_o^2 A \int_z^H m(z)\mu(z)dz$$
$$M'(z) = \int_z^H S'(z)dz \qquad (5\text{–}3)$$

In the first of these equations, n_o is the natural frequency of oscillation of the building, and A is the amplitude of oscillation at the top of the tower corresponding to a mean design wind velocity. The quantity $m(z)$ is the mass per unit height of the building, and $\mu(z)$ is the mode amplitude at height z for unit amplitude at the top of the building. Using sets of shear and overturning moment coefficients obtained from the wind tunnel tests (WSHJ 1966a), the shear forces and overturning moments at each floor were computed.

A comparison of the base shear and moment obtained from using the wind pressures from the 1968 NYC Building Code and the wind tunnel test results are shown in Table 5–3. The code-based values of base shear and overturning moment occur simultaneously on the same face of the tower, whereas the base shear and the overturning moment obtained from the wind tunnel tests represent the largest values related to most unfavorable wind direction, thus they may not occur simultaneously on the same face of the tower. For the description used to compute the values based on the wind tunnel tests, see NIST NCSTAR 1-2. The wind load used to design the towers are greater than that based on the code specified wind pressure values.

Table 5–3. Base shears and overturning moments based on the 1968 NYC Building Code and wind tunnel tests.

	1968 NYC Building Code	Wind Tunnel Tests
Base Shear (kip)	9,250	13,100
Overturning Moment (10^3 ft kip)	7,621	12,600

For external cladding and glazing, design wind pressures were specified in the WTC Design Criteria. Outward (negative) pressure acting normal to the surface varied from 65 psf below the 7th floor to 125 psf at the 109th floor. Inward (positive) pressures varied from 45 psf below the 7th floor to 55 psf at

the 108th floor. These pressures are based on the results of a series of wind tunnel tests that were performed specifically for this purpose (WSHJ 1967a).

Design criteria were also established for the antenna mast located on top of WTC 1 (WSHJ 1973). The antenna and its components were to be designed for the following conditions:

- A mean wind speed of 140 mph in any direction and no ice coating;
- A mean wind speed of 110 mph in any direction with an ice coating of ½ in. over all exposed unheated metallic surfaces with a minimum air temperature of 20 °F;
- A mean wind speed of 110 mph in any direction and no ice coating under a range of air temperatures from 10 °F to 90 °F;
- A mean wind speed of 40 mph in any direction and no ice coating under a range of air temperatures from –15 °F to 105 °F; and
- Dynamic effects of wind associated with the mean wind speeds specified above (dynamic effects of wind gusts were obtained by multiplying the mean wind forces by a factor of 5).

The requirement of a ½ in. thick coating of ice is consistent with the requirement in C26-905.6 of the 1968 NYC Building Code for the design of open-framed or guyed towers. Also, the NYC Code requires that exterior exposed frames, arches, or shells be designed for the forces and/or movements resulting from an increase or decrease in temperatures of 60 °F for metal construction (C26-905.7). These requirements are less stringent than those contained in the design criteria. The design criteria contain a section on how the wind forces were computed based on these velocities.

Design Criteria for WTC 7

No design criteria or calculations were available for WTC 7 with respect to wind loads. However, a wind tunnel study of WTC 7 was carried out in 1983 by the University of Western Ontario at the request of the structural engineer of record, Irwin G. Cantor, Consulting Engineers (Isyumov 1983). No document is available to show whether the wind tunnel test results were used in design of WTC 7.

5.1.4 Aircraft Impact

No building code in the United States has specific design requirements for impact of an aircraft, and thus, buildings are not specifically designed to withstand the impact of fuel-laden commercial aircraft. However, since the collision of a B-25 bomber into the Empire State Building in 1945, designers of high-rise buildings have become aware of the potential of the crash of aircrafts into buildings. A three-page document from the Port Authority of New York and New Jersey (PANYNJ or Port Authority) indicates that the impact of a Boeing 707 aircraft flying at 600 mph was analyzed during the design stage of the WTC towers in February/March 1964.[22]

[22] Letter with an attachment dated November 13, 2003 from John R. Dragonette (Retired Project Administrator, Physical Facilities Division, World Trade Department) to Saroj Bhol (Design and Engineering Department, PANYNJ).

No documents on the aircraft impact analysis are available to review the criteria and method used in the impact analysis of a Boeing 707 aircraft on the WTC tower and to verify the assertion in the three-page document that "…such collision would result in only local damage which could not cause collapse or substantial damage to the building and would not endanger the lives and safety of occupants not in the immediate area of impact." Without the original calculations of the aircraft impact analysis, any comment on the document would be a speculation. In March 1964, a calculation was made by the Port Authority to determine the period of vibration of the tower due to an aircraft impact at the 80th floor.[23] Although no conclusion was stated on the calculation sheet, it clearly indicates that the Port Authority recognized during the design stage the possibility of an aircraft impact on the tower.

5.2 STRUCTURAL DESIGN REQUIREMENTS

According to sub-article 1002.0 of the NYC Building Code (Adequacy of the Structural Design), the design of structural members was to conform to the applicable material standards mentioned in sub-articles 1003.0 through 1011.0 (C26-1002.1). If such computations as prescribed in these standards cannot be executed due to "practical difficulties," the structural design can be deemed adequate if the member or assembly performs satisfactorily when subjected to load tests in accordance with 1002.4(a). Provisions to determine the adequacy of completed or partially completed structures are also provided. Prequalifying load tests (C26-1002.4(a)) can be used to establish the strength of a member or assembly prior to having such members or assemblies incorporated into a structure. The test specimens are to be a true representation of the actual members or assemblies in all aspects, including the type and grade of material used. Support conditions for the members or assemblies being tested are to simulate the conditions of support in the building, except that conditions of partial fixity might be approximated by conditions of full or zero restraint, whichever produces a more severe stress condition in the member being tested. In regard to strength requirements, the member or assembly must be capable of supporting the following (note: no specific reference to a particular type of building material is given in this section of the Code):

1. Without visible damage (other than hairline cracks) its own weight plus a test load equal to 150 percent of the design live load plus 150 percent of any dead load that will be added at the site, and

2. Without collapse its own weight plus a test load equal to 50 percent of its own weight plus 250 percent of the design live load plus 250 percent of any dead load that will be added at the site.

The latter loading is to remain in place for a minimum period of one week, and all loading conditions in Article 9 of the Code are to be considered. Exceptions to the above load conditions are also given in this section.

The member or assembly is also subject to the following deflection requirements: the recovery of the deflection caused by the superimposed loads listed in item 1 above must be at least 75 percent. Also, the deflection under the design live load is limited to the values prescribed in C26-1001.5.

[23] A three-page calculation dated March 2, 1964 by E. Liu (Structural Engineer, the Port of New York Authority) (WTCI-408-LERA).

The Code also gives requirements for tests on models less than full size. The similitude, scaling, and validity of the analysis are to be attested to by an officer or principal of the firm or corporation making the analysis. The firm or corporation is to be approved by the Building Commissioner.

5.2.1 Concrete Requirements

According to sub-article 1004.0, design of reinforced concrete structural members was to conform to the requirements in that section and Reference Standard RS 10-3, which is the 1963 edition of *Building Code Requirements for Reinforced Concrete* (ACI 1963) with modifications, which was applicable to the design of WTC 1 and WTC 2. These modifications include the replacement of the requirements of ACI 318 Secs. 902 (Design loads) and 903 (Resistance to wind, earthquake, and other forces) with the following: "Building code requirements for loads and infrequent stress conditions shall apply." "Infrequent stress conditions" refer to such conditions as wind and earthquake. In other words, all loads are to be determined in accordance with the 1968 Code. In case of concrete structures designed by the ultimate strength design method, design (factored) loads are to be determined in accordance with Sec. 1506 of ACI 318-63.

According to the specifications for WTC 7 (WTC 7 Project Specifications 1984), the 1983 edition of ACI 318 was applicable (ACI 1983).

5.2.2 Steel Requirements

Design of steel structural members was to conform to the requirements in sub-article 1005.0 and Reference Standard RS 10-5, which is the 1963 edition of *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings* (AISC 1963b) with modifications, which was applicable to the design of WTC 1 and WTC 2. Similar to the design of reinforced concrete members, the NYC Building Code replaced the provisions of Sec. 1.3 (Loads and Forces) of the AISC Specification with a statement: "The provisions of the building code for loads shall apply." Other notable modifications to the AISC Specification are:

- The following paragraph is added to the definition of composite construction in Sec. 1.11.1: "Concrete materials shall meet the applicable requirements of the building code. Where concrete having a unit weight less than 130 pcf is used, the capacity of the shear connectors to resist applied load under the proposed conditions of use shall be investigated…"

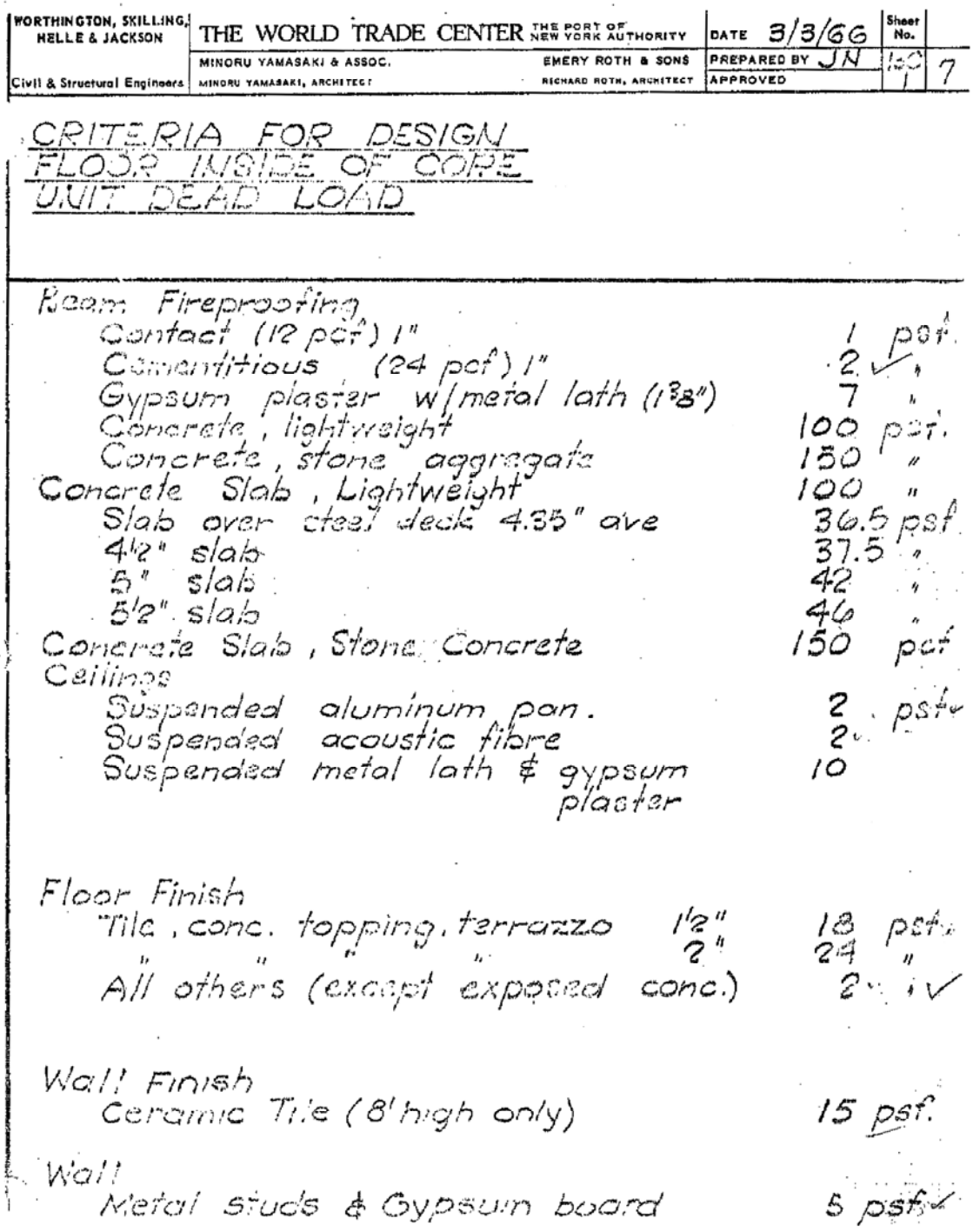
- Sec. 1.25.5 on field connections during erection is deleted and replaced with the following: "…No holes, copes or cuts of any type shall be made to facilitate erection unless specifically shown on the shop drawings or authorized in writing by the party or parties designated for inspection of such work."

The 1968 NYC Building Code requires that Reference Standards RS 10-6 and 10-7 be used for light gauge cold formed steel and open web steel joists, respectively (see *Comparison of Building Regulatory and Code Requirements for WTC 1, 2, and 7* [NIST NCSTAR 1-1B]).

According to the specifications for WTC 7 (WTC 7 Project Specifications 1984), the 1978 edition of the AISC Specification was applicable (AISC 1978).

5.2.3 Methods Used to Proportion Structural Members

The general methods that were used to proportion the structural members and components of the buildings are given in detail in Sec. 2.3 of NIST NCSTAR 1-1A. Since the 1968 NYC Building Code adopted the 1963 AISC Specification and the 1963 ACI 318, all steel members were designed following the allowable stress design procedure, and the concrete sections were proportioned following the ultimate strength design procedure (see Sec. 4.3.1).



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Civil & Structural Engineers

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MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT

EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT

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Sheet No. 1 of 7

CRITERIA FOR DESIGN
FLOOR INSIDE OF CORE
UNIT DEAD LOAD

Beam Fireproofing	
Contact (12 pcf) 1"	1 psf
Cementitious (24 pcf) 1"	2 "
Gypsum plaster w/metal lath (1 3/8")	7 "
Concrete, lightweight	100 pcf.
Concrete, stone aggregate	150 "
Concrete Slab, Lightweight	100 "
Slab over steel deck 4.35" ave	36.5 psf
4 1/2" slab	37.5 "
5" slab	42 "
5 1/2" slab	46 "
Concrete Slab, Stone Concrete	150 pcf
Ceilings	
Suspended aluminum pan.	2 psf
Suspended acoustic fibre	2 "
Suspended metal lath & gypsum plaster	10
Floor Finish	
Tile, conc. topping, terrazzo 1 1/2"	18 psf
" " " " 2"	24 "
All others (except exposed conc.)	2 "
Wall Finish	
Ceramic Tile (8' high only)	15 psf
Wall	
Metal studs & Gypsum board	5 psf

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Figure 5–1. Design dead load criteria for WTC 1 and WTC 2: floor inside of core.

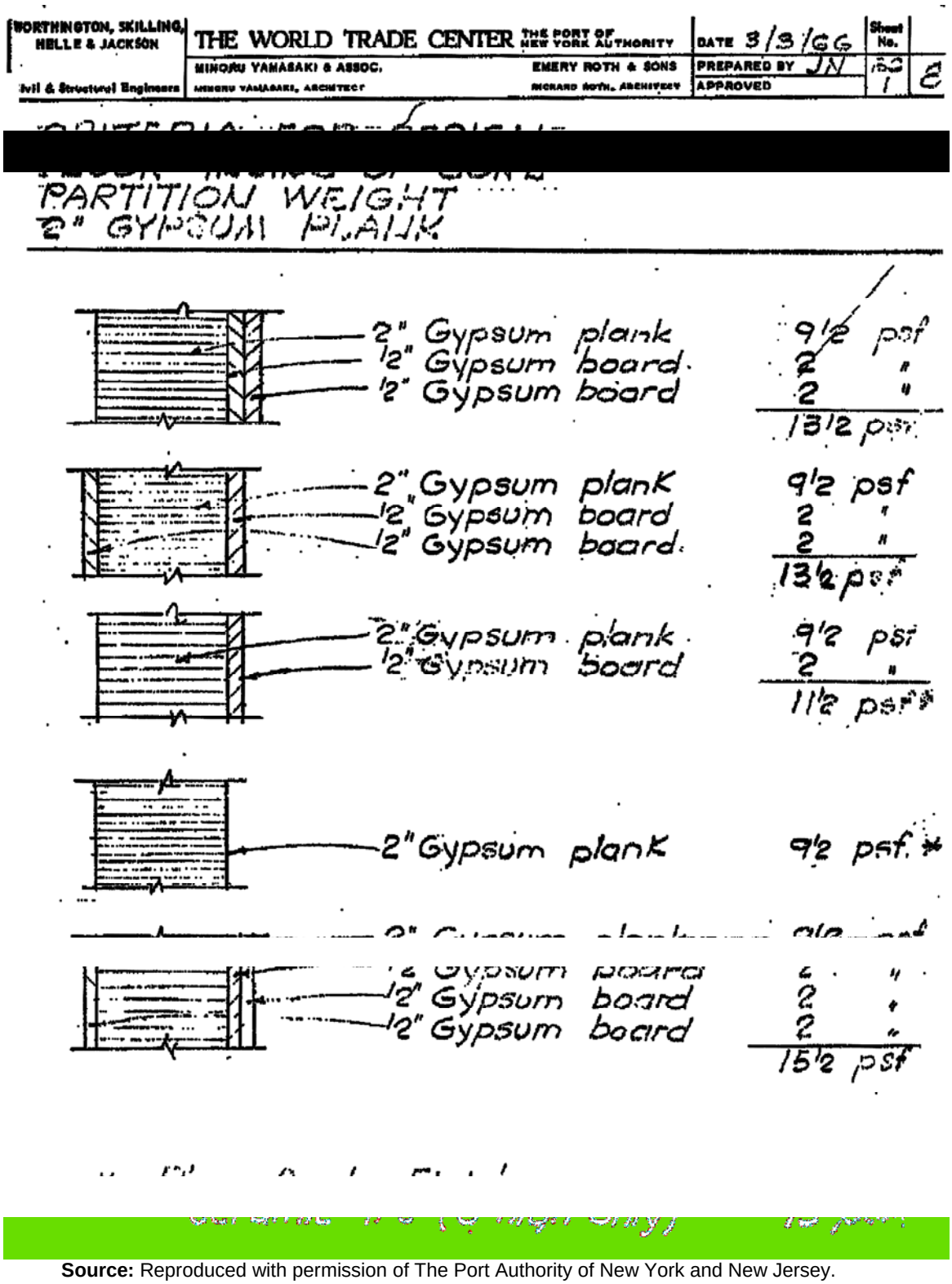

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Figure 5–2. Design partition load criteria for WTC 1 and WTC 2: floor inside of core.

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EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT

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CRITERIA FOR DESIGN DESIGN LOAD
FLOORS OUTSIDE OF CORE
LONGSPAN TRUSSES - ONE WAY

		FLOORS
Concrete Slab	36.5 psf.	10 thru 24
Slab Reinf.	1.5 "	26 thru 40
Steel Deck	2.0 "	45 thru 58
Structural Steel	10.0 "	60 thru 66
		68 thru 74
CONSTRUCTION DEAD LOAD =	50.0 psf.	79 thru 91
		93 thru 106
Ceiling	2.0 psf	
Mechanical & Electrical	2.0 "	
Fireproofing	2.0 "	
Floor Finish	2.0 "	
SUPERIMPOSED DEAD LOAD =	8.0 psf	
TOTAL DEAD LOAD (to be used for camber)	58.0 psf.	
SUPERIMPOSED LIVE LOAD See Sheet No. TF 16, 21 thru 28		

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Figure 5–3. Design dead load criteria for WTC 1 and WTC 2: floor outside of core.

LOADING SCHEDULE

AREA \ LOAD (PSF)	CONCRETE SLAB	FILL, FINISH, ROOFING	CEILING, DUCTWORK	PARTITIONS	FLOORING	BEAMS, ENCASEMENT, FIREPROOFING	TOTAL DEAD LOAD	LIVE LOAD	TOTAL LOAD
MAIN ROOF, BULKHEAD ROOF	50	10	8			7	75	30	105
8TH-20TH FL. 24TH & 4TH FL.	50		5	12		8	75	50	125
21ST-23RD FL.	50		5	12	15	8	90	75	165
7TH FLOOR NORTH SIDE	80		5	12		93	190	50	240
7TH FLOOR SOUTH SIDE	80	38	8	12		27	165	50	215
6TH FLOOR OFFICE SPACE	56		5	12		7	80	50	130
6TH FLOOR SWITCHBOARD ROOM	62	38				55	155	100	255
5TH FLOOR OFFICE SPACE	150	38	5			17	210	50	260
5TH FLOOR MECHANICAL	150	38	5			17	210	150	360
4TH FLOOR	56	75	5			10	146	100	246
3RD FLOOR NEW CONSTRUCTION	56	75	5			10	146	100	246
3RD FLOOR OVER EXISTING SUBSTATION							240	100	340
2ND FLOOR NEW CONSTRUCTION	56	60	5			10	131	150	281
2ND FLOOR EXISTING SUBSTATION							240	150	390
1ST FLOOR LOBBY	175	90				50	315	100	415
1ST FLOOR EXISTING SUBSTATION							300	225	525

NOTE:
ALL SPECIAL EQUIPMENT LOADS SHALL BE ADDED SEPARATELY TO ABOVE LOADING

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Figure 5–4. Design load criteria for WTC 7.

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MINORU YAMASAKI & ASSOC. — EMERY ROTH & SONS
MINORU YAMASAKI, ARCHITECT — RICHARD ROTH, ARCHITECT

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CRITERIA FOR DESIGN
FLOOR INSIDE OF CORE
SUPERIMPOSED LIVE LOAD - FLOOR DESIGN

Space	Live load psf	
Cafeteria	100	
Closets (Tenant Floors)	100	
Concourse	100	
Corridors within core (mechanical equipment floor)	100	
Corridors within core (skylobby floor)	100	
Corridors within core (typical office floor)	75	
Duct offset space	75	
Electric closet	75	
Electric substation & transformer room	75	note 1
Elevator machine room (plus elevator reactions)	50	
Elevator pits (plus elevator reactions)	50	
Expansion tank room	75	note 1
Janitor's closets	100	
Kitchen	100	
Kitchen service area	100	
Local passenger elevator lobbies (sky lobby floors)	100	

Note 1: on areas not occupied by equipment

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Figure 5–5. Design live-load criteria for WTC 1 and WTC 2: floor inside of core.

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MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT

EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT

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DATE 3/3/66
PREPARED BY JN
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Sheet No. BC 1 3

CRITERIA FOR DESIGN
FLOOR INSIDE OF CORE
SUPERIMPOSED LIVE LOAD - FLOOR DESIGN

[illegible]	75	note 1
Men's toilets	40	
Observation lobby	100	
Passenger elevator lobbies (tenant floors)	75	
Powder rooms	40	
Restaurant	100	
Roof	40	
Secondary motor room	75	note 1
Service room (mechanical equipment floor)	100	
Service room (tenant floor)	100	
Sprinkler tank room	75	note 1
Stairs	100	
Telephone closets	75	
Tenant spaces within core*	100	
Women's toilets	40	
1 Floor 109 (entire floor)	150	

Note 1: on areas not occupied by equipment
Note 2: use 75 psf for equiv. uniform load for preliminary design
* See next page BC/1 3A dated 29 JUNE 89

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Figure 5–6. Design live-load criteria for WTC 1 and WTC 2: floor inside of core.

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Sheet No. CC 2

CRITERIA FOR DESIGN
FLOOR INSIDE OF CORE
LIVE LOAD FOR COLUMN DESIGN

Space	Live load psf
Cafeteria	100
Closets (tenant floors)	100
Concourse	100
Corridors within core (mechanical equipment floor)	100
Corridors within core (skylobby floor)	100
Corridors within core (typical office floor)	75
Duct offset space	75
Electric closet	75
Electric substation & transformer room	75 note 1
Elevator machine room	50
Elevator pits	50
Expansion tank room	75 note 1
Janitor's closets	100
Kitchen	100
kitchen service area	100
Local passenger elevator lobby (skylobby floor)	100

Note 1; On area not occupied by equipment

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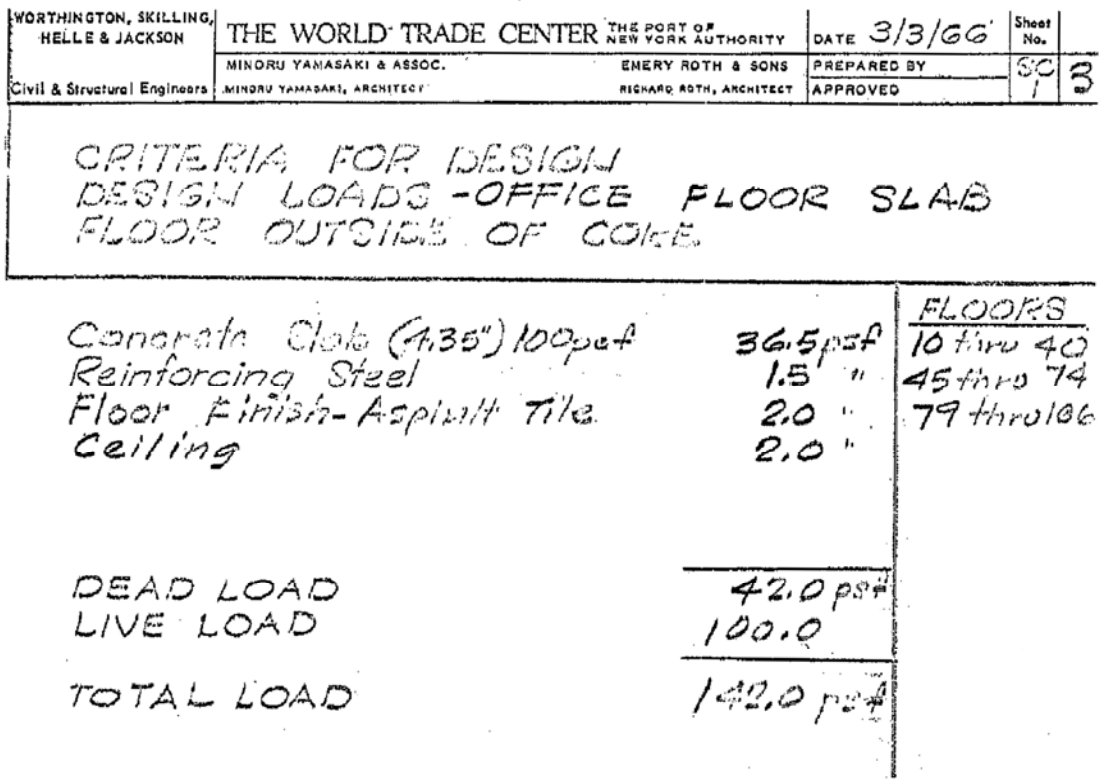
Figure 5–7. Design live-load criteria for WTC 1 and WTC 2: column inside of core.



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CRITERIA FOR DESIGN
DESIGN LOADS - OFFICE FLOOR SLAB
FLOOR OUTSIDE OF CORE

		FLOORS
Concrete Slab (4.35") 100pcf	36.5psf	10 thru 40
Reinforcing Steel	1.5 "	45 thru 74
Floor Finish - Asphalt Tile	2.0 "	79 thru 106
Ceiling	2.0 "	
DEAD LOAD	42.0 psf	
LIVE LOAD	100.0	
TOTAL LOAD	142.0 psf	

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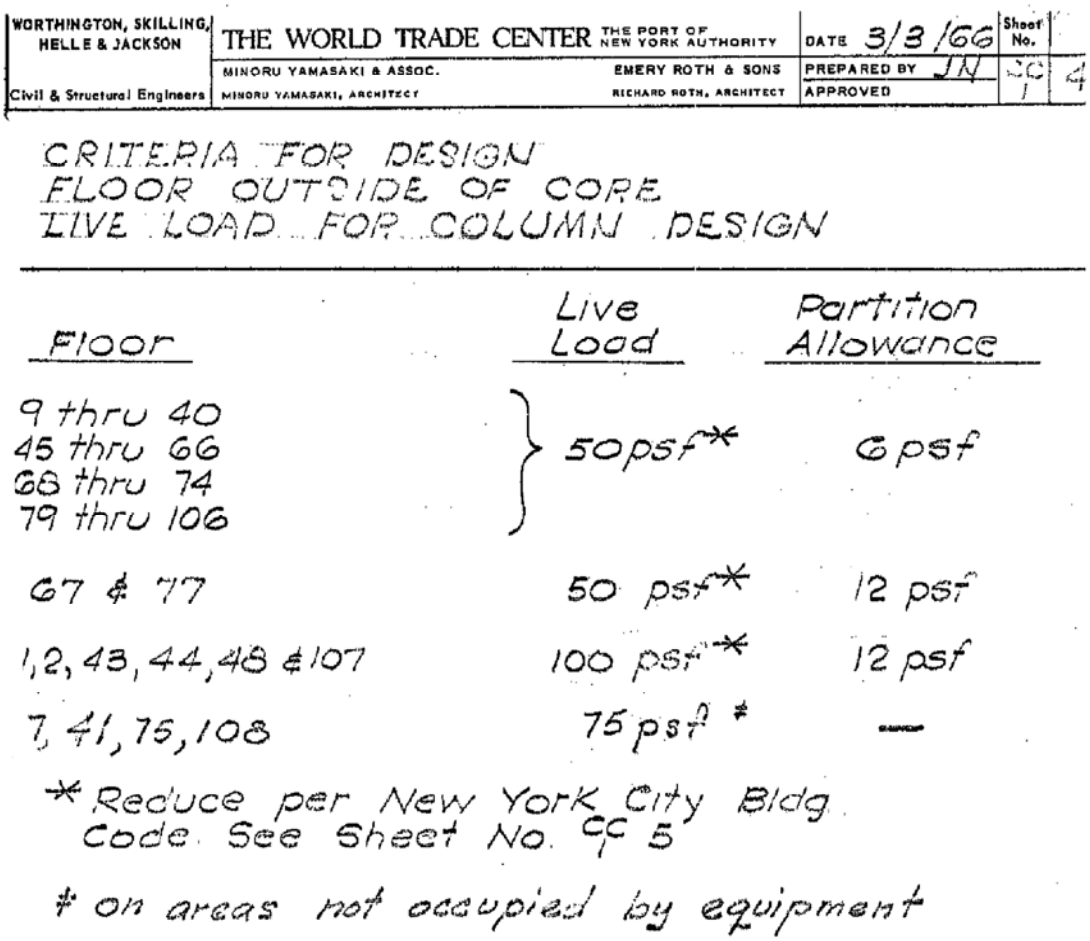
Figure 5–8. Design live-load criteria for WTC 1 and WTC 2: floor outside of core.



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CRITERIA FOR DESIGN
FLOOR OUTSIDE OF CORE
LIVE LOAD FOR COLUMN DESIGN

Floor	Live Load	Partition Allowance
9 thru 40 45 thru 66 68 thru 74 79 thru 106	50psf*	6 psf
67 & 77	50 psf*	12 psf
1, 2, 43, 44, 48 & 107	100 psf*	12 psf
7, 41, 75, 108	75 psf #	—

* Reduce per New York City Bldg. Code See Sheet No. CC 5

on areas not occupied by equipment

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Figure 5–9. Design live-load criteria for WTC 1 and WTC 2: column outside of core.

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Civil & Structural Engineers	MINORU YAMASAKI, ARCHITECT	RICHARD ROTH, ARCHITECT	APPROVED	1	

CRITERIA FOR DESIGN
LIVE LOAD REDUCTIONS

Live load reductions shall be taken in accordance with the requirement of the New York Building Code, Section C26-348.0 modified as follows:

a) Columns: In structures intended for storage purposes all columns, piers or walls and foundations shall be designed for 85% of the full assumed live load. In structures intended for other uses the assumed live load used in designing all columns, piers or walls and foundations shall be as follows:

100% of live load on roof
85% of live load on top floor
80% of live load on next to top floor
75% of live load on next floor below

On each successive lower floor, there shall be a 5% decrease in the percentage with a minimum of 50% of the live load provided for any floor. The live loads used as the basis for column live load reductions are the "Code Live Loads" for the appropriate occupancy, and are not the reduced live loads used for beam or truss design.

b) Girder members, except at roofs, which have a tributary area of 200 s.f. or greater shall be designed using a reduced live load in accordance with the design criteria sheets 4 and 5.

c) In designing trusses and girders which support columns and in determining

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Figure 5–10. Live-load reduction criteria for WTC 1 and WTC 2.

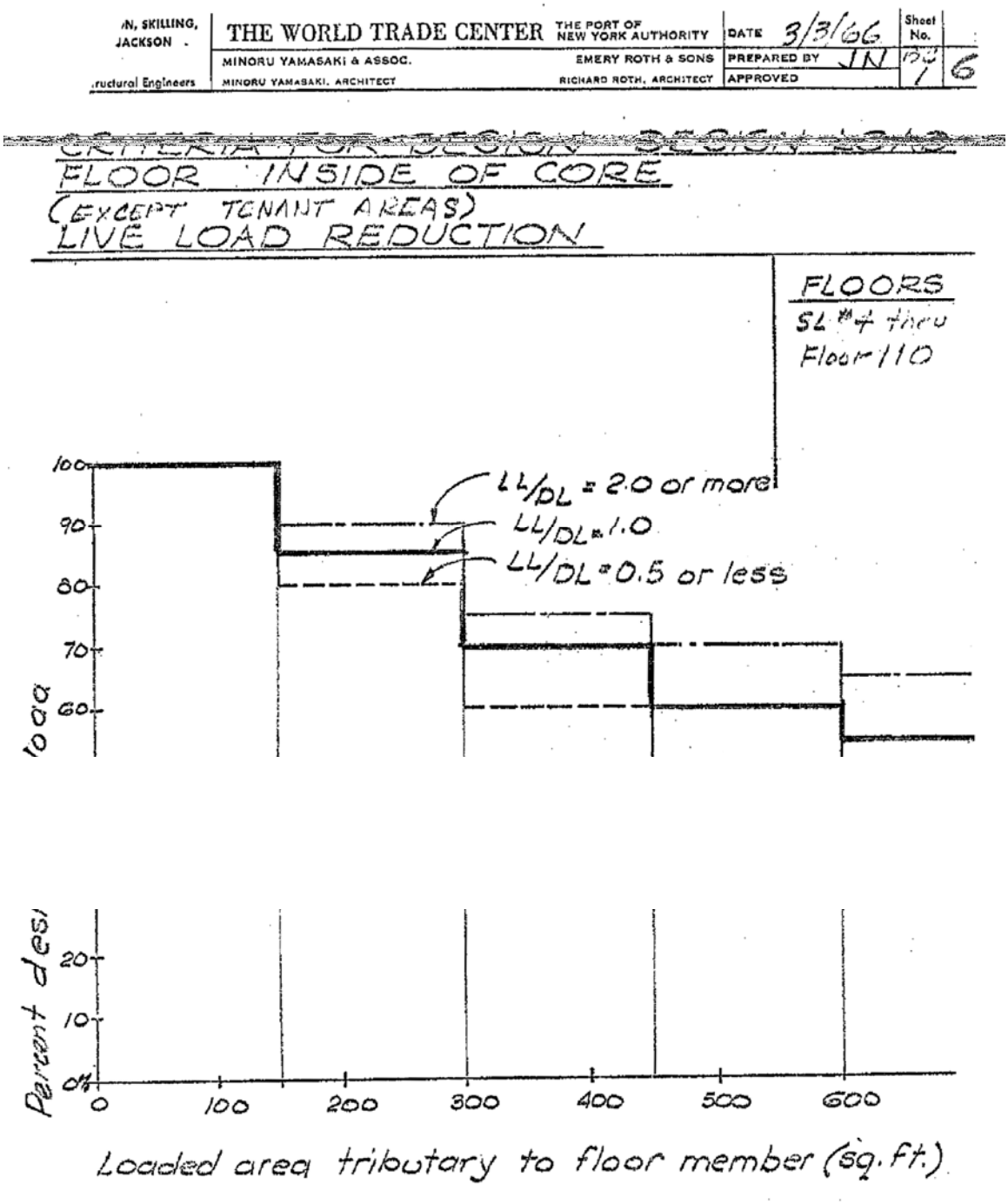

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Figure 5–11. Live-load reduction criteria for floors inside of core, except for tenant areas.

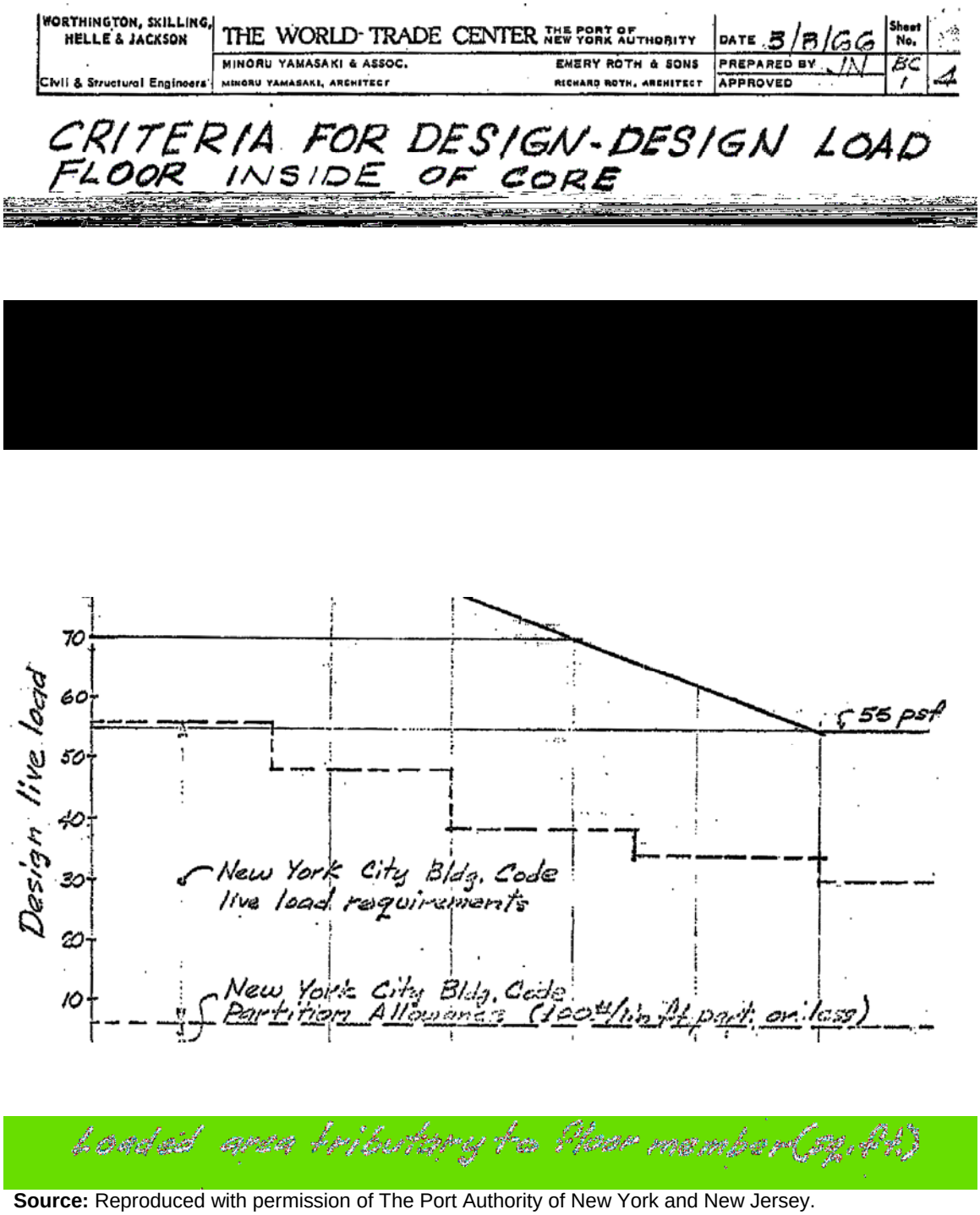

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Figure 5–12. Live-load reduction criteria for floors inside of core, tenant areas.

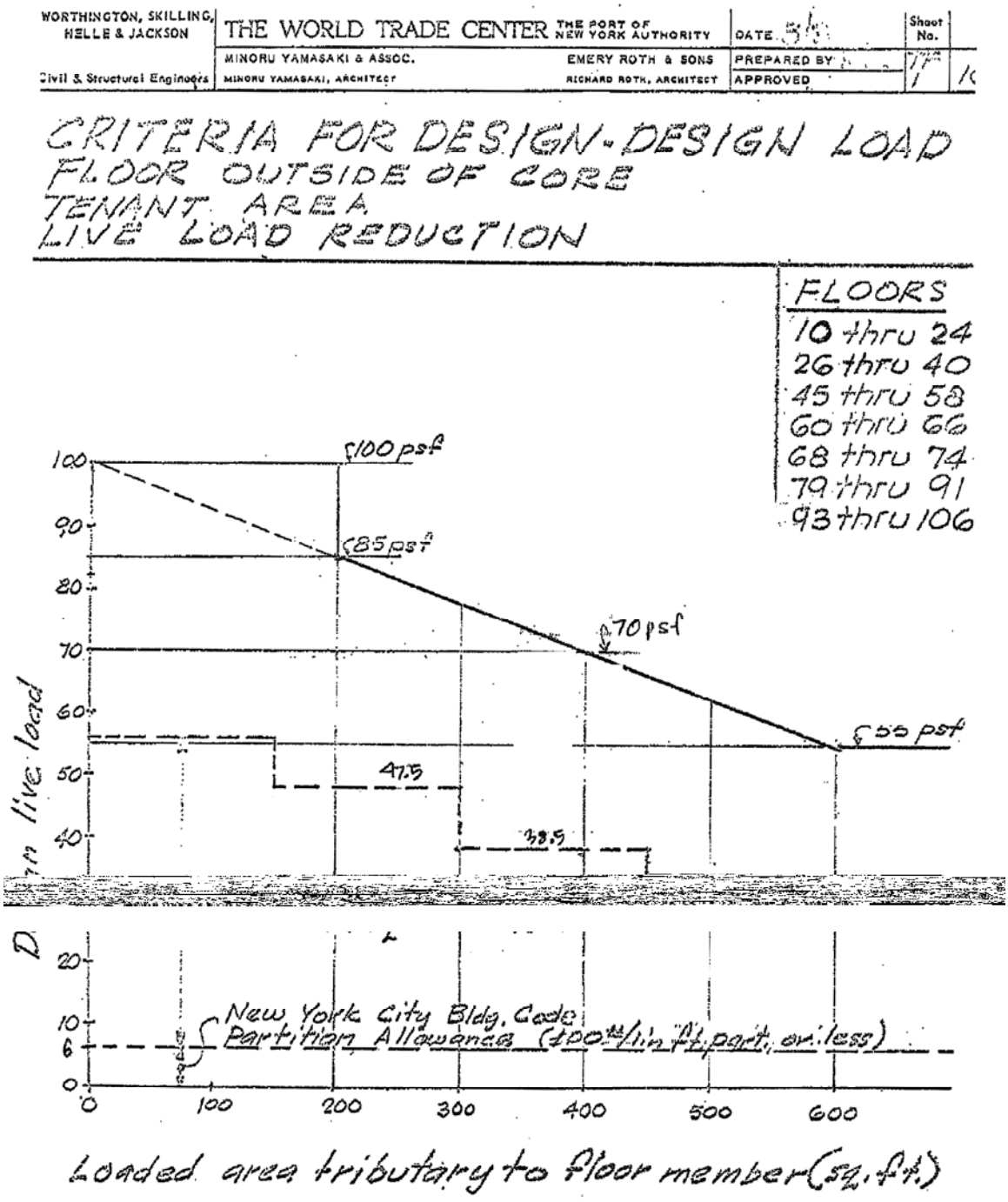

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Figure 5–13. Live-load reduction criteria for floors outside of core.

Chapter 6
INNOVATIVE FEATURES INCORPORATED IN STRUCTURAL DESIGN

6.1 INNOVATIVE FEATURES

A number of innovative features, which were applied to the design of a super high-rise steel building for the first time, were incorporated in the structural design of World Trade Center (WTC) 1 and WTC 2. They were incorporated in both the lateral-load-resisting system and the gravity-load-carrying system.

These features include the following:

- Application of the framed-tube system to resist lateral loads.
- Uniform exterior column geometry (14 in. by 14 in. cross-section) was maintained over most of the height of the 110-story buildings by using 12 different grades of steel.
- Use of deep spandrel plates as beam elements connecting perimeter columns.
- Use of long-span composite steel trusses for the floor system to develop diaphragm action in super tall buildings and to develop composite action by extending truss diagonals into the concrete slab.
- Application of sprayed fire-resistive materials on open-web steel trusses for fire protection.
- Application of viscoelastic dampers connecting the floor trusses to the perimeter framed tube system to control dynamic response.
- Use of wind tunnel test data to establish the wind loads used in the design of the towers.

Several prominent features are described below in detail.

6.2 LATERAL-LOAD-RESISTING SYSTEM

The structural design of high-rise buildings (over 40 stories) is usually controlled by lateral loads. It is well known that for high-rise buildings, the most efficient way to resist lateral loads is by mobilizing the exterior framing system. As described in Sec. 2.2.2, the lateral-load-resisting system of WTC 1 and WTC 2 used the framed-tube concept wherein the lateral loads are resisted by the exterior frames. A framed-tube system does not depend on shear walls or other bracing systems to resist lateral loads. Typically, the exterior wall is comprised of moment resisting frames with closely spaced columns and deep spandrel beams to form a Vierendeel-truss-type structural form.

In the United States, the first application of a framed-tube system was the 43-story DeWitt-Chestnut apartment building (later renamed The Plaza on DeWitt) in Chicago, which was completed in 1965. This building used reinforced concrete for the structural framing system. Since then, many variations of this

structural system have been used in a number of buildings. WTC 1 and WTC 2 were the first super high-rise steel buildings that were designed using the framed-tube concept.

The framed-tube system of WTC 1 and WTC 2 was comprised of closely spaced steel columns that were connected by deep spandrel plates. To assess the stiffness characteristics of the wall panel, a series of model tests using one-quarter scale models made of thermoplastics were carried out prior to final design of the frame-tube system (Gardner 1966). The model tests allowed the evaluation of changes in the overall stiffness of the wall panels as the sizes of the members that made up the wall panels varied, which included columns, spandrels, and stiffeners. The results of the model tests guided the design of the wall panels. Detailed descriptions of the tests are given in NIST NCSTAR 1-1A.

The columns and spandrels were shop-assembled and welded into 36 ft high by 10 ft wide panels, which consisted of three columns and three spandrels as shown in Fig. 2–9. These panels were erected on site by bolting the base plate of an upper column to a cap plate of a lower column (see Fig. 2–10). Such splices were staggered so that only one-third of the panels were spliced at each story level, except at the base of the building and at the mechanical floors where all of the panels were spliced at the same level. In such cases, supplemental welds were employed to improve connection capacity. Spandrels were connected at midspan with high-strength bolted shear connections.

6.3 COMPOSITE FLOOR SYSTEM

As described in Sec. 2.2.2, outside of the central core area, floor construction of WTC 1 and WTC 2 typically consisted of 4 in. of lightweight concrete on fluted metal deck supported by a series of composite floor trusses that spanned between the core and the exterior walls. The floor trusses consisted of double angles that were used for the top and bottom chords and round bars that were used for the diagonals. What made the floor system in WTC 1 and WTC 2 innovative was that (1) use of the lightweight composite floor system, comprised of lightweight concrete slab on long-span open-web steel trusses, to provide lateral stability of columns and diaphragm action in super tall buildings, (2) development of composite action by extending truss diagonals into the concrete slab (see Fig. 2–14), and (3) application of sprayed fire-resistive materials on open-web steel trusses for fire protection (for detailed description, see NIST NCSTAR 1-6B).

The first recorded tests on composite open-web steel joists were conducted under a project jointly sponsored by Granco Steel Products and Laclede Steel Company (who manufactured the trusses for WTC 1 and WTC 2) in September 1964.[24] In this study, the overall performance of non-composite joists was compared with composite joists. The joists were manufactured with their webs projecting above the top chord. The tests revealed that the composite joists had greater moment capacities and smaller deflections than the non-composite joists.

Since composite action was achieved by the “knuckle” functioning as a shear connector, a test program was carried out by Laclede Steel Company to determine the failure loads of the shear knuckles. The shear knuckle tests are described in detail in NIST NCSTAR 1-1A. The test results indicated that shear strengths of the knuckles were found to be well over the allowable values used in the design of the composite trusses.

[24] See Sec. 1.1 of Sen and Galambos (1968).

Additional tests on open-web joists were performed at Washington University (Tide and Galambos 1968). The findings, which were reported in February of 1968, were similar to those reported from the previous tests. In particular, the specimens with extended web diagonals into the concrete slab serving as shear connectors were shown to be strong and stiff, and failure was due to crushing of the concrete near the connectors. Further tests conducted at Washington University are reported in Sen and Galambos (1968). In summary, the findings from this study confirmed those obtained from earlier research programs.

The composite floor trusses used in the WTC towers were similar to those that were tested only in the sense that the webs were used as shear connectors. Other than that, they were different in all other aspects, including member sizes and overall lengths. It may have been the first time that this type of floor construction was used in a high-rise building, especially of this size.

6.4 VISCOELASTIC DAMPING UNITS

Viscoelastic damping units were used in the structural system of WTC 1 and WTC 2 to supplement the tubular steel frame in limiting wind-induced building oscillations. According to Mahmoodi (1987), "The selection, quantity, shape, and location of the dampers was based on the dynamic analysis of the towers (computer modeling, wind tunnel, etc.) and of the damping required to achieve performance standards." This may have been the first application of damping units for this purpose in tall building structures, and would certainly qualify it as an innovative system at that time.

The damping units were uniformly distributed throughout both of the buildings. One hundred four (104) dampers were used on each floor from the 7th to the 107th floor. The planned locations of damping units on the various floors of the buildings are contained in structural drawings D-AB1-2 through D-AB1-14.2 (WSHJ 1967). As the buildings oscillated from the wind, part of the energy of oscillation was dissipated by shear deformations in the viscoelastic part of the damping units.

Two testing programs were carried out to test the effectiveness and efficiency of the damping units in controlling building motion due to wind. The Minnesota Mining and Manufacturing Company (3M) conducted the first set of tests in May of 1967.[25] The Massachusetts Institute of Technology (MIT) conducted the second test program during 1968 and 1969.[26] These tests included variations in (1) amplitude and frequency of the applied cyclic axial deformation, (2) ambient temperature, and (3) a static preload superimposed on the simple harmonic loading. In general, it was found that "…the energy absorbing capabilities of the elements are generally adequate to provide the expected damping under design conditions and that the elements do perform satisfactorily under limited variations of loading conditions, speed of oscillation, duration of oscillation, and ambient temperature." Detailed descriptions of these tests are given in NIST NCSTAR 1-1A.

Two different types of damping units were used in WTC 1 and WTC 2. Type A damping units were used on floors with trusses spanning between the core and the outside wall, and were located between the bottom chords of the floor trusses and the columns of the outside wall (Fig. 2–16). Type B damping units were used on floors that had wide-flange beams spanning between the core and the outside walls (i.e.,

[25] Letter dated June 22, 1967 and enclosure from Don Caldwell of 3M to Peter Chen of SHCR (WTCI-501-L;see Appendix B of NIST NCSTAR 1-1A without appendixes that are contained in WTCI-501-L).

[26] "Test Program for World Trade Center Viscoelastic Damping Units," by Stephen H. Crandall of MIT, May 20, 1968 (WTCI-501-L, see Appendix B of NIST NCSTAR 1-1A).

floors 7, 9, 41, 43, 75, 77, and 107). This type of damping unit was located between the bottom flanges of the floor beams and the outside wall, as shown in Fig. 6–1. The use of dampers increased significantly the critical damping ratio of the towers. The reduction of oscillation during strong winds was estimated to be about 12 percent of the amplitudes without dampers. Expected time period during which building oscillation might be perceived by the occupants was estimated to be reduced by about 34 percent (SHCR 1967).

Type B damping units were slightly longer than Type A damping units. Also, the connections between Type A damping units and the floor trusses were different than those between Type B damping units and the wide-flange beams. Sheet DA-3 in the structural drawings shows specific details for each type of damping unit (WSHJ 1967).

Worthington, Skilling, Helle & Jackson (WSHJ) initially inquired about different types of viscoelastic damping materials in a letter to 3M in 1964.[27] A follow-up letter from them to 3M contained the physical and mechanical properties required for the viscoelastic material, based on calculations they had performed.[28] Additional correspondence on various aspects of the damping units, including the results of tests that were run at 3M that measured the properties of the damper material and the strength of an assembled damping unit prototype, was exchanged subsequent to these letters. In particular, it was noted that testing of an assembled truss damping unit by 3M was completed and that the results agreed with the theoretical predictions.[29]

6.5 WIND TUNNEL TESTS

Wind tunnel tests were part of an overall wind program that was developed by WSHJ for the design of the WTC (WSHJ 1964). Details of the wind program are given in NIST NCSTAR 1-1A. Briefly, the program consisted of four parts:

- **Meteorological Program** was to determine the mean wind speeds, the return periods, the magnitude of wind shear and gradient, the directional characteristics of the wind, and the energy spectra of wind gusts that were expected at the site of the WTC.

- **Wind Tunnel Program** was to (a) develop a physical model of lower Manhattan and subject the model to wind velocities obtained from the meteorological program, (b) obtain static and dynamic responses of the WTC towers, (c) study construction problems, and (d) study the effect of the structural parameters on the integrity of the towers.

- **Structure Damping Program** was to determine the critical damping ratio of the structural system and to determine ways of increasing this ratio.

[27] Letter dated July 16, 1964 from Alan G. Davenport of WSHJ to Carl A. Dahlquist of 3M (WTCI-450-L; see NIST NCSTAR 1-1A, Appendix D).

[28] Letter dated November 23, 1964 from Richard D. Steyert of WSHJ to Carl A. Dahlquist of 3M (WTCI-450-L; see NIST NCSTAR 1-1A, Appendix D).

[29] Internal correspondence dated February 1966 by Richard D. Steyert of WSHJ (WTCI-450-L; see NIST NCSTAR 1-1A, Appendix D).

- **Physiological Program** was to determine acceptable levels of response to wind-induced excitations as measured by perception levels of a cross-section of the population.

Wind tunnel tests were conducted at Colorado State University (CSU) and the National Physical Laboratory (NPL), located in Teddington, Middlesex, United Kingdom (WSHJ 1964). Tests were conducted on single-tower and twin-tower configurations subject to uniform and turbulent flow conditions.

6.5.1 Tests Conducted at CSU

Over 2,000 tests were conducted at the CSU Microclimatological Wind Tunnel to study the behavior of static and aeroelastic models (WSHJ 1964). One of the most important requirements in the modeling process was to achieve correct simulation of the wind velocity profile (considering both surface roughness and its influence on wind velocity with respect to height) as it approached the model of lower Manhattan. From the southeast direction, wind traveled across Brooklyn to the site of the WTC, which was a relatively rough urban area. From the southwest, wind traveled mainly across open water.

Aside from wind velocity, the principal variables in the wind tunnel tests were the following:

- Spacing of towers
- Number of towers
- Damping
- Wind direction
- Boundary layer characteristics
- Relative stiffnesses of the models

It was found that the models oscillated in the wind due to vortex shedding, gust buffeting, and wake buffeting under certain combinations of the variables listed above.

Two hundred tests were run at CSU to study the effect of tower spacing on the response of the buildings. It was concluded that the "as planned" spacing was satisfactory.

Aeroelastic tests and measurements of steady pressure for single-tower and twin-tower configurations in uniform flow provided a comparison between the performance of the models at CSU and at the NPL. The CSU report concluded that the aeroelastic tests at the two locations were in good qualitative and quantitative agreement (WSHJ 1965c). Models used for the pressure tests at the CSU were constructed of clear acrylic plastic at a scale of 1/500, the same scale used in the aeroelastic tests

The aeroelastic tests were designed to determine the predominant sway motion (i.e., deflections or amplitudes) of the towers and to provide a check of the steady-state component of the overturning moment at the base. To determine the pressure distribution on the towers, tests were conducted using models with pressure points along a regular grid. From these tests, shear forces and overturning moments were obtained along the height of the towers.

The tests also indicated that large lateral deflections at the top of the building occurred for wind velocities in the range of 125 mph to 130 mph for angles of incidence within approximately 10 degrees of normal (see Fig. 6–2). The results are plotted in Figs. 19 and 20 in WSHJ (1965c). The deflections showed a consistent dependence on the degree of damping and were shown to be inversely proportional to the damping ratio.

Tests were also conducted at CSU using the southeast and southwest models of lower Manhattan subjected to turbulent flow conditions (WSHJ 1966c).[30] Both single-tower and twin-tower configurations were considered. Definition of the grid system and tower configurations used in the tests is illustrated in Fig. 6–3. Also shown in the figure are the experimentally determined fundamental frequencies of the towers in the two principal directions in cycles per second (cps). Included in these tests were measurements of the maximum deflections at the tops of the towers (aeroelastic tests; wood models) and pressures along the height of the towers (thermoplastic models).

Similar to the other tests described above, test results for the single-tower model indicated that the most severe oscillations were transverse to the wind and occurred with the wind blowing within a small range of angles on either side of the normal to a face. The results also showed that an increase in turbulence, which was characteristic of the southeast model of lower Manhattan, appeared to suppress vortex shedding but gave rise to turbulence excitation with increased wind speed. Finally, it was observed that greater levels of damping reduced the dynamic response of the single tower in all cases, more so in uniform flow conditions than in turbulent conditions.

Based on the results obtained from the twin-tower wind tunnel tests, it was concluded that the response of the WTC towers was governed by three aerodynamic factors: (1) Magnitude of the effective turbulence forces induced by the wind flow, (2) Magnitude of the effective forces induced by vortex shedding and turbulence in the structure's own wake, and (3) Effective aerodynamic damping and coupling forces generated by the motion of the tower through the airflow. It was also noted that the effective mass, the effective stiffness, the mode of vibration, and the mechanical damping of the towers influenced these factors (WSHJ 1966).

A theoretical method was derived and was used to predict the dynamic behavior of the towers (WSHJ 1966c). Results from the theoretical models were compared to the results from the wind tunnel tests. A comprehensive discussion on this comparison can be found in WSHJ (1966c).

The results from the wind tunnel tests were used in the design of the exterior columns and spandrels, which is discussed in Sec. 2.3.2 of this report.

The extensive wind tunnel testing that was performed to establish the lateral wind loads used in the design of WTC 1 and WTC 2 was state-of-the-art at that time.

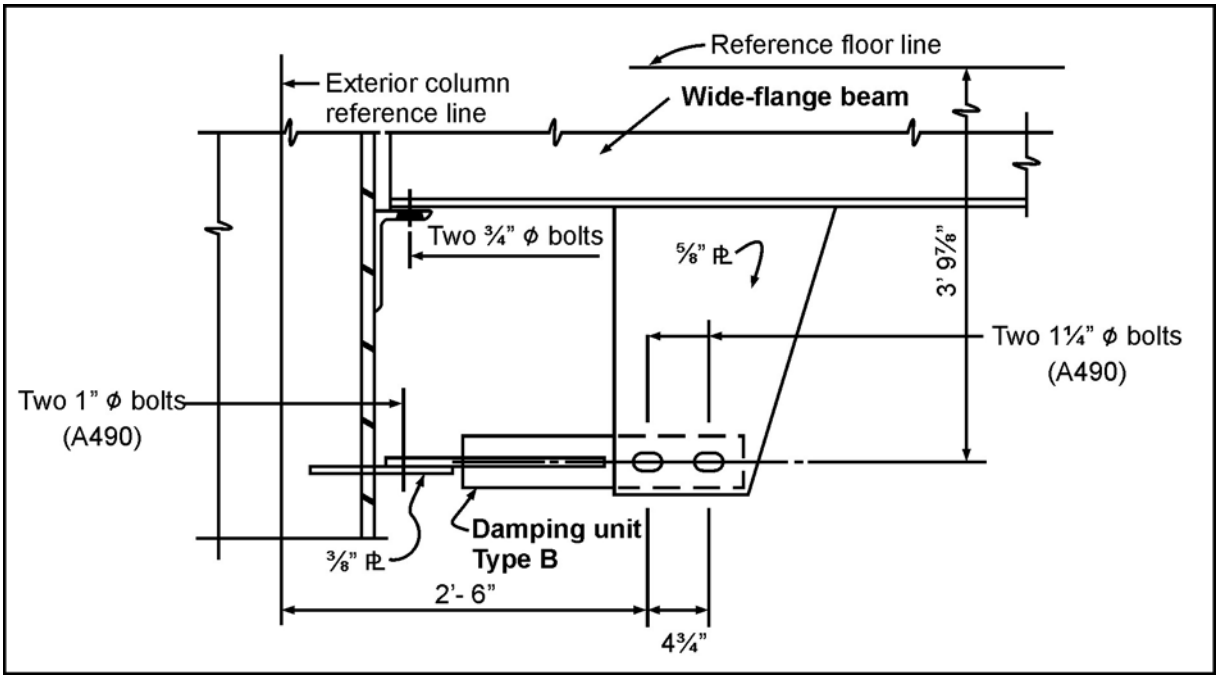
[30] The meteorological program found that winds were stronger from westerly and northerly quadrants. Wind from the southeast direction was chosen in the wind tunnel program not because the velocity from this direction was the greatest, but because winds from this direction were the most turbulent (wind in this direction traveled over Brooklyn, which is a relatively rough urban terrain). Turbulence plays an important part in the dynamic excitation of structures, especially tall, slender structures. A fundamental discussion on turbulence and resulting aeroelastic phenomena can be found in Simiu and Scanlon (1996).

6.5.2 Tests Conducted at NPL

Tests were performed on single-tower and twin-tower models at NPL to measure deflections at the tops of the towers in both smooth (uniform) flow and turbulent flow conditions (Whitbread and Scruton 1965). The models were constructed of light timber framework supported on diaphragms at 6 in. intervals from a central 2 in. diameter aluminum tube. The models had an external covering of plywood.

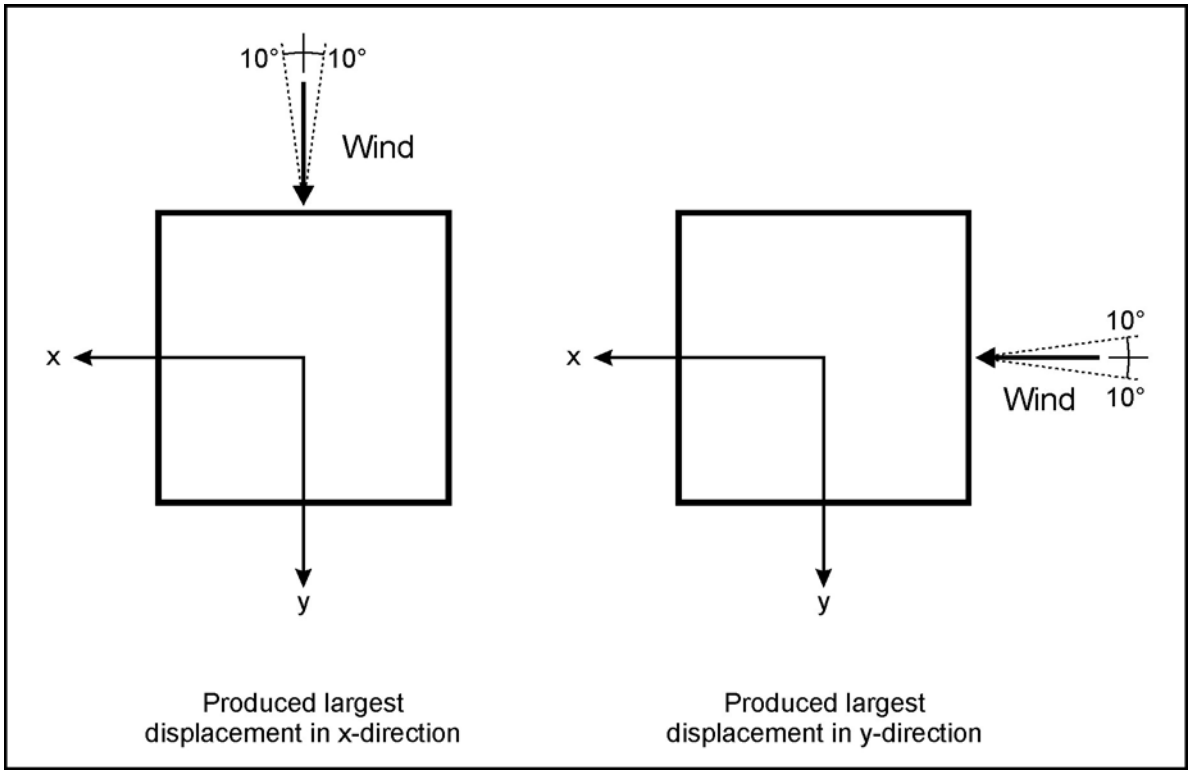
Principal differences between the CSU and NPL models were (WSHJ 1965c): (1) the model scale was 1/400 at the NPL compared to 1/500 at the CSU, (2) displacements were determined from output of accelerometers mounted near the tops of the models at NPL compared with strain gauges at CSU, and (3) displacements were recorded on a resetting digital voltmeter at the NPL compared with chart records at CSU. In the NPL tests, a grid of tubes in a plane normal to the wind stream was used to provide the required velocity profile over the height of the model. According to Whitbread and Scruton (1965), the velocity profile achieved in this manner was similar to that observed in the tests carried out at CSU on the model of lower Manhattan.

As noted previously, WSHJ reported that the overall results obtained from the tests conducted at NPL were in good qualitative and quantitative agreement with those obtained from the tests performed at CSU.



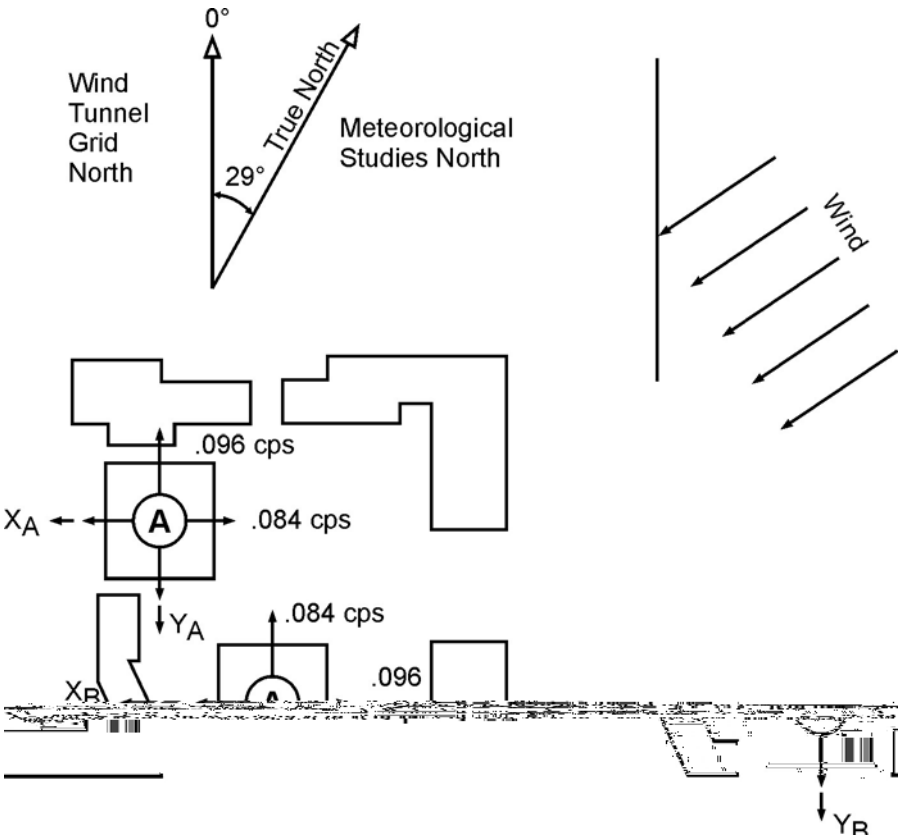
Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 6–1. Wide-flange beam member with Type B damping unit.



Source: WSHJ 1965c. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 6–2. Wind directions that produced the greatest displacements at the top of the tower during the wind tunnel tests.



Source: WSHJ 1966c. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 6–3. Definition of grid system and tower configurations for wind tunnel tests at Colorado State University.

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- Finishing
- Tolerances

Specific inspection requirements during fabrication of various structural members were covered in the contract documents between PONYA and individual fabricators. The individual contract documents which contain the inspection requirements during fabrication are found in appendixes of NIST NCSTAR 1-1A.

Some salient features of the fabrication inspection requirements for different structural framing systems are presented below.

7.2.1 Floor Trusses

The contract between the PONYA and the Laclede Steel Company, the manufacture of the floor trusses, contained the specifications for fabrication, including welding of structural steel, and also a quality control and inspection program (see Appendix E of NIST NCSTAR 1-1A). In addition to the quality control requirements for steel fabrication in the AISC Specification (AISC 1963), Chapter three of the contract included a list of specific requirements for inspection during fabrication, including: continual visual inspection and surveillance of the fabrication process of steel trusses by qualified contractor's supervisory personnel; physical and nondestructive testing welding of truss panel points; and full-scale testing of completely fabricated steel truss components.

7.2.2 Box Core Columns and Built-Up Beams

The contract between the PONYA and the Stanray Pacific Corporation contained the specifications for the box core columns and built-up beams from the 9th story to the roof. The requirements for fabrication, including welding of structural steel, inspection, and quality control, were in the contract specification. Appendix E of NIST NCSTAR 1-1A addresses the applicable sections of the contract specifications and other quality control requirements in detail.

In addition to the inspection requirements in the contract, special requirements were added for inspection, testing, coordination, and supervision by an independent testing agency at the fabrication plant before structural components left the fabrication yard. These additional requirements were necessary because a major portion of the steel used for the core structural members was to be produced in Japan and England.[31] The description of a comprehensive program for "supervision, coordination, inspection, and testing based on the use of the personnel and facilities of a local independent testing agency supervised by a resident engineer (a professional engineer employed full time by the structural engineer Skilling, Helle, Christiansen, & Robertson [SHCR])" was attached to the letter sent from Leslie Robertson of SHCR to Malcolm P. Levy of PONYA (see footnote 31). The scope of this program was two-fold:

- To provide the Port Authority assurance through adequate documentation that fabricated steel conformed to the contract documents and to ensure on-time delivery of fabricated steel.

[31] Letter dated June 5, 1967, from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-491-L; see NIST NCSTAR 1-1A, Appendix E).

- To provide detailed inspection by checklist and by non-destructive testing prior to final acceptance of the members.

The responsibilities of the resident engineer included the following items:

- Prior to fabrication, performing a complete study of the fabricator's quality control procedures, proposed fabrication procedures, provisions for storage of incoming material, and provisions for loading and shipping of completed building components.
- Ensuring proper interpretation of the contract drawings and specifications.
- Directing the work performed by the independent testing agency and its inspectors.
- Performing surveillance of the quality of work on a continuous basis.

The structural engineer (SHCR) also recommended that an independent testing agency be hired for mill inspection of Japanese steel.[32] The main responsibility of the testing agency was to verify the accuracy of the certified mill testing reports by witnessing tests at the manufacturing mill. Procedures were established for witnessing the tests at both Stanray Pacific and Pacific Car & Foundry in the United States. The Port Authority subsequently contracted with Superintendence Inc., an international inspection agency, who provided the mill inspections in both countries.[33]

The Port Authority set forth requirements for the independent testing portion of the mill inspection program.[34] The requirements, which were part of PONYA's overall quality control program on fabricated steel for the WTC, depended on whether the steel was from a domestic source or from a foreign source. For steel obtained from domestic sources, the independent testing portion of the mill inspection program consisted of the following:

- For steel with yield points less than 50,000 psi, one tensile test and one check analysis on samples selected at random from 1 out of 10 heats.
- For steel with yield points of 50,000 psi and higher, one tensile test, one bend test, and a check analysis on samples selected at random from 1 out of 10 heats.

For steel obtained from foreign sources:

- For steel with yield points less than 50,000 psi, one tensile test and one check analysis on samples selected at random from 1 out of 10 heats to be performed abroad. In addition, one sample suitable for a tensile test from 1 out of 4 heats was to be shipped by the inspection agency to a laboratory in the United States for tensile testing and check analysis.

[32] Letter dated April 5, 1967 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-489-L; see NIST NCSTAR 1-1A, Appendix E).

[33] Letter dated September 21, 1967 from R. M. Monti of PONYA to R. E. Morris of the Stanray Pacific Corporation (WTCI-490-L; see NIST NCSTAR 1-1A, Appendix E).

[34] Letter dated November 13, 1967 from R. M. Monti of PONYA to R. E. Morris of Stanray Pacific Corp. (WTCI-498-L; see NIST NCSTAR 1-1A, Appendix E).

- For steel with yield points of 50,000 psi and higher, one tensile test, one bend test, and a check analysis on samples selected at random from 1 out of 10 heats to be performed abroad. In addition, one set of samples suitable for machining into a tensile specimen and a bending specimen was to be selected at random from 1 out of 4 heats and shipped by the inspection agency to a laboratory in the United States for testing.

The Port Authority paid special attention to the quality control of structural steel members fabricated using steels produced in Japan and England.

7.2.3 Exterior Columns from Elevation 363 ft to the 9th Floor Splice

The Pittsburgh-Des Moines Steel Company (PDM) fabricated the column trees, as depicted in Fig 2–8, from elevation 363 ft to the 9th floor splice. Per the contract specifications, PDM developed the procedures for quality control and welding (see Appendix E of NIST NCSTAR 1-1A). The final draft of the quality control program was submitted to the PONYA on September 28, 1967, and was subsequently approved by SHCR.

Different specifications were written by PDM for the different types of welds that were to be used in the manufacture of the column trees. These specifications were reviewed and approved by SHCR, and subsequently approved by the PONYA.

The PONYA hired the Pittsburg Testing Laboratory, an independent inspection company, in 1967, for mill inspection at PDM's suppliers' plants and for fabrication inspection at PDM's shop.

7.2.4 Exterior Columns Above the 9th floor Splice

The contract between the PONYA and the Pacific Car & Foundry Co. (PCF) contains the specifications for the exterior walls (box columns and spandrel plates as shown in Figs. 2–9 and 2–11) from the 9th story splice to the roof. Requirements for fabrication and welding of structural steel are in the specification, and inspection and quality control requirements are in Sec. 105 of the contract. These requirements can be found in Appendix E of NIST NCSTAR 1-1A.

The quality control and welding procedures were prepared by PCF, and subsequently reviewed by SHCR and approved the PONYA, subject to the following conditions:

- The first three full penetration spandrel butt welds performed by each new welding machine operator or welder was to be subjected to ultrasonic testing.

- Where a spandrel weld was rejected, all welds made by the same welder or welding machine were to be tested by the ultrasonic testing technique for the spandrel in question, as well as for the spandrels produced immediately before and after the subject spandrel.

- Approval of the Pacific Car & Foundry Co. quality control and testing program did not include approval of any welding process or procedure subject to American Welding Society qualification tests.

- Visual inspection was to be carried out by certified Pacific Car & Foundry Co. inspection personnel on 100 percent of all types of welds included in the work.

Weekly inspection reports were submitted by the SHCR resident engineer at the Pacific Car & Foundry plant in Seattle, WA, to the SHCR home office in New York.[35] These reports reference a test jig that was built by Pacific Car & Foundry. Fabricated wall panels were checked for compliance with required tolerances on the jig before they were approved for shipment.

7.2.5 Rolled Columns and Beams

The contract between the PONYA and the Montague-Betts Company, Inc. contains the specifications for the rolled core columns, interior columns, louver wall struts, and rolled beams that were used in both towers. Requirements for fabrication and welding of structural steel are in the specifications, and inspection and quality control requirements are in the contract. These requirements can be found in Appendix E of NIST NCSTAR 1-1A.

The quality control and testing program was part of the contract. In particular, the following specific points were to be included in the quality control program:

- Material received should be checked against the certified mill test reports for size, grade, heat number, and color code. One copy of each certified mill report should be submitted to PONYA and SHCR.

- Overhangs, gross laminations, excessive slag inclusions, and similar defects should be defined and repair procedures for these defects should be outlined.

- Certification papers for each welder and welding machine operator should be submitted to PONYA and SHCR. Welding procedures must be prepared and the fabricator must perform qualification tests where applicable. All welds should receive 100 percent visual inspection. Non-destructive testing of welds needs to be described.

- The amount of periodic inspection of work in progress and the persons performing this inspection should be described. The inspection of finished work should be documented in reports submitted to PONYA and SHCR.

7.2.6 Other Requirements

Where problems arose in the fabrication yards, particularly when it came to fabrication tolerances, specific requirements that addressed the specific problems were adopted. The typical method used to remedy a problem was for the fabricator to submit a procedure for correction to the PONYA. The procedure was subsequently accepted or rejected by SHCR, and final approval by the PONYA was contingent upon the fabricator satisfying the requirements set forth by SHCR. These deviations from the original specifications are presented in Chapter 8 of this report.

[35] Weekly inspection reports contained in WTCI-749-L.

7.3 FABRICATION INSPECTION REQUIREMENTS FOR WTC 7

No contract documents were available to review for the inspection requirements during fabrication of structural members for WTC 7. However, WTC 7 project specifications for structural steel referred to the following codes and standards for fabrication:

- New York City (NYC) Building Code (1968)
- Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, AISC
- Specifications for Structural Joints using ASTM International (ASTM) High Strength Bolts, ASTM A 141 Rivets, and ASTM A 307 Unfinished Bolts, Research Council on Riveted and Bolted Structural Joints
- Specifications for Structural Joints using ASTM A 325 or A 490 Bolts, AISC
- *Code of Standard Practice,* AISC (except that the first sentence of Sec. 4, paragraph d shall not apply)
- Code of Arc and Gas Welding in Building Construction, AWS Standard Code D1.1, American Welding Society
- *Steel Structures Painting Manual,* Vols. 1 and 2, Steel Structures Painting Council (SSPC)
- Handbook of Bolts, Nut and Rivet Standards, Industrial Fasteners Institute

Structural steel was to be fabricated and assembled in the shop to the "greatest extent possible" according to these codes and standards.

The project specification called for a separate contract for testing and inspection of fabrication including welding. This contract was not available to the NIST investigation, and implementation of this contract could not be ascertained.

7.4 INSPECTION DURING CONSTRUCTION

Construction of WTC 1 and WTC 2 was overseen and managed by the Tishman Realty & Construction Company (TRCC), acting as the construction manager. In that role, TRCC as the general contractor coordinated the scheduling of the various activities required on the project, including the day-to-day construction activities at the site. The Port Authority required that all correspondence pertaining to administration of a prime contractor's contract, including contract changes, matters pertaining to field problems, job progress, and schedule be submitted to TRCC.[36] Karl Koch Erecting Co. (KKE) performed structural steel erection (see NIST NCSTAR 1-1A). As pointed out in Sec. 7.1, the record of construction and inspection were not available to the investigation. However, construction inspection identified a number of problems during the erection of WTC 1 and WTC 2, such as material defects, damaged

[36] General instructions from Malcolm P. Levy of PONYA to prime contractors for WTC contracts [WTCI-239-P; see Appendix F of NIST NCSTAR 1-1A].

structural members, fabrication errors, and fabricated and field welding defects. In a number of cases, the Port Authority granted construction deviation and repair requests by the fabricators and the erector, and they are presented in Sec. 7.5.

Although WTC 7 project specifications have general erection requirements for fasteners, anchor bolts, column bases, installation, and bracing, no inspection requirements during construction are given in the specifications. Further, the records of construction and inspection documents were not available to the investigation.

7.4.1 Erection Marks and Marking System WTC 1 and WTC 2

To facilitate steel erection, a marking system for structural steel in WTC 1 and WTC 2 was developed by the Port of New York Authority and Nassau Bridge Detailers. The marking system was devised to identify following structural members:

- Exterior wall columns – below the first story splice
- Exterior wall columns – above the first story splice
- Core columns
- Louver wall struts
- Vertical bracings at exterior wall columns
- Vertical bracings at core columns
- Interior pipe posts and hangers
- Floor beams
- Horizontal bracings at exterior walls
- Prefabricated floor units
- Loose deck and loose power/telephone cells for beam-framed areas
- Anchor bars and anchor plates
- Shear studs
- Viscoelastic damping units
- Grillages, column base plates and anchor bolts

This system was used by the fabricators to properly identify the different steel members/pieces that were used in the tower construction. For detailed description of the marking system, see Appendix F of NIST NCSTAR 1-1A.

7.4.2 Quality Control and Inspection Program for WTC 1 and WTC 2

A quality control and inspection program was developed by Karl Koch Erecting Co., who performed structural steel erection work, submitted to the Port Authority for approval. The quality control and inspection program included information on the following:

- Survey control
- Control of construction and erection loads
- Field welding
- Bolting of structural steel
- Control of stud welding operations
- Erection procedures
- Control of workmanship
- Control of erection tolerances
- As-built drawings
- Safety programs

For detailed description of the inspection program, see Appendix F of NIST NCSTAR 1-1A. Section 7.5 cites a number of construction errors identified during construction inspection.

7.5 DEVIATIONS GRANTED

The WTC towers were very complex steel frame buildings. The structural frames of the towers incorporated many beams, columns and trusses that were formed by welding steel plates. During fabrication and erection of structural members, errors were noted by the steel fabricators and the erector. Such errors included mainly dimensional deviations of structural members from the design and fabrication drawings. The PONYA was requested by the fabricators and the erector to approve deviations to contract drawings and specifications.

For deviation requests, the following procedure was established by the PONYA. All deviations resulting from difficulties encountered in complying with the contractual requirements for fabrication or erection were submitted by the fabricators or erector to the Office of the Construction Manager of PONYA. Deviations were also requested when, in the opinion of a fabricator or erector, an alternative detail or procedure was warranted. For expediency, such requests were usually submitted at the same time to the SHCR.

Typically, the Office of the Construction Manager approved a deviation after SHCR reviewed the details of the deviation and recommended its approval. In many cases, SHCR submitted alternative methods, which were incorporated into the deviation.

The deviations that were granted may be categorized into the following groups:

- Fabrication/erection tolerances
- Defective (cracked, laminated, misfit) components
- Fabricator/erector-preferred procedure
- Material substitutions
- Frequency/rate of weld inspections

Listed below are types of deviations granted by PONYA for each of the above categories. NIST NCSTAR 1-1A gives a detailed listing of fabrication and erection related deviation requests by fabricators and the erector.

7.5.1 Deviations Relating to Fabrication and Erection Tolerances

The following is a list of approved deviation requests for fabrication and erection of box beams, box columns, and floor trusses.

- Flange offset of 3/16 in. instead of 1/8 in. from the web for box-column sections fabricated by Stanray Pacific Corporation.
- Out-of-square tolerances of box beams and a maximum twist of box columns by Mosher Steel Company.
- Greater depth of the floor truss end bearing of 20 trusses (4.5 in. vs. specified 4 in.) by Laclede Steel Company.
- Field modification procedures for vertical struts of floor trusses to meet erection tolerances by Karl Koch Erecting Company.
- Change of fabrication tolerances of floor trusses by Laclede Steel Company.
- Fabrication modifications of floor trusses to avoid erection difficulties to Laclede Steel Company by the PONYA.

7.5.2 Deviations Relating to Defective Components

The following is a list of specific requests relating to deviations for defective components of column trees and floor trusses.

- Fabrication error for truss connectors that were 1/4 in. narrower than the required width by Laclede Steel Company.

- Fabrication errors of placing filler plate at incorrect locations at the bearing end of floor trusses by Laclede Steel Company. These errors were approved by the inspection company Pittsburgh Testing Laboratory subject to approval by SHCR.

- Repair procedures to correct fabrication errors by Laclede Steel Company.

- Repair procedure to correct laminations in column trees by Pittsburgh-Des Moines Steel Company.

- Repair procedure to correct cracks that developed in a number of column trees by Pittsburgh-Des Moines Steel Company.

- Repair procedure to correct fabrication errors by adding back up plates by Pittsburgh-Des Moines Steel Company.

- Repair procedure for butt welds in column trees by Pittsburgh-Des Moines Steel Company.

7.5.3 Deviations Relating to Alternate Fabrication and Erection Procedures

The following is a list of specific requests relating to deviations for alternate fabrication and erection procedures of core columns, floor trusses, exterior wall columns, and beam seats.

- Deviation of weld splice location of core columns from the contract drawings by Stanray Pacific Corporation.

- Use of Hobart automatic arc welding equipment to expedite welding process by Laclede Steel Company.

- Elimination of clipped corners of stiffener plates in the exterior wall columns by Pacific Car & Foundry.

- Substitution of different beam seat angles of (8 by 6 by 7/8) in. with (8 by 6 by 1) in. angles by Pacific Car & Foundry.

7.5.4 Deviations Relating to Product Substitutions

The following is a list of specific requests relating to deviations for product substitutions in the exterior wall.

- Substitution of different steel plates with yield strengths ranging from 42 ksi to 100 ksi for specific plates that were originally specified for use in the exterior wall by Pacific Car & Foundry.

- Substitution of 3/4 in. thick plates for 5/8 in. and ½ in. thick plates by Pittsburgh-Des Moines Steel Company.

- Substitution of ASTM A36 steel with ASTM A 441 modified steel by Pittsburgh-Des Moines Steel Company.

7.5.5 Deviations Relating to Inspection Practice

The following is a list of specific requests relating to deviations in inspection practice for the exterior wall and welds.

- Modifications to radiographic inspection procedures for butt-weld joints by Pittsburgh-Des Moines Steel Company was not approved. Instead, SHCR suggested an alternate program to be followed.

- Revision to the quality control program with respect to the minimum inspection rate for welds by Stanray Pacific Corporation.

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Chapter 8
STRUCTURAL MAINTENANCE AND MODIFICATIONS DURING OCCUPANCY

8.1 INTRODUCTION

Both architectural and structural modifications were made to meet the occupancy needs of individual tenants throughout the history of occupancy of the World Trade Center (WTC) 1, 2, and 7.[37] Examples of modifications include openings cut in existing floors to construct new stairways linking two or more floors, and reinforcement of floor framing members to accommodate heavy loads imposed by tenants. All modifications were reviewed by the Port of New York Authority (PONYA), later called the Port Authority of New York and New Jersey (PANYNJ), to maintain structural integrity of the buildings and to ensure that modifications were compatible with existing building conditions. In order to guide tenants in their modification process, the PONYA issued *Tenant Alteration Review Manual* (PONYA 1971). This manual was first issued in 1971 soon after the first tenant occupied WTC 1 in December 1970, and subsequently updated periodically through 1997.

In anticipation of structural degradation, in 1986, the PANYNJ issued the *Standard for Structural Integrity Inspection of the World Trade Center Towers A & B* (PANYNJ 1986) to guide periodical inspection of structural members. Deteriorated and damaged members were identified for repair. The standard was used by consultants who were retained by PANYNJ for systematic examination of WTC 1 and WTC 2.

In 1998, the PANYNJ issued the *Standards for Architectural and Structural Design* (PANYNJ 1998) for modification works. The standards included not only the design guide, but also included specifications and standard details to be used in modification works. Tenants proposing any modifications were required to follow the requirement specified in the standards.

In this chapter, the documents described above are presented, and significant modification and repairs to the structural systems of WTC 1, 2, and 7 are summarized. NIST NCSTAR 1-1C provides more detailed description of structural maintenance and modification during occupancy of WTC 1, 2, and 7.

8.2 TENANT CONSTRUCTION REVIEW MANUALS

PONYA issued the first edition of the Tenant Construction Review Manual in 1971, shortly after the first tenants occupied WTC 1 in December 1970 and prior to initial occupancy of WTC 2 in January 1972. Subsequent editions were issued in 1979, 1984, 1990, and 1997.

[37] The manual and standards mentioned below and the records on structural modifications, inspection and maintenance presented in this chapter were made available to the NIST investigation by PANYNJ. The *Tenanat Alteration Review Manual*, the *Standard for Structural Integrity Inspection of the World Trade Center Towers A & B, and* the *Standard for Structural Integrity Inspection of the World Trade Center Towers A & B* are given in Appendices A through F of NIST NCSTAR 1-1C.

The purpose of these manuals was to present the technical criteria, standards, and requirements that were to be followed by tenants that were planning construction work in any PONYA facility. The manuals included the criteria that were used by the Engineering Department of the Port Authority when reviewing proposed construction or alterations. Requirements were given for alterations and modifications to architectural, structural, geotechnical, civil, mechanical, plumbing, and fire protection systems.

The General Requirements section of the manual required that all tenants submit an application form to the Port Authority outlining the scope of work, the design criteria, and the plans prior to construction. The design was to be performed by a registered architect or licensed professional engineer. Contractors were required to comply with all applicable provisions of federal, state, municipal, local, and departmental laws, ordinances, rules, regulations, and orders, except where stricter requirements were contained in the project specifications.

8.2.1 1971 Edition

The 1971 edition of the Tenant Construction Review Manual (see footnote 37) requires that all structural modifications conform to the provisions of the 1968 New York City (NYC) Building Code. Registered design professional were to submit structural calculations for review by PONYA. The PONYA structural reviewer was responsible for the structural integrity of all walls and partitions. Building frames were checked for stability and sidesway, including the effects of these on the columns.

A comprehensive inspection program was implemented for all construction. Inspection was required during various phases of construction and was mainly to be performed in accordance with the 1968 NYC Building Code Sec. C26-106.3 (Materials, Assemblies, Forms and Methods of Construction; Inspection Requirements) and Sec. C26-107.3 (Service Equipment; Inspection Requirements). The architect, engineer, or other person who supervised the work was required by PONYA to be present at final inspection.

8.2.2 1979 Edition

In the 1979 edition of the Tenant Construction Review Manual (see footnote 37), structural requirements were modified and expanded. Significant differences between the 1971 and 1979 editions were based on updates of the Structural Chapter of the 1968 NYC Building Code. These include:

- Rules and regulations relating to resistance to progressive collapse under extreme local loads.
- Rules and regulations for the design of composite construction with metal decks or lightweight concrete.
- Rules related to structural design based on electronic computer computations.
- Rules for application and protection of sprayed fire-resistive material (BSA Cal. #118-68-GR).[38]

[38] Denotes number of the New York City Board of Standards and Appeals (BSA) document.

- Rules for arc and gas welding and oxygen cutting of steel covering the specifications for design, fabrication, and inspection of arc and gas welded steel structures and the qualification of welders and supervisors (BSA Cal. #1-38-SR).

Significant updates to controlled inspection of materials, operations, and equipment include:

- Inspection requirements for proper use of admixtures for concrete.
- Deletion of the requirement for checking welders' licenses or qualifications as this item was covered in the new rules and regulations relating to structural items.
- Acceptance of mill, manufacturers', and suppliers' inspection and test reports as evidence of compliance with the provisions of the Code for all structural materials and assemblies.
- Inspection of sprayed fire-resistive material since such inspection was added for the first time in C26-502.2(f) of the 1968 NYC Building Code in 1976 (Local Law 55). This new section of the code required that the installation of all sprayed fire-resistive material on structural members, except those encased in concrete, be subject to the controlled inspection requirements of C26-106.3, which requires all materials designated for controlled inspection were to be inspected and/or tested to verify compliance with code requirements. All required inspections and tests were to be made and witnessed by or under the direct supervision of an architect or engineer who the owner retained and who was acceptable to the architect or engineer who prepared the plans. The architect or engineer was to file with the NYC Building Department signed copies of all inspection and test reports, together with a signed statement that the material and its use or incorporation into the building complied with code requirements.

8.2.3 1984 Edition, Revised 1990

Except for some editorial changes, the requirements of the 1984 edition of the Tenant Construction Review Manual remained virtually the same as those of the 1979 edition. In the revised March 1990 edition, requirements were added concerning the role of consultants working on the project who were not the architect or engineer of record.

The scope of structural review of the alterations and/or modifications consisted of compliance with the applicable codes, standards, and design criteria given in the Structural Review section of the manual. In particular, the provisions of the then applicable New York City (NYC) Building Code were to be satisfied for work performed in New York City.

The revised March 1990 edition (see footnote 37) of the manual included a requirement that all structures were to be designed for earthquake zone 2 forces in accordance with the BOCA (Building Officials Code Administrators, Inc.) code. Local laws that contained seismic provisions more stringent than those in the BOCA code were to take precedence. Also, reference was made to ASTM International (ASTM) E 580, Standard Practice for Application of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Requiring Moderate Seismic Restraint for lightweight ceilings to resist seismic forces.

The Controlled Inspection section of the manual contained a comprehensive inspection program that was to be implemented for all construction. Controlled inspection requirements were abstracted from the NYC Building Code Secs. C26-106.3 and 107.3. All materials, equipment, and construction designated by the Code for controlled inspection were required to be inspected and/or tested to verify compliance with the Code. Controlled inspection was required to be made and witnessed by or under the direct supervision of a registered architect or professional engineer retained by the tenant and acceptable to the architect or engineer responsible for the plans.

The inspection requirements were significantly reorganized and modified in the revised March 1990 edition of the manual. Requirements for approval/acceptance of materials and controlled inspections were abstracted from the applicable sections of the NYC Building Code.

8.2.4 1997 Edition

The requirements of the 1997 edition of the Tenant Construction Review Manual are essentially the same as those in previous editions of the manual. The most notable change was related to earthquake design. The manual added horizontal force factors for overhead signs, anchorage for suspended ceilings weighing more than 4 psf, elevator and counterweight guardrails and supports, sprinkler piping, gas and high hazard piping, other piping, and heating, ventilation, and air conditioning (HVAC) ducts, along with new notes pertaining to sprinkler piping, other piping, and HVAC ducts. These requirements were added to the manual to ensure that potential overhead hazards would not fall on building occupants during a seismic event.

No significant changes were made to the inspection requirements from the 1990 edition of the manual.

8.3 STANDARDS FOR STRUCTURAL INTEGRITY INSPECTION OF THE WTC TOWERS

To guide the PANYNJ in the evaluation of the structural integrity of the WTC towers, the Engineering Department of PANYNJ issued *Standards for Structural Integrity Inspection of the World Trade Center Towers A & B* (PANYNJ 1986)[39] in 1986. These standards were used to identify structural degradation, and to repair damaged structural members.

Three methods were used to evaluate the structural integrity of the towers: (1) statistical inspections, (2) review of maintenance and tenant complaint reports, and (3) building movement and deformation measurements.

In the first method, periodic visual inspection of selected structural components in “higher-potential trouble areas” was to be made initially by qualified outside consultants. The periodic inspections were to be supplemented by occasional visual inspections when the structure was exposed during tenant remodeling or general maintenance work.

In the second method, various reports were to be examined by the Engineering Department of PANYNJ, which could possibly shed light on underlying structural problems. Maintenance reports of non-structural

[39] See Appendix E of NIST NCSTAR 1-1C for the complete document.

repairs, water leakage, and tenant complaints about unusual building movements, vibration, or noise are examples of such reports.

In the third method, the performance of systems within the buildings was to be evaluated by the Engineering Department through measurement of movement or deformation using appropriate tests and instruments. Measurements were to be performed on individual components in the towers as well as on the entire towers themselves.

8.3.1 Visual Inspections

Since the visual inspection of the entire structure, or even a major portion of WTC 1 or WTC 2, was not practical, a statistical inspection program was implemented. This approach involved sampling those components and systems that were important to structural integrity at locations with "a relatively higher potential for occurrence of defects or problems."

Visual inspection was to be supplemented by the use of simple hand tools, measurements, and recording techniques, as required. Loose, cracked, or rust-stained sprayed fire-resistive materials and concrete or masonry encasement covering structural steel members and connections was to be removed prior to examining the steel. After inspection, any removed fireproofing had to be properly replaced. Also, where it was necessary to drill a hole through a structural steel element to provide access for a borescope or any other device for inspection, the access hole was to be sealed with weld metal, body putty, or caulking, as appropriate.

Periodic inspection of WTC 1 and WTC 2 was to be carried out on the following components at various time intervals:

1. **TV antenna mast on the top of WTC 1.** This program consisted of four parts: (a) inspection of the structural steel elements in the antenna, (b) inspection of the high tensile bolts and studs, (c) inspection of the weatherproof enclosure, and (d) inspection of the radomes. Inspection of these components was to be performed on a "continuing basis," as weather and operational restrictions permitted. A complete inspection of the mast structure within the weatherproof enclosure was to be performed at least once a year; the other components were to be inspected at least once every 3 years.

2. **Exterior roof and wall elements.** Every year, the exterior roof and wall elements were to be inspected for signs of water intrusion. Roof leakage was to be ascertained from an examination of the spaces immediately below the roof areas. Wall leakage was to be determined from signs of water staining on interior finishes.

3. **Room occupancies.** An inspection of room occupancies and uses throughout both towers was to be performed on an annual basis to verify that design live load was not exceeded.

4. **Accessible column envelopes, including fireproofing.** Every 2nd year, accessible columns were to be inspected for bowing or deviation from plumb. Also, fireproofing was to be examined for signs of rust or cracking. Inspection for lateral displacement or rotation of columns in elevator shafts, where the columns were braced on only one axis by connecting beams or concrete slabs, was required.

5. **Fireproofing and masonry partitions on diagonal bracing and transfer trusses.** Fireproofing and masonry partitions enclosing the diagonal bracing on exterior column lines in both towers below the Service Level Floor and the transfer trusses below floor 1 in WTC 2 under exterior and core columns were to be inspected every 2nd year for cracking, stains, and other possible signs of structural distress.

6. **Hat truss members.** Every 2nd year, the hat truss members between floor 107 and the roof in the core area were to be inspected.

7. **Exterior box columns and spandrel plates.** Exterior box columns and spandrel plates under column trees below floor 7 were to be inspected every 4th year. Exterior aluminum covers and sprayed fire-resistive material were to be removed to gain access to the exterior surfaces of the box columns and spandrel plates. Both the columns and plates were to be visually inspected for bowing or distortion, cracking, and corrosion. Visual inspection was also required for accessible welds. Ultrasonic testing of full or partial penetration welds and adjacent base metal was to be performed where base metal thickness exceeded 1.5 in.

   The interior of the box columns was to be examined by a borescope for the presence of water and the existence of rust on the interior plate surface. This was to be accomplished by drilling an access hole in the column or the spandrel plate.

   The "tree" junction where the three superstructure columns merged was also to be inspected. The top surface of the horizontal diaphragm plate that capped the tapered box column just below the point where the three separate columns merged was to be examined, as was the exterior column plate between this location and the column splice at elevation +372 ft 4 in.

8. **Steel floor framing over mechanical spaces.** Every 4th year, the steel floor framing over mechanical spaces and other areas without suspended ceilings was to be inspected.

9. **Concrete slabs, partitions, and finishes.** Concrete slabs, partitions, and finishes were to be inspected every 4th year for signs of distress, which could indicate excessive structural deformation.

Occasional inspections were also to be made of the structural steel framing, connections, and concrete slabs when general repairs or remodeling was done that involved removing ceilings, partitions, finishes, or other coverings. In particular, the top of the concrete slab was to be examined for cracking, spalling, and exposed or corroded top reinforcement. Where reinforcing bars were corroded and where concrete had spalled, repairs were to be made as tenant relocation permitted.

8.3.2 Review of Reports

General maintenance reports and complaints from tenants were to be used to search for possible problems related to underlying structural defects. Water damage caused by leaks at the roof level or at the exterior walls, broken plumbing, and cracks in partitions or the concrete floor slab were to be reviewed to determine whether such events were caused by structural deformations. Records were to be kept of tenant complaints of building sway, floor vibration, sagging ceilings, unusual noise, and other items. Visual inspection of the appropriate area of the building was to be performed where a reasonable assessment of

the data in the reports or logs was tied to a specific structural element or system. Reports and log data were to be correlated with testing and measurements.

8.3.3 Periodic Measurements

Periodic measurements of various types of deformation and vibration were to be made by the Engineering Department of PANYNJ for the purposes of monitoring changes in certain important characteristics of the buildings. Adverse changes in such measurements were assumed to reflect possible structural deterioration.

Measurements of the following items were to be performed on a periodic basis:

1. **Natural frequency of the towers.** Accelerometers were to be used to measure natural frequencies of the towers on a monthly basis. Wind speed and direction were also to be recorded at that time.

   Accelerometers were installed only in WTC 1.

2. **Natural frequency of the TV mast on WTC 1.** Accelerometers and amplifiers were to be installed within the heated enclosure of the TV mast on the top of WTC 1 at a level of about 2/3 of the height of the mast above its base. One accelerometer was to be oriented to measure N-S displacements, and one was to be oriented to measure E-W displacements. Displacement measurements, as well as wind speed and direction, were to be recorded once a month.

   There is no evidence that accelerometers were installed on the TV mast.

3. **Natural frequency of the floor construction.** The natural frequency of the floor construction was to be measured when floor space had been emptied due to tenant change or remodeling. The natural frequency and damping values of the floor structure were to be measured by performing a “heel drop” test. In such tests, vibrations induced in the floor structure by a vertical impact were recorded using an accelerometer attached to the floor. Vibration measurements were also taken for an impact load of 100 lb dropped from approximately 6 in. above the floor slab on to a 1 in. thick neoprene pad.

4. **Viscoelastic dampers.** This program consisted of continuously measuring and recording the movements of WTC 1. Wind speed and direction were also to be measured. It was anticipated that such measurements would continue until the end of 1985 or longer, depending on available funds.

   Twelve viscoelastic damping units (four units from each of three floors) were to be removed from WTC 1 annually and were to be tested by the Minnesota Mining and Manufacturing Company (3M), who were the manufacturers of the damping units. Temperature effects and shear strength were to be tested.

5. **Plumbness and level.** Building plumbness and floor level checks were to be performed semiannually for each tower, preferably in the early morning hours in August when wind velocity was low and outside air temperatures were moderate.

Building plumbness was to be determined by measuring the offsets from a vertical laser beam, which was to be projected up from the bottom of freight elevator shaft 50, to the shaft walls. Offset measurements were to be taken at 20-story intervals.

Floor levelness was to be determined by measuring the relative elevation of 16 benchmarks on the floor slab at floor 70 of each tower.

8.3.4 Recordkeeping

Standards for Structural Integrity Inspection lists the defects and signs of distress that were to be noted and recorded during inspection of the structural steel and the reinforced concrete. Detailed descriptions of the defects and signs of distress are given in NIST NCSTAR 1-1C.

In general, a description was to be made of the defect or indication of distress. Measurements, sketches, and photographs were to be provided in those cases where a written description was not adequate. The use of a tape recorder was also permitted.

If defects that appeared to require more than routine attention were uncovered, a separate report of such findings was to be submitted to the Engineering Department, PANYNJ. For conditions of a serious nature, immediate notification was to be made to the Engineering Department in person.

Three categories of urgency were established for repairs. Repairs falling into the "immediate" category included possible closure of the area and/or structure affected until interim remedial action (such as shoring or removal of a potentially unsafe element or structure) could be implemented. Such action was to be undertaken immediately after discovery, and a description of the action taken and recommendations for permanent repair were to be included in the inspection report.

The "priority" category was for those conditions where no immediate action was required, or for which immediate action had been completed, but for which further investigation, design, and implementation of interim or long-term repairs should be undertaken on a priority basis (i.e., taking precedence over all other scheduled work).

Repairs falling into the "routine" or "non-priority" category could be undertaken as part of a scheduled major work program or other scheduled project, or when routine facility maintenance was to be performed, depending on the type of repair that was required.

Standards for Structural Integrity Inspection outline the various measurements and test data that were to be recorded during the inspection process. Also given are the criteria that determine whether a possible problem may exist, based on the recorded measurements.

8.4 STANDARDS FOR ARCHITECTURAL AND STRUCTURAL DESIGN

Standards for Architectural and Structural Design was issued on February 27, 1998, by PANYNJ and contained architectural and structural design requirements, specifications and standard details for tenant alterations that were to be made specifically at WTC 1 and WTC 2.[40]

Prior to any design work, the tenant's consultants were required to perform a field inspection of all areas that would be affected by the alterations so that the latest information was available for all structural elements, including, but not limited to truss reinforcement, stair openings in slabs, and core-hole locations.

Tenants are required to submit calculations and construction drawings to PANYNJ for review and approval. All construction documents were required to be signed and sealed by a professional engineer or registered architect licensed to practice in the state of New York.

Minimum loads to be used in the calculations were also specified. Calculations to compare the proposed loading with the allowable loads were required to conform to the latest edition of the NYC Building Code. Both allowable stress design and load-and-resistance-factor design were acceptable design methods.

All work was required to conform to the latest edition of the NYC Building Code, including any revisions. Provisions in the latest editions of the following codes took precedence over those in the NYC Building Code whenever they were more stringent:

- American Institute of Steel Construction, Specification for the Design, Fabrication and Erection of Structural Steel for Buildings. Supplement 1 is specifically excluded.
- American Concrete Institute, Standard Building Code Requirements for Reinforced Concrete, ACI 318.
- American Welding Society, Structural Welding Code – Structural Steel (AWS D1.1) and Reinforcing Steel (AWS D1.4).

Any steel plates that were added to reinforce existing framing or for other reasons were required to conform to ASTM A36, and any reinforcing bars that were added were required to conform to ASTM A 615 Grade 60.

Welding materials for structural steel and reinforcing steel were required to be E7018 conforming to American Welding Society (AWS) A5.1 *Specifications for Covered Carbon Steel Arc Welding Electrodes*. Specifications for non-shrink grout were also specified.

8.5 STRUCTURAL INSPECTION PROGRAMS

Beginning in 1990, the Port Authority of New York and New Jersey implemented a systematic facility condition survey program of WTC 1 and WTC 2 using *Standards for Structural Integrity Inspection*,

[40] The complete document is in Appendix F of NIST NCSTAR 1-1C.

which was developed in 1986. WTC 7, which was not owned by PANYNJ, was also inspected based on the criteria in *Standards for Structural Integrity Inspection* . Prior to 1990, both WTC 1 and WTC 2 were inspected occasionally by the Engineering Department of PANYNJ.

The survey program included:

1. Condition survey of WTC 2 in 1990 by the Engineering Quality Assurance Division of PANYNJ.

2. Condition survey of WTC 1 in 1991 by the Office of Irwin G. Cantor, Consulting Engineers, for the Engineering Quality Assurance Division of PANYNJ.

3. Condition survey of WTC 7 in 1997 by Ammann & Whitney for the Engineering Quality Assurance Division of PANYNJ.

4. Due diligence physical condition survey of WTC 1 and WTC 2 in 2000 by Merrit and Harris for PANYNJ prior to entering into a long-term leasing contract for the WTC buildings with Silverstein Properties.

In addition to these four separate condition surveys, Leslie E. Robertson Associates (LERA) and other engineering firms conducted periodic inspections of the towers under the WTC Structural Integrity Inspection (SII) Program, which was based on the proposal originally submitted to PANYNJ by LERA in 1990.

This section summarizes the findings of these condition surveys. Detailed descriptions of the condition survey programs and findings are given in NIST NCSTAR 1-1C.

8.5.1 Facility Condition Survey of WTC 2

The scope of work, which was designed to minimize impact on tenant and facility operations, included inspection of (1) the exterior wall system (columns, spandrel plates, and splices), (2) core columns (including column splices and lateral bracing below the 7th floor), (3) the space frame (hat trusses), (4) floor systems (floor slabs and decks, trusses, rolled beams, bridging, and connections), and (5) the damping system. Thirty floors throughout WTC 2 were selected for inspection, including all four of the two-story mechanical equipment rooms.

Inspection Procedures and Methodology

To assess the condition of the structural system in the tower, both visual inspection and nondestructive testing methods were performed. The thickness of steel members was checked using an ultrasonic thickness gauge. Fillet welds were tested for cracks and discontinuities using magnetic particle or dye penetration test methods, and groove welds were tested using the ultrasonic method.

Exterior Walls (Columns and Spandrels)

Exterior columns and spandrels were inspected at (1) column field splice connections, (2) spandrel field splice connections, and (3) the inside of the spandrel plate face at the column/floor truss seat connections.

A total of 59 column splices were inspected and all were found to be in good condition. On two of the floor levels, the columns had only three bolts at the splice location, although the design called for four. According to the report, this had no effect on structural integrity.

Spandrel plates, splice plates, and spandrel bolted connections were also found to be in good condition. Scattered rust stains were observed on the spandrel fireproofing as well as on the inside of some of the steel box columns.

No priority recommendations were made in the report. The report recommended that a long-term maintenance program be developed and implemented to clean and paint the inside surfaces of the exterior box columns to prevent further corrosion of the structural steel.

Core Columns

Core columns were inspected from elevator shafts and from office area floors. Twenty-five elevator shafts were randomly selected for inspection, and the elevator core framing was primarily inspected with fireproofing materials in place. In general, some defects were found in the fireproofing. In most of the shafts, several small regions and a few large areas of fireproofing were found to missing from core framing members. In the worst case, 100 percent of the fireproofing was found to be missing from the south face of column 908 between floors 27 and 29 in elevator shaft number 1. Exposed steel members exhibited only isolated locations of light surface corrosion.

Gypsum wallboards surrounding the elevator shafts were also found to be in good condition, although isolated holes were detected at various locations.

Inspection of column splices and eccentric-braced column connections with fireproofing removed showed that all bolts, welds, and structural steel were in good condition.

No priority recommendations for repair were made in the 1990 report. The report recommended that the fireproofing that was missing from the framing members in the elevator shaft be replaced, including those regions where the fireproofing was removed for inspection. It also recommended that the holes in the gypsum wallboards surrounding the elevators be repaired.

Space Frame (Hat Trusses)

From floor 107 to floor 110, a steel space frame system, also known as “hat trusses” was interconnected with columns in the core and the exterior walls. The hat trusses were constructed of rolled wide-flange and welded-box sections, and were designed to support a future antenna. Thirty three locations were inspected visually from the floor below. Visual inspections of truss connections were made closely at six locations after removing the fire resistant material (“fireproofing”). The space frame system was found to be in good condition. The exposed areas exhibited light surface corrosion. Both bolted and welded connections were found to be in good condition with no significant deterioration.

Floor Framing

In the main lobby, beams and connections that were inspected within the core area were found to be in good condition. Fireproofing was missing at various locations, exposing light surface corrosion on these elements.

On floors 9 through 41, the floor framing that was inspected was also found to be in good condition. Light corrosion was observed on all core beams and beam connections, and on floor truss connections. The most significant deficiencies were found at the damping units, where a number of such units were missing from 1 to 4 fasteners in the connections to the framing members.

Floor framing on floors 43 through 75 were found to be in good condition. The most significant deficiencies were found on floors 64 and 75. A deformed bottom chord was found on the main truss along column 343 on floor 64; no signs of distress were observed. On the 75th floor, untightened bolts were found at truss seat connections at several locations, which, according to the report, had no significant affect on the structural integrity of the framing, since they served for erection purposes.

The floor framing on floors 77 through 107 was found to be in good condition with light surface corrosion observed on all core framing beams and connections. The most significant deficiencies were concrete slabs that had separated from the metal deck at floors 93 and 108. According to the report, structural integrity was not comprised, since the metal deck served as only formwork for the concrete.

The floor framing and slabs were found to be in good condition except where hairline cracks were found in concrete beam encasement at various locations on all four mechanical equipment room levels.

No priority recommendations for repair were made in the report. All of the deficiencies noted above were considered to have no significant effect on structural integrity.

Damping System

Visual inspection of damping units noted missing non-structural fasteners. Of 30 floors examined, at least 1 damping unit on each of 4 floors (18, 29, 37 and 38) had missing fasteners, ranging from 1 to 4. No priority recommendations for repair were made in the report.

Mechanical Equipment Rooms (Floors 7-8, 41-42, 75-76, 108-109)

The floor framing and slab inspected on the Mechanical Equipment Room (MER) floors were found to be in good condition. On all MER floors, most of the structural framing was inaccessible due to HVAC ducts, fans, electrical equipment, or plumbing.

Hairline cracks were found in concrete beam encasement at various locations on all four MER floors. Exposed steel exhibited light surface corrosion, and no deterioration was found at the underside of floor slabs.

The report recommended no priority repair. As mentioned above, all the deficiencies found were considered to have no significant effect on structural integrity. The report recommended that utility supports found to be bowed or vibrating be replaced as part of the facility's regular maintenance program.

Roof

Roof framing, which consisted of rolled steel wide flange beams supporting a structural concrete slab, was found to be in good condition. Hairline cracks in the fireproofing and in the underside of the concrete slab were found at various locations.

No priority recommendations for repair were made in the report. The report recommended repairs that were none structural in nature.

8.5.2 Facility Condition Survey of WTC 1

The scope of the survey was based on experience gained from the survey of WTC 2 in 1990. As in the case of the WTC 2 survey, the scope of work was designed to minimize impact on tenant and facility operations. The exterior wall system, core columns, floor framing, damping system, space frame (hat truss), mechanical equipment rooms, and roof were inspected.

Exterior Walls (Columns and Spandrels)

A total of 28 exterior column splices were inspected throughout 14 office floors on floors 9 through 106. Nondestructive testing was performed on the plate splice welds, and ultrasonic testing was performed to verify plate thickness at 26 of these locations. All inspected columns splices were found to be in good condition.

The inside faces of the steel box column plates exhibited scattered areas of light to moderate corrosion and peeling paint. Ultrasonic thickness testing on the outer column plates above and below the splice location indicated no cross-section loss.

Spandrel plates, splice plates, and bolted connections were also found to be in good condition. Scattered rust stains were observed on the spandrel fireproofing.

On the floors above 106, only the joints at floor 108 were inspected. No structurally significant deterioration was found.

No priority recommendations for repair were made in the report. The report noted that missing fireproofing should be replaced on the spandrel plates and splices.

Core Columns

Core columns were inspected in 13 elevator shafts with fireproofing left in place. Corner core column splices were inspected on two office area floors. Core floor beam to column connections were also inspected at 25 of 56 locations on 14 floors.

The exterior wall column splices were found to be in good condition. Results from nondestructive testing of the splice plate welds were acceptable, and results from ultrasonic thickness testing showed no significant loss in member thickness.

Several small areas and a few large areas of fireproofing were missing from some of the steel beams and columns in the express elevator shafts. According to the report, the probable cause of missing fireproofing on the columns was due to the high speed of the elevators moving up and down the shafts. All exposed steel was found to be in good condition with light to medium surface rust.

Gypsum wallboards were found to be in good condition, except for two isolated holes in two elevator shafts at the 58th and 69th floors.

Similar to the case of the express elevator shafts, fireproofing was found to be missing on some of the steel columns and beams, and some isolated holes were found in some of the gypsum wallboards in the local elevator shafts.

Inspection of core corner column splices and floor beam to column connections showed all of the elements to be in good condition.

No priority recommendations were made in the report. The report recommended that missing fireproofing from the framing members in the elevator shafts be replaced, including those regions where the fireproofing was removed for inspection during the condition survey. It also recommended that the holes in the gypsum wallboards be repaired.

Floor Framing

Fourteen office floors (11, 13, 22, 30, 35, 52, 54, 61, 65, 78, 84, 86, 90, and 93) were selected for inspection. Inspection of the structural elements at these levels followed the following sequence:

1. Six long-span trusses and two short-span trusses were selected from the plans for even, random distribution of inspection locations throughout the floor area.
2. Floor framing, damping unit, utility supports, steel decking, inside faces of steel spandrel plates, spandrel splices, and core concrete or rolled steel members were visually inspected. Structural steel members were examined for signs of deformation or corrosion with fireproofing still in place.
3. Fireproofing was removed to inspect the condition of steel framing members at the following locations: (a) six truss locations, (b) one core floor beam, (c) two spandrel plate splices, and (d) two exterior columns (plaster removal). Visual inspections were made using lights, scrapers, wire brushes, and mirrors for signs of cracking, deformation, or corrosion.
4. Nondestructive testing was performed on column splice welds and welded floor framing connections. Testing was performed by the Port Authority's Materials and Research Division.

On 2 of the 14 floors inspected, column splices on 7 core columns were inspected after removal of the gypsum board firewalls. Top sides of exposed concrete floor slabs were also inspected where carpeting or floor tiles had previously been removed.

Two typical conditions were observed during inspection of the floor trusses: (1) small areas of fireproofing were missing at scattered locations throughout the floor framing, and (2) the underside of the floor trusses exhibited light rust. Welds were tested at various connections and were found to be in good

condition. In some cases, the connection of the truss to the exterior spandrel plate had one bolt and a weld instead of the typical two-bolt connection. These field welds were also tested and were found to be in good condition.

The metal deck and concrete slabs that were inspected were also found to be in good condition, except for the slab in the southeast corner of the 60th floor where cracks were found on the top surface.

The report made no priority recommendations for repair for any of the floor framing members. Routine recommendations were made as follows: (1) patch elastomeric sealer at the construction joint south of columns 504 and 505 under the 13th floor, (2) even though the modifications made to the bridging trusses at the 10th and 61st floors did not meet the original design, no further modifications were needed, (3) patch spalls that were created in concrete slabs when partition rails were removed, and (4) patch cracks on the 60th floor with elastomeric sealer

Damping System

At all of the locations that were inspected, the damping units did not have fireproofing covering them. Light rust was observed on the surfaces of the units. A non-structural bolt was missing on one of the damping units under the 30th floor.

Space Frames (Hat Trusses)

A total of 199 members were inspected in the space frame (hat truss). Light rust was found on diagonal braces, beams, and connections where fireproofing was missing. No priority recommendations were made in the report. Routine recommendations were made to replace missing fireproofing.

Mechanical Equipment Rooms and Space Frame

All four mechanical equipment room floor levels (floors 7-8, 41-42, 75-76, and 108-109) were inspected. Floor slabs at these levels were found to be in good condition with scattered cracks found on the slab surfaces. Scattered patches of fireproofing were found missing from the underside of the metal decks outside the core area.

A concrete encased beam on the 110th floor was subjected to steam from a leaking steam valve. Moderate rusting was found on the member, but no significant section loss was found.

Hangers supporting ducts and piping were visually inspected, and some were found to be subject to excessive vibration. Loose hanger rods and fatigue of pipe supports were also found at various locations. Beams that supported the duct hangers had fireproofing missing where the hangers were mounted.

The report included a priority recommendation to replace the leaking valve under the 110th floor that caused the floor beam to corrode. Routine recommendations were made to repair cracks in the concrete slabs and to repair hangers that were found to be vibrating, bowed, sagged, and/or deformed.

Roof

No significant structural deficiencies were found at the roof level. Cracking and spalling of the concrete slab was found in localized areas of the roof.

No priority recommendations were made in the report. Routine recommendations included removing and replacing existing patches in the roof slab and patching spalled areas in the concrete slabs.

8.5.3 Facility Condition Survey of WTC 7

The scope of work was designed to minimize impact on tenant and facility operations and was limited to unoccupied floors and floors that had vacant space. The column splices, wind bracing system, interior beam connections, floor slabs, and the Consolidated Edison (Con Edison) Substation were all inspected.

According to the report, no problems or deterioration were found on the column splices, wind bracing, or the interior beam connections at any of the locations that were inspected. Rust buildup was found between the flanges of members that rested on top of one another at the main roof level where the steel framing was exposed. The report recommended that the steel be cleaned and painted to prevent further deterioration, even though this was not considered to be a structural problem.

Fireproofing was found to be missing from the steel framing at various locations where utility supports were installed on all of the floors that were inspected. It was most prominent on the fifth floor framing above the main lobby and the second floor framing above the loading dock area. It was recommended in the report that the fireproofing be replaced.

Loose concrete was found on the north face of column 51 on the 46th floor of the cooling tower area. Silverstein Properties personnel immediately removed the loose concrete.

Floor slabs were found to be in good condition. No deficiencies were found, except for some shrinkage cracks on the top of some of the exposed slabs and some damage to the metal deck.

The Con Edison station was found to be in very good condition, and no action was required at that time.

8.5.4 Due Diligence Condition Survey of WTC 1 and WTC 2

This section discusses the findings of the condition survey of WTC 1 and WTC 2, which was performed by Merritt & Harris, Inc. in 2000 for PANYNJ (Merritt & Harris 2000). On-site evaluations were performed to assess the general physical condition of the property, as it existed at that time. In particular, WTC 1, WTC 2, WTC 4, WTC 5, the retail mall and plaza, central services, and the subgrade were inspected. The following discussion focuses on the findings for WTC 1 and WTC 2.

Inspection Procedures and Methodology

Observations were limited to those portions of the project that were visible during walk-through. In many areas, building finishes concealed structural components from view.

Findings of Inspection

Merritt & Harris reported the following findings and recommendations for both WTC 1 and WTC 2.

According to the report, the building structure appeared to be in good overall condition, based on observations of portions of the structure that were not concealed by building finishes. No apparent movement or settlement of foundations was observed, and interior slabs were reported to be in good condition.

The report noted that LERA and other engineering firms had performed, on a regular basis, SII of various structural systems and that those studies had indicated the following deficiencies: (1) rusting of steel columns in the elevator shafts, (2) missing fireproofing, and (3) floor coring damage.[41] The due diligence condition survey report went on to note that the most recent SII recommended repairs were underway at the time the report was written.

Damping units had been tested every 5 years, most recently in 1996. The report noted that approximately two-dozen damping units were kept in stock for replacement. The report also stated that LERA strongly recommended that the analysis of wind acceleration measurements be continued.

The report noted that an ongoing program of re-fireproofing structural steel members was in place at the time of the inspection. Re-fireproofing the structural steel was supposed to provide a 2 h fire rating for those members. Such work was performed on an entire floor when the space was being built-out for new occupancy. At the time of inspection by Merritt & Harris, Inc., approximately 30 floors had been completed in the two towers.

8.5.5 Structural Integrity Inspection Program

In 1986, PANYNJ implemented an inspection program to detect, record, and correct any signs of distress, deterioration, or deformation that could signal structural problems. This structural integrity inspection program, which was based on an inspection and testing plan prepared by LERA, contained detailed guidelines on inspection, record-keeping, and follow-up procedures.

Inspection findings under this program were to be categorized as “Immediate,” “Priority,” or “Routine.” Repairs falling into the “immediate” category included possible closure of the area and/or structure affected until interim remedial action (such as shoring or removal of a potentially unsafe element or structure) could be implemented. Such action was to be undertaken immediately after discovery, and a description of the action taken and recommendations for permanent repair were to be included in the inspection report. The “priority” category was for those conditions where no immediate action was required, or for which immediate action had been completed, but for which further investigation, design, and implementation of interim or long-term repairs should be undertaken on a priority basis (i.e., taking precedence over all other scheduled work). Repairs falling into the “routine” or “non-priority” category could be undertaken as part of a scheduled major work program or other scheduled project, or when routine facility maintenance was to be performed, depending on the type of repair that was required. An important requirement in the inspection program was that where inspection procedures involved the removal of fireproofing, such fireproofing was to be properly replaced on completion of inspection.

[41] Detailed findings of the Structural Integrity Inspections are given in NIST NCSTAR 1-1C.

A summary of the findings from the SII can be found in NIST NCSTAR 1-1C.

LERA's proposed plan to monitor the structural integrity of the World Trade Center Complex included WTC 1, WTC 2, WTC 4, WTC 5, WTC 6, the Vista Hotel, and the subgrade.[42] The plan called for inspection/monitoring of the following items in WTC 1 and WTC 2:

- TV mast (WTC 1 only)
- Roof water tightness and curtain wall
- Space usage
- Accessible columns, including exterior box columns at locations of spandrel intersections and "tree' junctions below floor 7 and above floor 1 (Plaza Level)
- Bracing at exterior column line below elevation 294 ft 0 in., and in WTC 2 only, the transfer trusses below floor 1 under exterior columns
- Hat truss between floor 107 and the roof
- Floor framing for mechanical spaces
- Floor framing for tenant areas
- Concrete slabs, partitions, and finishes
- Steel framing, slabs, and the like where exposed for general repairs or tenant remodeling
- Measurement of natural frequency of tower and TV mast
- Floor natural frequency
- Damping units
- Plaster ceilings in main lobby
- Marble wall panel supports
- Review of maintenance reports
- Fire stairs

Inspection and monitoring of these items were to occur at regular intervals. A summary of the structural integrity inspections conducted and their corresponding dates is given in Table 8–1.

[42] Letter dated January 12, 1990, from Saw-Teen See of Leslie E. Robertson Associates to Suren Batra of the Port Authority of New York and New Jersey (WTCI-123-P).

Table 8–1. Summary of Structural Integrity Inspections Completed for WTC 1 and WTC 2.

Inspection Program	Date(s) of Inspection Reports
Space Usage Survey	1995, 1996, 1997, 1998, 1999
Accessible Columns	1993, 1995, 1996, 1997, 1998
Plaza Level Box Columns	1998
Bracing Below Elevation 294 ft 0 in.	1991, 1995
Hat Trusses	1992, 1995
Floor Framing Over Mechanical Areas	1992, 1996, 1999
Floor Framing Over Tenant Areas	1992, 1995, 1997, 1999
Natural Frequency Measurements	1993, 1995, 2000
Natural Frequencies of Floors	1995
Viscoelastic Damping Units	1996

Space Usage Surveys

The purpose of the space usage surveys was to identify possible structural overloading of the slabs and floor framing due to changes in occupancies and uses or due to additions of heavy equipment or furniture. Surveys were conducted annually over a 5-year period starting in 1995, with two surveys conducted in 1996. The only priority recommendation was made in the 1995 report, which advised PANYNJ to distribute the load of the granite slabs on floor 106 of WTC 1 over a larger area.

Accessible Columns

Surveys of the accessible columns (columns in the core area that are not enclosed by an architectural finish, which can be visually inspected) in the elevator shafts of WTC 1 and WTC 2 were performed to:

- Ascertain the condition of the accessible columns with respect to rusting, cracking, bowing, and deviation from plumb;
- Identify specific locations of structural distress or damage;
- Identify locations of damage to the fireproofing;
- Identify lateral displacement or rotationN309 -2.367 Td <0078>Tl 8 dama

- Identify locations and signs of distress in slabs, partitions, column enclosures, and steel framing;
- Identify locations of inadequate fireproofing; and
- Provide recommendations and procedures for remedial work for both structural and fireproofing damage and/or inadequacies.

Surveys for floor framing supporting tenant areas were conducted in 1992, 1995, 1997, and 1999. No immediate recommendation was made in the 1992, 1995, 1997 and 1999 reports. Priority recommendations were made in the 1999 report concerning restoration of fireproofing on a truss on floor 89 in WTC 2, repair of spalled concrete on floor 89 of WTC 2 and floors 33 and 91 in WTC 1, and repair of damaged reinforcement on floor 91 of WTC 1. In the 1992, 1995 and 1997 reports, PANYNJ was directed to replace or repair damaged fireproofing on steel members.

Natural Frequency Measurements

The purpose of this inspection program was to determine the natural frequencies of oscillation of WTC 1 due to wind excitation. Only WTC 1 was instrumented with accelerometers at six locations on floor 108, which measured the accelerations in both principal directions of the building with respect to time due to wind. These natural frequencies were to be compared with corresponding values that had been determined in the past. A significant change in the tower's dynamic behavior was considered to be a possible indication of diminishing structural integrity. According to the reports, characteristics that may have been observed or inferred by review of the recorded acceleration data were:

- Integrity of the lateral-load-resisting system;
- Condition of the viscoelastic damping system;
- Condition of other sources of inherent structural damping; and
- Other changes that affect fundamental characteristics of the lateral-load-resisting system.

Reports were prepared by LERA in 1993, 1995, and 2000.[43] The 1993 and 1995 reports compared the available measured first mode natural frequencies of WTC 1 to those determined by the structural engineer in 1966, which were 0.084 Hz in the north-south direction and 0.096 in the east-west direction (WSHJ 1966). A summary of the measured first mode natural frequencies from the 1995 report, which contained the most current data, is shown in Table 8–2. No recordings were reported for the period between 1981 and 1991.

[43] These reports were prepared by Leslie E. Robertson Associates [WTCI 4073/66-L, 4056/66-L, 4094/66-L].

Table 8–2. Measured first mode natural frequencies for WTC 1.

Date	Wind Speed (mph) and Direction	Measured Frequency (Hz)	
		N-S	E-W
10/11/78	11.5, E/SE	0.098	0.105
01/24/79	33.0, E/SE	0.089	0.093
03/21/80	41.0, E/SE	0.085	0.092
12/11/92	49.0[a]	0.087	0.092
02/02/93	20.0, NW	0.085	0.095
03/13/93	32.0, NW	0.085	0.094
03/10/94	14.0, W	0.094	0.094
12/25/94	37.0, W	0.081	0.091

a. No direction was given in the report.

Both the 1993 and 1995 reports concluded that the measured and computed first mode frequencies compared well, especially for the greater wind speeds. The 1995 report also concluded that the February 1993 bombing had no permanent measurable effect on the dynamic response of WTC 1. Both reports recommended that WTC 2 be instrumented similarly to WTC 1.

The 2000 SII report pointed out that PANYNJ had not been able to analyze the data acquired from the instrumentation of WTC 1 since 1998 because the PANYNJ laboratory that contained playback and analytical equipment necessary to assess the recorded data was dismantled in the fall of 1998. The report recommended that the capability to assess and analyze the accelerometer data be re-established as soon as possible. The report further recommended that WTC 1 be additionally instrumented at a mid-level floor, and that WTC 2 be instrumented at its top floor and at a mid-level floor.

Natural Frequencies of Floors

The purpose of this inspection program was to determine the natural frequencies of the floor systems in WTC 1 and WTC 2 and to compare them with corresponding values that had been determined in the past. A significant change in the vibration characteristics of the floor system was considered to be a possible indication of diminishing structural integrity.

For purposes of determining the natural frequencies of the floor construction, a typical tower floor was divided into three zones, which corresponded to the type of floor truss that was used in that zone: short-span zone, long-span zone, and two-way zone.

Vibration characteristics of the floor systems were studied both analytically and experimentally. In 1971, Teledyne Geotronics of Long Beach, CA made field measurements of vertical vibration on floors 13, 27, and 32 of WTC 1 using seismometers. The field measurements were obtained under the direction of Skilling, Helle, Christiansen, Robertson (SHCR). SHCR also made analytical estimates of the natural frequencies of the floor systems at that time (SHCR 1971). They determined that the natural frequencies of the long-span and short-span trusses, considering viscoelastic damping, were 4.6 Hz and 7.9 Hz, respectively. A summary of the natural frequency test results for WTC 1 is contained in Table 8–3.

Table 8–3. Summary of natural frequency test results for floors of WTC 1, March 1971.

Floor Zone	Frequency Range (Hz)
Long-span	4.6 to 5.1
Two-way	4.6 to 5.7 7.0 to 7.9
Short-span	7.9

In March of 1995, Cerami and Associates, of New York, NY, made field measurements on floors 17, 22, 26, 38, and 88 of WTC 1 and floors 23, 24, an 58 of WTC 2 using the following equipment: piezo-electric accelerometer, vibration meter, peak band pass filter, and strip chart recorder (Cerami 1996). The floors were subjected to a standard heel-drop test or by jumping in place. All field work was performed under the direction of LERA. A summary of the test results for WTC 1 and WTC 2 are given in Table 8–4.

The SII report produced by LERA in April of 1995 summarized the analytical and experimental results to date (LERA 1995). Based on the available data, the report concluded that there had been no significant measurable change in the performance of the typical floor systems in WTC 1 and WTC 2.

Table 8–4. Summary of natural frequency test results for floors of WTC 1 and WTC 2, March 1995.

Floor Zone	Frequency Range (Hz)
WTC 1	
Long-span	4.5 to 5.3
Two-way	4.6 to 4.9 6.6 to 7.6
Short-span	7.8 to 8.8
WTC 2	
Long-span	4.8 to 5.6
Two-way	4.9 to 5.4 7.5 to 7.8
Short-span	7.9 to 8.0

Viscoelastic Damping Units

A summary of the integrity of the viscoelastic damping units in WTC 1 and WTC 2 was given in a report by LERA in 1996 (LERA 1996). Also given in the report is a historical review related to the performance of the damping units.

The report concluded that based on the then available studies, the integrity of the damping units was good, and that no action was required at that time beyond the routine testing of the damping units.

Inspections Related to Explosion of February 16, 1993

Six different inspections were performed before and after repairs were made to WTC 1 in the aftermath of the terrorist attack in February 1993. Summaries of these inspections were reported in a series of inspection reports prepared for the PANYNJ.[44] No anomalies were detected in the welds used to repair structural members.

8.5.6 Summary of Structural Integrity Inspection Programs

In general, the structural integrity inspections found that the structural systems of WTC 1, 2, and 7 were in good condition. The inspection consultants made numerous routine and some priority recommendations for repairs to the PANYNJ. According to the PANYNJ, all of the construction records on repairs following the inspections were lost on September 11, 2001. Thus, it cannot be determined whether all of the recommended repairs were performed. However, in 1999, the PANYNJ issued guidelines requiring that fireproofing be upgraded for steel floor trusses when full floors were undergoing alterations.

8.5.7 Modifications and Repairs to Structural Framing Systems of WTC 1, 2, and 7

Most of the modifications to the structural systems of WTC 1, 2, and 7 were done to accommodate tenant requirements (see NIST NCSTAR 1-1C). These generally involved cutting holes in existing floor slabs to construct new stairways linking two or more floors or reconstructing the floor system over previously cut openings. In other cases floor or column members were reinforced to accommodate new floor loadings imposed by tenant requirements.

Modifications to the structural systems were to follow the Tenant Construction Review Manuals of PANYNJ, which are summarized in Sec. 8.2.

Modifications and Repairs Made to WTC 1

Openings Made in Floor Slabs

Slab openings were made in the floor slabs on the following floors during the following years:

1. Floors 93 to 95, 1978 (openings were made in floors 94 and 95 between columns 901, 902, 1001, and 1002 in core)

2. Floors 99 to 101, 1979 (openings were made in floors 100 and 101 between columns 707, 708, 806, and 807 in core, and in floor 99 between columns 701, 702, 801, and 802)

3. Floors 89 and 90, 1985 (opening was made in floor 90 between columns 901, 902, 1001, and 1002)

4. Floor 107, 1995 (opening was made in floor 107; location could not be determined)

[44] These reports can be found in WTCI-67-L.

5. Floors 105 to roof, 1997 (opening was made in floor 105 near columns 704 and 804A in the core)

6. Floors 93 to 100, 1999 (openings were made on all floors; location could not be determined)

Most openings were made to accommodate new stairs and elevators.

Closing of Previously Opened Floor Slabs

Openings that had been cut primarily for stairways were subsequently closed on the following floors during the following years:

1. Floor 95, 1972 and 1985 (new beams and floor deck were added near lines 124 and 239)

2. Floors 91 and 92, 1987 (new beams and floor deck were added between columns 901, 902, 1001, and 1002 in the core)

3. Floors 96 and 100, 1998 (new beams and floor deck were added between columns 119 and 123 on floor 96 outside of the core and near columns 707, 708, 806, and 807 on floor 100)

Structural Members that were Reinforced

Various floor members were reinforced to accommodate floor loads that were greater than the original design loads. Members were reinforced on the following floors during the following years:

1. Floors 97 to 100, 1979 (cover plates were added on existing beams on floor 98 between columns 601 and 602 and between columns 701 and 702; on floor 98, diagonals were added to existing floor trusses on the east side of the core between columns 218 and 221; on floor 99, floor trusses along lines 309, 311, 313, 315, 317, 319, 321, 323, 325, 327, and 329 were reinforced; and, on floor 99, core perimeter columns were reinforced)

2. Floor 86, 1996 (floor trusses were reinforced in the northwest corner of the building)

3. Floor 85, 1998 (cover plates were added to existing beams and existing floor trusses were reinforced)

4. Floors 47 and 48, 2001 (floor trusses were reinforced)

Repair Work Following the February 26, 1993, Explosion

Damage from the Explosion

The explosion of February 26, 1993, occurred on Level B2 near the center of the south wall of WTC 1 and adjacent to WTC 3 (Vista Hotel). Structural steel columns, diagonal braces, and spandrel beams in the vicinity of the blast were damaged. Concrete floor slabs at Levels B1 and B2 and unreinforced masonry walls were also damaged over a large area. A detailed description of damage of structural members and subsequent repairs is given in NIST NCSTAR 1-1C.

Briefly, the explosion tore out the diagonal brace between column 324 at Level B2 and column 327 at Level B1 and severely bent the diagonal brace between column 324 at Level B2 and column 321 at Level B1. Spandrel beams at Level B1 from column 321 to 324 and from column 324 to 327 were also damaged by the blast. Spandrels were bowed and cracked and some had missing bolts.

The explosion caused a crack along the field splice in column 324. Ultrasonic testing determined that the crack extended across the full width of the weld on the south face of the column and at each end of the weld on the north face. A magnetic-particle testing procedure determined that the crack extended across the east face of the column and the majority of the weld on the west face as well.

The explosion also damaged floor beams framing into the tower side of column 324 at Levels B1 and B2. Concrete spandrel beams at Level B3 between columns 318 and 330 also sustained damage. Masonry walls in WTC 1 were breached over distances of approximately 50 ft to the east and 120 ft to the west of the blast origin.

Repair Work

The diagonal bracing members between Levels B1 and B2 that were damaged by the explosion were removed and replaced with new members.

New plates were added to the damaged spandrel beam at Level B1 between columns 324 and 327 and between columns 321 and 324. Also, the cracked weld on the south face of the spandrel beam at Level B1 near column 324 was removed and replaced.

An eight-step procedure was prescribed for repair of the crack in column 324 immediately adjacent to the field weld at the column splice above Level B2. No documentation was found to confirm that this crack was repaired according to that procedure.

Repairs were made to the floor beams framing into columns 321, 324, and 327. Repairs were also made to connections between floor beams and columns on Levels B3 and B4. Along the south face of WTC 1, the damaged concrete spandrel beams were demolished and replaced.

Modifications and Repairs Made to WTC 2

Openings Made in Floor Slabs

Slab openings were made in the floor slabs on the following floors during the following years:

1. Floor 77, 1979 (openings were made at nine locations in the northeast quadrant of the building)

2. Floor 96, 1987 (opening was made near columns 901 and 902 in the southeast quadrant of the building)

3. Floors 94 and 95, 1993 (opening was made between columns 507, 508, 607 and 608)

4. Floors 99 to 101, 1997 (openings were made; locations could not be determined)

5. Floor 99, 1998 (opening as made between columns 601, 602, 701, and 702 in the core on Floor 99)

6. Floors 25 and 26, 1999 (opening was made near column 901 in the core)

7. Floors 88 and 89, 1999 (openings were made; locations could not be determined)

Most openings were made to accommodate new stairs.

Closings of Previously Opened Floor Slabs

Openings that had been cut were subsequently closed on the following floors during the following years:

1. Floors 37 and 38, 1997 (new framing and floor deck was added near column 608)

2. Floors 95 and 96, 2000 (new beams and floor deck were added between columns 901, 902, 1001, and 1002)

Structural Members that were Reinforced

Members were reinforced on the following floors during the following years:

1. Floor 96, 1993 (a number of floor trusses and their connections were reinforced in the northeast quadrant of the building)

2. Floor 81, 1991 (two-way floor trusses were reinforced in area occupied by United Parcel Service)

Other Modifications

In 1994, the slab in the elevator lobby on floor 90 (bounded by columns 702, 703, 902, and 903) was repaired for Fiduciary Trust; NIST has not found evidence of the reason for this modification. The existing slab was demolished and was replaced with a 5 in. thick lightweight aggregate concrete slab.

Modifications and Repairs Made to WTC 7

Modifications Made due to New Loading Requirements

Members were reinforced primarily to accommodate floor loads that were greater than the loads for which these members were originally designed. Members were reinforced on the following floors during the following years:

1. Floor 38, 1988 (cover plates were added to existing beams along lines 30, 35, 37 and 40)

2. Floor 24, 1989 (cover plates were added to existing beam on line 45 and to two adjacent beams)

3. Floor 47, 1989 (cover plates were added to existing beams on line 2-5 and to the existing girder on line 56)

4. Floors 11 and 12, 1990 (cover plates were added to eight existing beams and girders in the northwest corner of the building on floor 11, and to three existing beams between lines 48 and 49 and to the girder between columns 70 and 73 on floor 12)

5. Floor 19, 1991 (cover plates were added to existing beams; location could not be determined)

6. Floor 12, 1992 (cover plates were added to 11 existing beams in the northwest corner of the building, and a new beam was added between existing beams)

7. Floors 18 and 19, 1992 (cover plates were added to existing beams on lines 31, 32, and 33)

8. Floor 28, 1993 (additional shear studs were added to existing beams located in the mechanical/electrical room)

9. Floors 7 and 8, 1993 (a new beam was added between lines 7 and 8)

10. Floors 7-29, 1994 (cover plates were added to 22 existing beams between lines 5 and 25 on the south side of the building and on each floor between levels 7 and 29, and to eight existing beams on the east side of the building between lines 31 and 37)

11. Floor 20, 1995 (cover plates were added to existing beams along lines 23 and 25, and WT sections and cover plates were added to existing beams east of line 19)

12. Floor 37, 1999 (a new beam was added between two existing beams along lines 76 and 77)

13. Floor 13, 1999 (additional shear studs were added to an existing beam; location could not be determined)

14. Floor 40, 1999 (four new beams were added near column 76 and WT sections were welded to the bottom of two existing beams)

15. Floor 31, 2000 (cover plates were added to an existing beam between columns 77 and 80)

16. Floor 38, 2000 (cover plates were added to existing beams between columns 76 and 77 and between columns 77 and 78, and to existing girders between columns 76 and 79, 77 and 80, and 78 and 81)

17. Floor 39, 2000 (new beams were added between columns 76 and 77)

Openings Made in Floor Slabs

The floor slabs on floors 41 and 43 were completely removed on the east side of the building to accommodate the trading floors for Salomon Brothers Inc. Columns 76, 78, 79, 80, and 81 were reinforced with plates that ran from the top of the 39th floor to the underside of the 49th floor due to the removal of the floor slab at the 39th floor. Similarly, column 74 was reinforced with plates that ran from

the top of the 43rd floor to the underside of the 44th floor due to the removal of the floor slab at the 43rd floor.

Other slab openings were made in the floor slabs on the following floors during the following years:

1. Floors 3 and 4, 1989 (openings were made on the 3rd floor on the west, north, and east sides of the building; on the 4th floor, openings were made on the north side of the building)

2. Floor 3, 1989 (openings were made near columns 24 and 25)

3. Floor 11, 1990 (opening was made between columns 77, 78, 80, and 81)

4. Floor 43, 1994 (opening was made near column 71 in the core area)

Modifications Made to Beam Webs and Flanges

Modifications were made to beam webs and flanges on the following floors during the following years:

1. Floor 28, 1993 (openings were cut in the web of an existing beam; location could not be determined)

2. Floors 4 to 7, 16, 21, 29, 38, and 45, 1993 (notches were cut in the bottom flanges of various beams and plates were welded to the upper side of the bottom flanges)

3. Floor 1, 1998 (notch was cut into the top flange of an existing beam, and two plates were welded under the top flange; location could not be determined)

4. Floors 36 to 44, 1999 (openings were cut in the web of an existing beam framing into column 75 on all floor levels; the beams was reinforced with web plates and a WT section welded to its bottom flange)

5. Floors 42 and 44, 1999 (openings were cut in the webs of numerous beams along the north and east sides of the building)

Other Modifications

A list of structural modifications that were made to WTC 7 prior to April of 1997 is given in Chapter IV, Sec. A(5) of the Facility Condition Survey Report for WTC 7 (PANYNJ 1997). The following is a summary of the modifications that are noted in that report:

1. In the Convention Area on the 3rd floor between column numbers 45 and 48A, steel plates were installed around the perimeter of the room between the slab and the floor surface (behind the wall coverings and above the suspended ceiling). According to the PANYNJ report, these plates were installed to protect attendees of the Convention Center from the magnetic field generated from the Con Ed Substation beneath the conference rooms. No documentation was located that provides any additional details on this modification.

2. On the north side of the 5th floor generator room, masonry block walls were added to partition the eight transformer vaults installed for Salomon Brothers. The vaults were between columns 46 and 53. No documentation was located that provides any additional details on this modification.

3. A penthouse was constructed on the 47th floor roof to house the chiller plant and the cooling towers for Salomon Brothers. The chiller plant was an enclosed steel-framed structure with corrugated steel walls. It was approximately 25 ft in height and took up about one-third of the square footage of the 47th floor roof. The cooling towers were supported on a steel frame and were enclosed by louvered walls on the north and south sides and by the chiller plant and the bulkhouse on the east and west sides, respectively. No documentation was located that provides any additional details on this modification.

The list of modifications in the PANYNJ report also included the removal of the floor slabs on floors 41 and 43 to accommodate the trading floors for Salomon Brothers, as noted above.

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Chapter 9
COMPARISON OF FIRE SAFETY CODES AND PRACTICES

9.1 COMPARISON OF FIRE PROVISIONS IN BUILDING CODES

9.1.1 Introduction

The 1968 New York City (NYC) Building Code (NYCBC 1968) was compared with four other building codes to determine the extent to which the codes and mandatory referenced standards were utilized in the design and construction of the towers. The other codes are: the 1964 New York State Building Construction Code (NYSBC 1964); the 1965 Building Officials and Code Administrators/Basic Building Code (BOCA/BBC 1965); the 1967 Municipal Code of Chicago Relating to Buildings (MCC 1967); and the 2001 edition of the NYC Building Code (NYCBC 2001). In addition, comparisons of fire safety requirements were made to the 1966 edition of the National Fire Protection Association (NFPA 101), Code for Safety to Life in Buildings and Structures. While not a building code, National Fire Protection Association (NFPA) 101 is widely adopted for its requirements on life safety in fires.

The codes selected for comparison are nationally or regionally recognized model regulations that are the basis for laws and reflect the standards of practice of the time. The 1964 New York State Building Construction Code was the governing building code outside the New York City limits. The 1965 BOCA Basic Building Code was typically adopted by local jurisdictions in the northeastern region of the United States. The 1968 NYC Building Code is compared with the 1967 Municipal Code of Chicago (MCC) to see whether there are any substantial differences in the fire safety requirements of the two codes. In the late 1960s and early 1970s, several tall buildings were built in Chicago including the Sears Tower (110 stories) and the John Hancock Tower (100 stories), both of which were classified as business use and incorporated innovative design features. In addition, the 2001 edition of the NYC Building Code was compared with the 1968 version to examine the extent to which Local Laws modified the code provisions, and in most cases, is only addressed in areas where changes occurred between the two versions.

A provision by provision comparison was made between the 1968 NYC Building Code and these codes. The code provisions that were compared are limited to the requirements related to structural stability, active and passive fire safety, and emergency egress and are presented in the reports NIST NCSTAR 1-E and 1-F.

The NYC Building Code was regularly modified by local laws, two of which, Local Law 5 (1973) and Local Law 16 (1984), had a significant influence on the fire and life safety features of WTC 1 and WTC 2, even though the buildings were completed and occupied at the time of adoption. Normal practice is not to apply building code changes to existing buildings unless they undergo major renovation or change in primary use, although Local Laws 5 (1973) and 16 (1984) did contain some retroactive provisions. The Port Authority of New York and New Jersey (PANYNJ or Port Authority) chose to follow the revised provisions and to retrofit the buildings as required under the new provisions. The resulting changes to WTC 1 and WTC 2 are discussed primarily in the sections on modifications to the building systems and in reports NIST NCSTAR 1-G and 1-H. Local Laws 5 (1973) and 16 (1984) were in place at the time WTC 7 was designed and constructed, and the requirements of these local laws were

reflected in that building. There were no significant revisions to the NYC Building Code that affected the fire and life safety features of WTC 7.

9.1.2 Interrelation of Codes, Standards, and Practices

Model codes that include minimum requirements for public health, safety, and welfare are developed in an open process by private sector organizations. The resulting model codes are traditionally organized into volumes according to the regulatory official responsible for their enforcement. These include a building code, fire code, plumbing code, mechanical code, and so forth. These model codes contain mandatory references to standards and reflect generally accepted standards of practice of the time.

These model codes and referenced standards do not become law until they are adopted legislatively or administratively by a jurisdiction empowered to enforce regulations. These jurisdictions may modify specific provisions of the model codes and referenced standards to suit local conditions and traditional practice. This adoption process is governed by general rules applicable to the adoption of laws that cover public notice and consultation, public debate, and access to the final regulation, often described by the term due-diligence. Once legally adopted, the totality of the modified model codes and standards are refered to as building regulations.

The provisions contained in building codes generally specify what is required under specific conditions. The building codes contain references to standards that provide further details on how the provisions are to be implemented to meet the intent of the code. New York City makes use of nationally recognized technical standards but adopts them with modifications to meet local needs and accepted practices. These modified standards are known as Reference Standards (RS) and are available from the city. Reference standards take on the force of law when they are included in the building regulation as mandatory references and enforced by the regulatory official. For the WTC towers, the Port Authority utilized the New York City reference standards and the source standards from NFPA and others in design guidelines, manuals, and procurement contracts associated with system upgrades.

In some cases, trade associations and professional societies develop practices that may guide how building design and construction work is done. While not strictly enforceable unless referenced in the code, such practices represent a consensus of what is reasonable or prudent. A few, relevant practices are discussed in this section.

9.1.3 Comparison of New York City and Contemporary Building Codes

While New York City developed its own building code, its code development committees were influenced by the same forces that bore on the model codes. Thus, there were relatively few differences between the NYC Building Code and the others.

Construction Classification

The model building codes classify building constructions into different "Types." Although there are some variations in categories, they are reasonably consistent.[45] The main categories are Type I (fire resistive), Type II (non-combustible), Type III (ordinary), Type IV (heavy timber), and Type V (combustible).

Types I and II are constructed with non-combustible exterior and interior bearing walls and columns. Fire resistance ratings (see Fire Ratings) are greatest for Type I, and Type II is any (non-combustible) construction not meeting Type I requirements. For Type III, exterior bearing walls are non-combustible and interior bearing walls and some columns may employ approved combustible materials. Type IV is known as *heavy timber*, which utilizes large, solid cross section wooden members such as in post and beam construction. Type V is all other types of construction, including traditional wood frame construction. Common non-combustible structural elements are made of steel or reinforced concrete. Combustible structural elements are usually made of solid- or engineered-wood and laminates.

Combustibility of the materials in a structural element is determined in an ASTM International (ASTM) E 136 test in which the material is placed in a furnace at 750 °C (1,380 °F), which is a "typical" fire temperature. Some minor surface burning (e.g., from paint or coatings) is allowed in the first 30 s, but there cannot be any significant energy release as indicated by more than a 30 °C (54 °F) increase in the furnace temperature, and the test specimen cannot lose more than half its initial mass. Materials that pass are designated non-combustible, and the rest are combustible.

Within each construction type, there are several sub-categories determined by the fire resistance ratings of the columns, beams, and floor supports. In some codes, these sub-categories are identified by letters following the type (e.g., 1B or 3A) or by a set of three numbers that represent the fire resistance required (in hours) of exterior bearing walls; columns, beams, girders, trusses, or other components supporting loads from more than one floor; and floors or components supporting loads of a single floor, respectively (e.g., Type 1 [3,3,2]).

For unsprinklered office buildings, the following construction classes are permitted in the five building codes reviewed.

- Type 1A and 1B—NYCBC 1968, NYSBC 1964, BOCA/BBC 1965 (Unlimited height)
- Type 1A, 1B, 1C, 1D—NYCBC 2001 (Height limited to 75 ft)
- Type 1A only—MCC 1967 (Unlimited height)

The 1938 NYC Building Code did not include Type 1B construction for office occupancies. The reasons for the inclusion of Type 1B construction for office occupancies in the 1968 NYC Building Code are not recorded (record keeping in the codes and standards development process was very poor prior to the Hydrolevel vs. ASME Supreme Court decision in 1982). The codes then and now tend to follow each other, as champions of changes to one code usually try to change all of the codes.

[45] Construction type definitions varied among the model codes until an effort in the 1970s by the Board for the Coordination of the Model Codes to eliminate unnecessary differences.

The 1950 edition of the Basic Building Code (BOCA), the regional model code used in the Northeastern United States, included a Type 1B construction class with unlimited height and area for business and low hazard storage occupancies without sprinklers. Among other model codes, the Standard Building Code (1946-47 edition, SBCCI) had a Type 2 construction similar to Type 1B for business occupancies and buildings more than 80 ft in height; the National Building Code (1934 edition, NBFU) had a semi-fireproof construction similar to Type 1B for buildings above 75 ft; and the Uniform Building Code (1927 edition, ICBO) had a Type 2 construction similar to Type 1B for buildings above 75 ft. The 1968 NYC Building Code is consistent with the 1950 BOCA in its inclusion of the Type 1B construction.

Mandatory sprinkler requirements for new high-rise buildings was first introduced in the NYC Building Code in 1984 (by Local Law 16), in BOCA in 1984, and in the Chicago Building Code (which allows a compartmentation alternative) in 1975. Before Local Law 16 was adopted, the 1968 NYC Building Code permitted Type 1A, 1B, 1C, and 1D construction for sprinklered office buildings of unlimited height. In the 2001 NYC Building Code, the minimum permitted construction classification for sprinklered office buildings of unlimited height is Type 1C.

Selection of Construction Type for WTC Towers

The 1938 NYC Building Code recognized one construction type for buildings of unlimited height and area, namely Class 1—Fireproof Structures, which required a 4 h fire rating for columns and a 3 h rating for floors. In the 1968 NYC Building Code, Group I (Noncombustible) construction was subdivided into "Class 1A—4-hr protected" and "Class 1B—3-hr protected" construction. Class 1A specified similar protection as the previous Class 1, and Class 1B specified a 3 h rating for columns and girders supporting more than one floor and a 2 h rating for floors including beams. Both Class 1A and Class 1B construction permitted unlimited height and area for unsprinklered business occupancy.

Since building codes set minimum levels a building that qualifies for less than the highest construction class (1A) all or portions of that building can be constructed to a higher class, but where two or more classes are used in the same building, the building is classified by the lower class (see for example 7.2.1.2 in NFPA 5000). In such situations, the classification(s) selected for construction is at the discretion of the owner/architect.

Fire Ratings

The structural elements of a building are protected against failure in fire for a specified period, as determined in the ASTM E 119 test. The intent of the fire rating requirements is for the structure as a minimum to withstand design loads (including fire) without local structural collapse until occupants can escape and the fire service can complete search and rescue operations.

Fire resistance requirements in the building codes are greatest for structural members that are essential to the stability of the building as a whole. These include columns and other major gravity load carrying members that connect directly to columns such as girders and trusses.

For various construction classes, the building codes specify different fire resistance ratings. The building codes reviewed all specify fire resistance ratings for high-rise office occupancies as follows:

- Type 1A
  - Columns: 4 h (supporting more than one floor)
  - Beams: 3 h (floor construction)
- Type 1B
  - Columns: 3 h (supporting more than one floor)
  - Beams: 2 h (floor construction).
- Type 1C (for sprinklered buildings only)
  - Columns: 2 h (supporting more than one floor)
  - Beams: 1½ h (floor construction).

The choice among permitted construction classes for a particular building is made by the architect and/or the owner. Thus, an unsprinklered high-rise office building that was designed according to the 1968 version of the NYC Building Code could follow either Type 1A or 1B, and if designed subsequent to the passage of Local Law 16/1984, a high-rise office building would have to be sprinklered but it could follow Type 1C as a minimum classification. Similar reductions in the minimum required fire resistance ratings for sprinklered buildings are found in all model building codes over this period, as requirements for fire sprinklers, especially in high-rise buildings, have become common.

Type 1B, and eventually Type 1C, construction was permitted for high-rise office occupancies because this occupancy is considered low risk. Most other use groups in high-rise buildings were restricted to Type 1A, which is the construction type with the maximum structural fire protection defined in these codes.

Practice Related to Fire Resistance Ratings

Building codes specify fire resistance ratings for the structural members of buildings as a function of

- Building height,
- Construction type, and
- Use group (Occupancy),

with modifications for the presence of fire sprinklers. For example, the International Building Code (IBC 2003), Section 703.2 states,

> The fire-resistance ratings of building elements shall be determined in accordance with the test procedures set forth in ASTM E 119 or in Section 703.3. Where materials, systems or devices that have not been tested as part of a fire-resistance-rated assembly are incorporated into the assembly, sufficient data shall be made available to the building official to show that the required fire-resistance rating is not reduced.

This section appears to have been based on the 1981 BOCA (Sec. 1403.1.1) which required that, "The fire resistance ratings of building assemblies and structural elements shall be determined in accordance with the test procedures set forth in ASTM E 119…"

IBC Section 703.3 allows the fire resistance of a building element to be established by:

- Fire resistance designs documented in approved sources
- Prescriptive designs of fire-resistance-rated building elements prescribed in Section 720,
- Calculations in accordance with Section 721,
- Engineering analysis based on building elements with ratings established by ASTM E119, or
- Alternative protection methods permitted by IBC and approved by the building official.

These alternative methods were included in the other model building codes on which the IBC is based. For example, the 1997 Uniform Building Code contains tables of prescribed ratings for specific materials and assemblies which may be depended on as an alternate to ASTM E 119 testing. The 1994 Standard Building Code permits calculated fire resistance using specified methods or testing by ASTM E 119.

In the 1968 New York City (NYC) Building Code, Section C26-501.1 requires that,

> Samples of all materials or assemblies required by this code to have a fire-resistance rating, … shall be tested under the applicable test procedures specified herein … . The fire-resistance rating of materials and assemblies listed in reference standard RS 5-1 (which references ASTM E 119) may be used to determine conformance with the fire resistance requirements of this code.

In traditional practice, the architect (sometimes different from the design architect, called the code architect or architect of record) specifies the fire resistance ratings needed to comply with the building code. The required ratings are normally not shown on the architectural drawings (although the construction type may be); rather they are shown in the supporting material submitted to the building department for plans review.

Building codes require that an ASTM E 119 test be performed to determine the details of the assembly that would meet the requirement. In some cases the architect may choose to use an assembly that has already been tested and rated. Such assemblies are listed by testing laboratories in directories, databases accessed on test laboratory web sites, or in test reports available from manufacturers of materials used in the assemblies such as the producers of fireproofing products. These sources are very detailed and indicate the thickness of the specific product tested that is required to achieve a specific hourly rating.

Enforcement officials are expected to verify that even the smallest details are followed or that the variations do not affect performance. Alternatively, some codes include descriptions of generic assemblies that can be assumed to achieve specified ratings, or provide calculation methods to determine the thickness of sprayed fire-resistive material needed to achieve a specific rating. These methods are often based on W/D (width to depth) ratios, which must be applied differently as a function of member geometry.

An additional variable that affects the needed thickness of fireproofing is whether the assembly is restrained. It is traditionally assumed that an assembly that is thermally restrained requires less fireproofing. Note that the NIST tests of the floor assemblies used in the towers showed the opposite. However, the definition of restrained is not trivial and needs to be specified by the structural engineer.

In some cases, it is not clear who actually determines the required thickness of fireproofing material. If the bid specifications for the fireproofing contract simply require the assemblies to be sprayed to achieve a specific hourly rating (which may be the case where a specific product is not identified to be used), then the thickness determination may be left to the fireproofing contractor.

Standards of practice for sprayed fire-resistive material are contained in the Underwriters Laboratories (UL) guide card (UL 2001) (although technically this only applies when a UL Listed assembly is used) and in manuals published by the Association of Wall and Ceiling Industries (AWCI 1997). There is also the American Institute of Architects Masterspec on Spray Applied Fireproofing (AIA 2000) that is similar to the Association of Wall and Ceiling Industries (AWCI) manual. Additional guidance may be provided by the manufacturers of fireproofing materials that are specific to the characteristics of those products.

The UL guide information (BXUV) includes a number of limitations on the application of listed assemblies, including:

- Limits on the size (flange width and web depth, pipe outer diameter) without the use of a mechanical break such as metal lath or fasteners,
- Use of bonding agents or conduct of a bond strength test in accordance with ASTM E 736 whenever the steel is painted (other than a paint specified in the listing)
- Conduct of thickness testing in accordance with ASTM E 605.

The AWCI Technical Manual contains similar limitations and instructions, including the production of a test report on thickness and density, bond strength, correction of deficiencies, and patching procedures. Further, the AWCI manual describes a quality assurance program and requires that the fireproofing contractor retain the services of the licensed engineer or architect qualified to make the determination of restrained and unrestrained members. The AWCI manual is not cited as a mandatory reference in any model code; rather it is voluntarily followed by contractors that are members of the association. The American Institute of Architects (AIA) Masterspec is similar to the AWCI manual, except that it is written to be incorporated into the fireproofing contract, which would make it enforceable against the contractor.

Some building codes require that sprayed fire-resistive material on steel structural members be subjected to inspection at the time of installation. Local Law 55 (1976) amended the 1968 NYC Building Code to

require that all required, sprayed fire-resistive material on structural members, except those encased in concrete, be subjected to a controlled inspection, meaning that it must be conducted under the supervision of a building inspector or a licensed design professional who assumes responsibility for compliance. This provision applied to all installations after the date of enactment (November 1, 1976) and was not retroactive. The inspection was to include verification of the thickness of the material, its density, and its adhesion, each utilizing a specific ASTM test method. There are no code requirements nor general practice by which sprayed fire-resistive material is inspected over the life of the building. Most building codes contain a requirement that sprayed fire-resistive material that is installed in areas where it is subject to mechanical damage shall be protected and maintained in a serviceable condition. For a detailed discussion of the fireproofing system found in the towers, see NIST NCSTAR 1-6A.

9.1.4 Occupancy Group

All building codes define categories of occupancy (which may have more than one sub-class). The group designations vary in different codes. The ones presented here are those used in the 1968 NYC Building Code. These are:

- High Hazard (Group A)
- Storage (Groups B-1 and B-2)
- Mercantile (Group C)
- Industrial (Group D-1 and D-2)
- Business (Group E)
- General Assembly (Group F-1 through F-4)
- Educational (Group G)
- Institutional (Groups H-1 and H-2)
- Residential (Groups J-1 through J-3)
- Miscellaneous (Group K)

Building codes use occupancy as a surrogate for risk factors that determine the level of performance needed. For example, occupancy is determined by a combination of factors such as types and quantity of combustible contents, common ignition sources, and typical occupant characteristics. Business occupancies (which includes office buildings) are considered among the lowest risk because they typically contain grades of furniture that constitute relatively low combustible loads, few ignition sources, and a population that is predominately adult, and not sleeping. The most risky occupancies are High Hazard, in which are found highly flammable, toxic, or explosive materials, and Institutional (e.g., hospitals and prisons) in which occupants are likely to be incapable of unassisted egress.

In some codes, including the 1968 NYC Building Code, occupancy groups are subclassified with a “fire index” rating in hours. For example, “high hazard” occupancy is assigned a fire index of 4 h, while

"business" occupancy is assigned a fire index of 2 h. These fire indexes are used to specify the performance of separations between spaces of different use in a mixed-use building. For example, spaces of different use with the same fire index are separated by a partition of lower rating than for uses with a different fire index. Many buildings are mixed use because they contain spaces used for different purposes as defined in the building codes.

Business (Group E)

The business use group includes all office buildings, but this can range from a construction office in a trailer temporarily located on a construction site to a high-rise office building like the World Trade Center. Business occupancies are characterized by an average occupant load, occupants who are generally physically fit and do not sleep in the space. Combustibles are average in quantity and include higher quality furniture and paper.

Assembly (Group F)

The assembly use group includes any place used for the gathering of more than 50 people for civic, social, or religious functions, recreation, food and drink, or awaiting transportation. Assembly use is characterized by the highest occupant loads, which may include families with small children and older adults. Combustibles are light in quantity and vary in character depending on specific use.

9.1.5 Egress Systems

The 1968 NYC Building Code contains requirements for the number and capacity of stairs and for the assumed occupant load that are similar to requirements in the other contemporaneous codes (see Appendix A). Codes of the time required that multiple stairs be located "as remote from each other as practicable." New York City permits scissor stairs,[46] and the code requires the exit doors to be at least 15 ft apart. Local Law 16 (1984) first imposed a remoteness requirement of 30 ft or one-third the maximum travel distance of the floor (whichever is greater), which was not retroactive, so it did not apply to WTC 1 and WTC 2 but did apply to WTC 7.

The 1968 NYC Building Code also contains a requirement that, " …vertical exits should extend in a continuous enclosure to discharge directly to an exterior space or at a yard, court, exit passageway or street floor lobby …" (C26-602.4). Similar requirements are found in the 1965 BOCA Basic Building Code and in 1966 NFPA 101, but not in the 1964 New York State Building Construction Code or the 1966 Municipal Code of Chicago. Current code language (2003 IBC, section 1003.6) defines continuous as: not " … interrupted by any building element other than a means of egress component."

The requirement for exit stairs to discharge to a public way was the subject of ongoing discussion with respect to the A and C stairs in WTC 1 and WTC 2 terminating at the mezzanine level, which was not at street level but rather at the Plaza level. The Port Authority's position was that the Plaza was a street and the Concourse was an underground street, and that the arrangement met the intent of the Code. NIST found PANYNJ documents indicating that the NYC Department of Buildings agreed with this

[46] Scissor stairs refers to two separate interior stairways contained within the same enclosure and separated by a fire rated partition.

interpretation (e.g., Solomon 1975), but did not find any documents from the NYC Department of Buildings confirming this. Thus, the issue continued to come up as a deviation with the Code as late as 1996 (see Section 11.4).

9.2 SUMMARY OF DIFFERENCES BETWEEN CODES

In Construction Classifications, NYC Building Code 1968, NYS Building Code 1964 and BOCA/BBC 1965 all recognized Class 1A or Class 1B (with the same fire resistance ratings for building elements) for most unsprinklered buildings of unlimited height while MCC 1967 recognized only Class 1A. New York City imposed a 75 ft height limit on unsprinklered buildings with the adoption of LL 16 (1984).

At the time of construction, sprinklers were primarily for property protection and were rare even in high-rise buildings (except for underground spaces). Fire alarm systems were mostly manually initiated, but there was a concern about smoke being recirculated through the heating, ventilating, and air conditioning (HVAC) systems, so smoke detectors controlled dampers at return shafts to prevent this. This is the arrangement of the fire alarms system originally installed in the towers. Voice communication systems were a response to phased evacuation with the recognition that it was necessary to provide instructions to occupants who were relocated or held within the building at least until they were told to leave. Requirements for voice systems first appeared in national standards in the mid-1980s (e.g., the 1985 edition of NFPA 72F), at the same time as New York City adopted LL 16-1984.

All building codes rely on referenced technical standards to provide the details of design, installation, operation, and maintenance of required systems. Most building codes reference national (consensus) standards as published, but New York City cites its own Reference Standards that are based on the national standards but are often highly modified. For example, fire alarm systems and fire sprinkler systems are addressed in RS 17, with Class E fire alarm systems (required in office occupancies) covered in RS 17-3A and general fire alarm system requirements in RS 17-5. The former is written entirely by a NYC code committee, and the latter is based on NFPA 72 (National Fire Alarm Code), but highly modified by the deletion of many sections and modification of many others. One major modification is the fact that RS 17 does not incorporate the NFPA 72 "Survivability" section for high-rise voice communication systems, which requires duplicate communication trunks so that loss on one trunk does not result in loss of communication with a floor. However the Port Authority explicitly applied these survivability requirements from NFPA 72 in the specification of the voice communication systems installed in the towers following the 1993 bombing, as evidenced by the specification of Style R communication trunks routed in duplicate in stairways A and C, with interleaved speaker wiring.

Prior to 1988 all building codes determined egress capacity by the (22 in.) Units of Exit Width method, which New York City still uses. In 1988, other codes changed to a method involving an allowance of width per person which provides credit for non-standard widths of corridors and doors, but for standard dimensioned components yields the same results. Another difference in egress design is that New York City applies the occupant load factor for business occupancies (100 ft^2 per person) to the net floor area while other codes use the gross floor area. The NYC Building Code allows doubling the allowable stair capacity with the provision of one horizontal exit or tripling of the stair capacity on floors with two or more horizontal exits, where all the other codes only allow doubling for one horizontal exit. For a discussion of how this impacted WTC 1, see Sec. 10.1.1, Egress Provisions from Windows on the World.

There are a number of detail differences between NYC Building Code and the other building codes. The NYC Building Code has no requirements for fire extinguishers since they require occupant hose reels. The NYC Building Code in 1968 was the first code to include smoke developed ratings for finish materials in addition to flame spread. Now all of the codes have similar requirements. Most of these differences can be traced to the specific wording and citations by referring to the reports, NIST NCSTAR 1-E, 1-F, and 1-G.

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Chapter 10
INFLUENCE OF CODES AND STANDARDS ON THE DESIGN AND CONSTRUCTION OF WTC 1 AND WTC 2

10.1 EGRESS SYSTEM DESIGN

One of the largest impacts to the design of World Trade Center (WTC) 1 and WTC 2 resulting from the decision to follow the 1968 New York City (NYC) Building Code rather than the 1938 Code was the impact on the emergency egress system. The other large impact was the use of the 1-B Construction Class introduced in the 1968 Code rather than the 1-A Class that would have been required under the 1938 Code, in Sec. 9.1.3, see "Selection of Construction Type." In 1963, the Port Authority of New York and New Jersey (PANYNJ or Port Authority) instructed the designers of the WTC to follow the then current 1938 NYC Building Code. During this time, the code was in the process of being revised, and in 1965, the Port Authority directed its designers to adopt the draft version of the new code for their final designs. Some of the advantages of the new draft code were noted to be the following (Levy 1965):

- Fire towers[47] could be eliminated;
- Provisions for exit stairs were more "lenient;" and
- Criteria for partition weights were more "realistic."

It was not certain whether all the changes being proposed to the 1938 code would be incorporated into the final version of the new code. Thus in 1966, the Chief Engineer of the Port Authority suggested that the "architect/engineers prepare a listing of the elements of the design which do not conform to old code requirements, but are acceptable under the new. With this list in hand, we could initiate discussions, at top level in the Building Department, to see if we can secure agreement to go along with our design (Kyle 1966)."

A one-page document,[48] dated "2/15/67", with the initials "CKP" listed the following items:

1. Fire tower corridors [sic] eliminated.
2. Number of stairs reduced from 6 to 3. (Old plans had 5 stairs at 3'-8" and 1 stair at 4'-8" for a total population of 390. New plans have 2 stairs at 3'-8" and 1 stair at 4'-8" allowing a population of 390.)
3. The size of doors leading to the stairs are [sic] changed from 3'-8" to 3'-0".

[47] A "fire tower" is a stair tower enclosed within a 4 h fire rated shaft that is entered through a naturally ventilated vestibule. The 1938 Code stipulated that one of the required exits in most buildings over 75 ft in height be a fire tower.

[48] "Changes to Building to Conform to New York City Building Code," dated 2/15/67.

4. All stairs exit through a lobby. Old plans had fire tower stair exiting through a fire enclosed corridor.

5. Shaft walls are changed from a 3-hour rating to a 2-hour rating.

6. Corridors are limited to a 100' dead end and with a 2-hour rating.

7. Additional [word(s) missing] changed from 20 pounds per square foot to 6 pounds per square foot (based on partition weight of 50 pounds to 100 pounds per linear foot).

Apparently, this list represents elements of the WTC design that would not have satisfied the 1938 code, but did satisfy the then-current draft version of the new code.

Thus, the provision of three egress stairs located within the core exactly provided the 6½ units of required capacity for the occupant load in the office spaces. By locating the stairs at the edges of the core it, could be argued that they were as far apart as practical, but on some floors the provision of transfer corridors to go around equipment and to recover tenant space from the termination of local elevator shafts brought the stairs quite close with far less than the one third the maximum travel distance of the floor requirement of the 1968 NYC Building Code. The proximity of the stairs on some floors also resulted in standpipe spacings that exceeded the maximum 140 ft distance from any point on a floor in the 1968 NYC Building Code, since the standpipes were located in the stairways.

10.1.1 Egress Provisions from Windows on the World

The 106th and 107th floors of WTC 1 contained the *Windows on the World* complex, consisting of the *Windows on the World* restaurant, the *Greatest Bar on Earth*, numerous banquet and function rooms, kitchens and support areas, and offices from which the operation was run. While the configuration of the space may have changed over the life of the building these functions were all present from the time the building was first occupied.

Restaurants, bars, and function rooms are classified in building codes as assembly use, which carries a significant increase in occupant load and consequent provisions for egress. The design occupant load for assembly space is 15 ft^2 per occupant as opposed to the 100 ft^2 per occupant for the office use on most of the floors. Thus, while the design number of occupants on an office floor was 390, the design number of occupants for these floors was over 1,000 each (the exact number depends on the area of kitchens, dishwashing, and office space on the floor, all of which is at 100 ft^2 per occupant).

Locating assembly space high in a building poses particular challenges to egress design since the capacity of an egress component is not permitted to be decreased in the direction of travel. Thus where more or wider stairs are provided to meet capacity requirements these must be continued all the way down through the building with the associated impacts on space utilization.

Since Windows on the World first opened in April 1976 (Bhol 2005), it is unclear what conditions existed from that date to the time the agreed solution was implemented in 1995. The dates suggest that the need to provide for egress by the large occupant load of these floors was identified as a result of the Memorandum of Understandings between the Port Authority and the NYC Department of Buildings and FDNY executed in 1993 following the bombing. The Windows on the World facilities were closed

following the bombing and reopened in 1996 after a complete refurbishment that included the egress system changes (Bhol 2005).

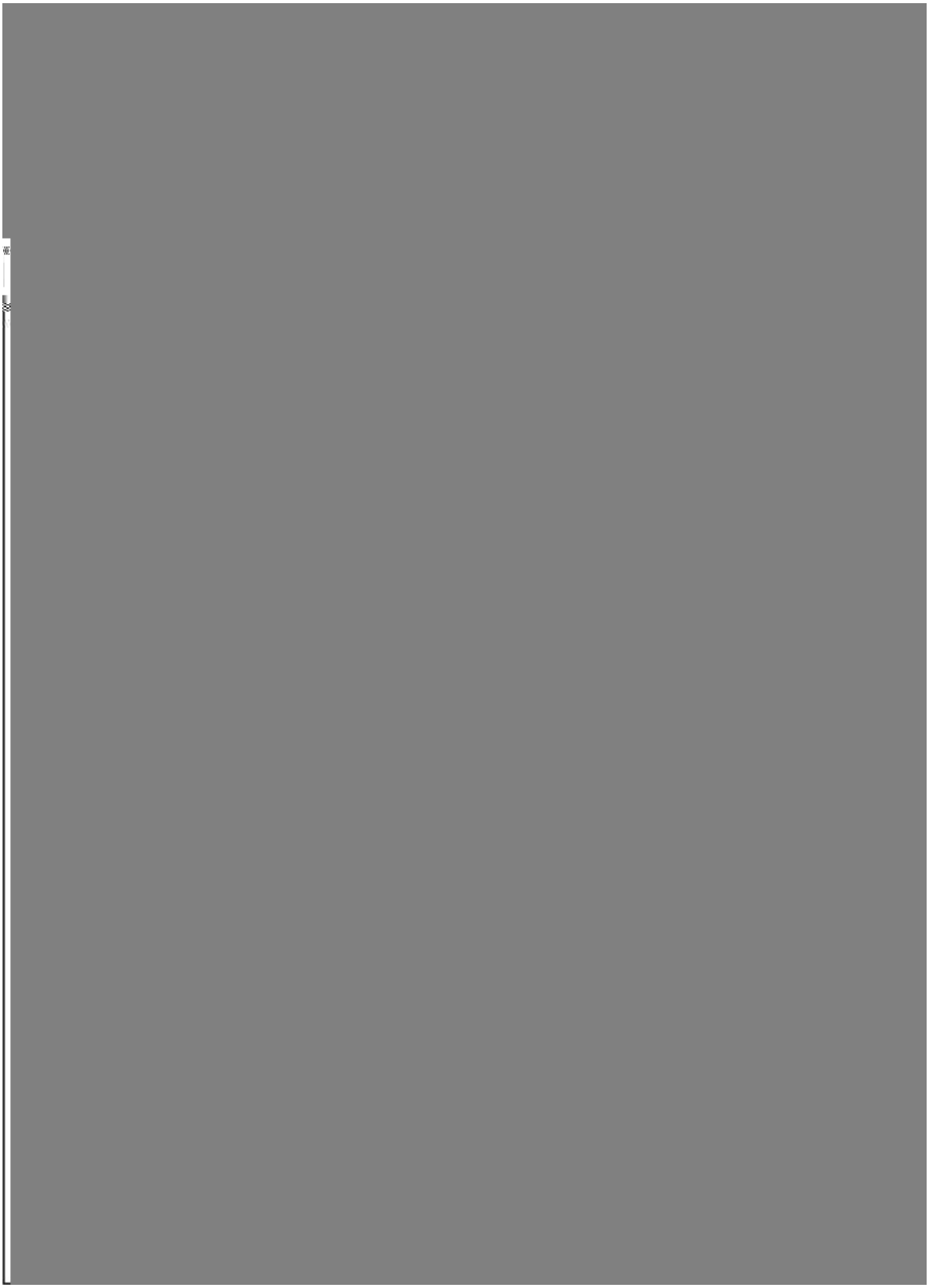
A letter dated January 27, 1995, from the PANYNJ to the Deputy Commissioner of the NYC Department of Buildings documents the confirmation of a meeting on December 6, 1994, at which they reached agreement on a plan to address egress requirements from the 106th and 107th floors (Fasullo 1995). The details of the agreed solution are summarized below. The Deputy Commissioner of the NYC Department of Buildings signed the letter to show concurrence with the agreed solution, as verification of meeting code requirements.

The basis for the agreed solution was to divide each floor into three areas of refuge in accordance with Section 27-372 of the (then current) NYC Building Code to provide additional capacity to the existing stairs in accordance with Section 27-367 of the (then current) NYC Building Code. Identical provisions were included in the version of the 1968 NYC Building Code in effect when the buildings were built as sections C26-604.5 and C26-603.3 respectively (the NYC Building Code was renumbered as the result of changes in New York State Laws, effective September 1, 1986).

The code provisions cited above allow for a doubling of allowed stair capacity when one area of refuge is provided on a floor and tripling the stair capacity for two or more areas of refuge on a floor. These areas of refuge must be separated by 2 h construction, be large enough for the expected occupant load at 3 ft^2 per occupant, each contain at least one stair, and have access to at least one elevator (above the 11th floor). Since three distinct areas of refuge were provided on each floor, the tripling of the capacity of the three stairs resulted in a maximum permitted occupant load of 1,170 people per floor.

Attached to (and referenced in) the letter were two plans entitled “106th Floor Egress Plan” and “107th Floor Egress Plan” that detailed the arrangement. The 2 h separation walls snaked across the floors and were not aligned on the two floors. Some areas that needed to remain open to free passage were protected with so-called Won-doors (accordion doors that are fire rated and are closed automatically on activation of the fire alarm system). Details of the egress system design calculations and corresponding NYC Building Code requirements are included on the plans to demonstrate that they met code requirements. Figures 10–1 and 10–2 are the actual attachments to the letter which included both diagrams of the arrangement of the rated partitions and the calculation of occupant loads for the 106th and 107th floors, respectively. Important details of the calculations have been enlarged by NIST.

By comparison to the (current) model building codes, the International Building Code and NFPA 5000, permit a doubling (but not tripling except in IBC Type I-2 and I-3 institutional uses) of the stair capacity for the provision of a horizontal exit on a floor. The horizontal exit must consist of a 2 h fire rated separation, contain at least one stair on each side, and have sufficient space for the expected occupant load at 3 ft^2 per person. A horizontal exit must be continuous down through the building to grade (NFPA 11.2.4.3.1 and IBC 1021.2), unless the floor assemblies are at least 2 h with no unprotected openings.



Source: Reproduced with permission of The Port Authority of New York and New Jersey. Enhancement by NIST.

Figure 10–1. Arrangement of floor 106 egress.

Source: Reproduced with permission of The Port Authority of New York and New Jersey. Enhancement by NIST.

Figure 10–2. Arrangement of floor 107 egress.

The concept of using horizontal exits to create areas of refuge was to provide a protected space in which occupants could wait to get into stairs that do not have adequate capacity for the numbers of people. In the world of post-September 11, 2001, it is unclear whether people will be comfortable waiting in a large queue to enter an egress stair, and what the impact would be of such a large group of people moving down the stairs on the orderly evacuation of lower floors. The decedent analysis in NIST NCSTAR 1-7 estimates the number of people in Windows on the World at 188. The early hour of the attacks saw much fewer patrons (such as the early arrivals for a breakfast meeting) that would have been expected later in the day. The occupant load would have permitted more than 2,000 people on these two floors, from which there were no survivors.

10.1.2 Egress Provisions from Top of the World

Similar to the Windows on the World facilities on the 106th and 107th floors of WTC 1, there was a public observation deck on the 107th floor of WTC 2 called Top of the World. The observation deck was open to the public daily and was accessed by a dedicated, express elevator from the Concourse level after paying an entrance fee. The facilities included several shops, food vendor, a small theater showing a 6 min film of a helicopter tour of New York City, exhibits depicting life in the city, and a perimeter viewing area with telescopes and information on major landmarks visible along each face of the building. Visitors could also ascend two escalators to an open, roof-top deck which was raised to provide unobstructed views.

Observation decks are Assembly Use spaces (Group F in the NYC Building Code) like restaurants and meeting spaces. Thus, the occupant load/egress capacity issues identified for Windows on the World also existed for Top of the World. That is, the occupant load for the observation deck was calculated as the net floor area times a load factor of 10 ft^2 per person. This clearly far exceeded the 390 people total capacity for the three stairways. Since NIST did not find any documentation of the arrangement of the space prior to 1995, it is unclear whether this deficiency existed from the original opening of the building until it was addressed in 1996.

NIST has correspondence between Andrew Renter (STV/Silver & Ziskind, an Architectural/Engineering Design firm) and Victor Weisberg (Ogden Series Corporation, the tenant and operator of the facility) dated February 5, 1996, and referencing comments received from Port Authority on January 19, 1996. This letter and the drawings referenced in it (which are also in NIST's possession) detail a proposed space arrangement that parallels the solution applied to Windows on the World the year before. The letter and drawings are part of a Tenant Alteration submittal to Port Authority that was approved on January 5, 1996. STV proposes dividing the floor into three areas of refuge, each containing an existing stairway, by 2 h fire rated partitions. The drawings show the existing space arrangement of the floor and calculates the occupant load for each using the load factors specified in the NYC Building Code. Their calculations reveal that the occupant load of the 107th floor was 1,751, which before the subdivision of the space into three areas of refuge, was 4½ times the maximum number of occupants permitted under the NYC Building Code.

After the proposed subdivision, the floor had an area of refuge of 5,610 ft^2 net (incorporating Stairway A) with an occupant load of 935 people, a second area of 2,430 net ft^2 (incorporating Stairway B) with an occupant load of 343 people, and a third area of 2,940 net ft^2 (incorporating Stairway C) with an occupant load of 473 people. STV observed that the occupant load of the perimeter gallery alone is 1,267 people,

which exceeds the stairway capacity of 1,170 after subdivision. Under Sec. 27-367 of NYC Building Code, the stair capacities are tripled with the provision of three areas of refuge, taking the capacities to 360 (Stairways A and C) and 450 (Stairway B) for a total of 1,170 people. Thus, even after the subdivision, only the area incorporating Stairway B had an occupant load less than the maximum capacity of the stair, and one area had an occupant load more than 2½ times the stair capacity.

These load calculations do not include the occupant load of the roof-top deck. Since these occupants were required to return to the 107th floor to exit the facility, this load also needed to be accommodated by the stairways and the refuge space provided on that floor. This fact is simply not addressed. As to the fact that the proposed solution still does not provide sufficient egress capacity for the occupant load under the NYC Building Code, STV's position appears to be that this is an existing condition and the solution (in their opinion) meets the intent of the Code, even though the problem existed from the time the building first opened against the 1968 NYC Building Code. Taking advantage of a New York City building code provision which permits a lower basis for occupant load, the PANYNJ permitted a maximum occupant load of 1,170 on the floor, which was enforced by the lessee of the space with periodic oversight by the PANYNJ.

NIST inquired of PANYNJ whether there was any means to limit the number of visitors to the observation deck. The following response was received:[49]

> For controlling the number of occupants on the observation level in WTC 2, there were turnstiles on the mezzanine before the entrance to the elevators that were used to count the number of people going up, but since the patrons exited via a different route & location, there was no way to count the number of people leaving - and thereby calculate the number actually on the deck. Since the turnstiles were not very effective, their use was discontinued later and the number of ticket sales was used for controlling the number of occupants. The length of the line waiting for the elevators to take people down were constantly observed by staff. If the crowds grew too large, ticket sales were halted until the crowd size was reduced.

Fewer than ten people who were present on the observation level perished on September 11th. The number of people who were present and managed to evacuate is unknown.

10.2 REQUIREMENTS FOR A FOURTH STAIRWAY

The 107th floor of WTC 1 contained, since it first opened in 1976, a public restaurant known as Windows on the World. At the time of the attacks this facility also included a conference center and associated catering operations on floor 106 and parts of 107 not occupied by the restaurant and the Greatest Bar in the World. Similarly, the 107th floor of WTC 2 contained a public observation deck that opened with the building. The architectural design of these floors reflected the needs of the use as the window openings were much wider on these floors than the openings found on the office floors below. Prior to 1993, the 106th and 107th floors appear to have been operated with occupant access to three stairwells (two at 44 in. and one at 56 in.) and no fire-rated barriers meeting the building code requirements for areas of refuge.

[49] Email from Saroj Bhol, PANYNJ, to Shyam Sunder, NIST, dated March 15, 2005.

However, NIST does not have records of the arrangement of these floors prior to the 1994 agreement that created the areas of refuge discussed below.

After the 1993 bombing, a review of the life safety of the towers by the New York City Department of Buildings and PANYNJ led to a redesign of the 106th and 107th floor egress design. Taking advantage of the capacity tripling allowance in NYCBC §27-367, each floor was divided into three distinct areas, each separated from the others by two-hour fire rated walls, each containing one stairwell and at least one elevator, and each providing access to the other two areas with sufficient floor area to hold occupants from the other areas. Memos between the NYC DoB and PANYNJ in 1993 indicate that both parties found the arrangement met the intent of the building code requirements. In a 2005 interrogatory, PANYNJ indicated that the number of stairwells serving the 106th and 107th floors in WTC 1 was not discussed. Further, the due diligence study (1997) regarding life safety at WTC 1 and WTC 2 did not mention the exit capacity from Windows on the World nor Top of the World.

Drawings summarizing the egress calculations for WTC 1 floors 106 and 107 indicate a design occupant load of over 1,000 persons on each floor. The 1968 and current version of the NYCBC (and all national model codes) require four exits from areas with an occupant load of over 1,000 persons. In response to a NIST question regarding this issue, a 2005 communication from PANYNJ regarding the minimum number of required stairwells for these floors stated that:

> "Based on PA's meeting on exits from the Windows on the World with the DOB on December 6, 1994, it's PA's understanding that '20% of the floor area' in section 27-367 is intended to be the total floor area in the building occupied by the principal use."

The 2005 PANYJ interpretation refers to an allowance for reducing the design capacity (by between 50% and 67%) using the area of refuge arrangement referred to previously, if the public assembly space (in this case the entirety of floors 106 and 107) constituted less than 20% of the floor area occupied by the principal use. The key phrase in the interpretation of the building code language is related to the definition of principal use. The PANYNJ, according to the 2005 communication, defined the area of principal use as the entirety of WTC 1, thereby allowing the capacity reduction as the two floors in question would be less than 20% of the total floor area of the entire building.

In 2005, NIST asked for a clarification of §27-367 from the NYC DoB regarding the definition of principal use and the applicability of the capacity reduction clause. The NYC DoB response contradicted the interpretation of PANYNJ:

> "The idea behind the 20% allowance is the fact that the PA [NIST note – PA refers to Public Assembly] space is used by the same tenant employees who are very familiar with the building and regularly participate in the fire drills. If we are talking about a roof top restaurant or an observation deck that is opened for the general public and tourists, the concept of exit reduction shall not be allowed."

In other words, the intent of the 20% clause is to exempt eating areas, conference rooms, or other assembly spaces which serve only occupants who would come from other places in the building. Thus, the space would not result in a net increase to the total building population. Restaurants open to the public and observation decks open to the public would not be eligible for exit reduction.

Based upon current interpretation of Section 27 of the NYCBC, four exits would have been required for floors 106 and 107 in WTC 1 and 107 in WTC 2. Since all the codes (including BCNYC) require that the number of exits may not decrease in the direction of egress travel, all occupied above-grade floors in WTC 1 and WTC 2 should have been served by four stairwells.

10.3 ELEVATORS

Local Law (LL) 5 (1973) required that elevators be provided with an emergency recall system. This requirement was incorporated subsequently into the American Society of Mechanical Engineers (ASME) A17.1, Safety Code for Elevators and Escalators, that governs elevator design and operation in all building codes. The ASME Code requires that:

- All passenger elevators be marked with signs stating that they cannot be used during a fire;
- Fire detectors installed in every elevator lobby and machine room be arranged to initiate a recall of the elevators to the ground floor where the doors open and the elevator is taken out of service; and
- Fire service personnel can use a special key to operate any individual car in a manual mode as long as they feel it is safe to do so.

The elevator and building codes require that at least one elevator serving every floor be connected to emergency power. Currently, there are no U.S. building codes that permit elevators to be used as a means of occupant egress in emergencies, and ASME A17.1 (ASME 2000) requires signs at all elevators warning that they shall not be used in fires. There are some recent exceptions to this general rule, but these are limited to special cases. For example, NFPA 5000 permits protected elevators as a secondary means of egress for air traffic control towers, and the City of Las Vegas accepted elevators as a primary means of occupant egress from Stratosphere Tower based on a performance-based design (Bukowski 2003).

The United States' building codes (including New York City) require *accessible elevators* as part of a means of egress that may be used by the fire service to evacuate people with disabilities. These elevators must comply with the emergency operation requirements of ASME A17.1 (Phase II emergency operation by the fire service), be provided with emergency power, be accessible from an area of refuge or a horizontal exit (unless the building is fully sprinklered), and operate in a smoke protected hoistway. Phase II operation involves the use of an elevator by a firefighter for fire service access or for rescue of people with disabilities performed under manual control (with the use of a special key).

10.4 ACTIVE FIRE PROTECTION SYSTEMS

10.4.1 Fire Alarm Systems

At the time of design and construction of the WTC towers, most building codes did not require a fire alarm or required only a manual fire alarm system in buildings where occupants do not sleep. Also, concerns about smoke recirculation through heating, ventilating, and air conditioning (HVAC) systems resulted in codes being amended to require smoke detectors positioned at return air grilles to stop fans and prevent such recirculation.

In the 1970s (shortly after the adoption of LL 5/73), discussions of phased evacuation of tall buildings led to the concept of high-rise emergency voice communications systems and fire command centers from which incident commanders would manage fire incidents. The NFPA Committee on Protective Signaling Systems developed a guide (later made a standard), NFPA 72F, for such systems that paralleled LL 5/73 requirements (see NIST NCSTAR 1-1G for a complete discussion of the requirements of LL 5/73).

10.4.2 Fire Sprinklers

Neither the 1968 NYC Building Code nor any of the other contemporaneous codes that were examined required sprinklers in tall buildings except for underground spaces. Thus, only the parking garage under WTC 1 and WTC 2 was originally sprinklered. Although Local Law 16, adopted in 1984, required sprinklers in new office occupancies, it was not retroactive. The incentive to retrofit for sprinklers (as explained below) was the passage of Local Law 5 in 1973, which was retroactive.

In the 1968 NYC Building Code, Class 1B construction for business occupancies had no limit on floor area. Local Law 5 required compartmentation of large floor areas in existing business occupancies over 100 ft in height by the installation of fire rated partitions in accordance with the following:

- Compartmentation to 7,500 ft^2 with 1 h partitions; or
- Compartmentation to 10,000 ft^2 with 2 h partitions; or
- Compartmentation to 15,000 ft^2 with 2 h partitions and smoke detectors.

Compartmentation was not required, however, if "complete sprinkler protection" was provided. Compliance dates for these provisions were revised in 1979 by Local Law 84, so that one-third of the total area of buildings had to be in compliance by December 13, 1981, two-third of the total area had to comply by August 7, 1984, and full compliance was required by February 7, 1988.

Following the February 13, 1975, fire in the lower stories of WTC 1 (Powers 1975), an independent consultant was retained to review WTC life-safety provisions, including response to Local Law 5. It is reported that the "consultant concluded that the existing structural fire retardants of the building are sufficient to make the probability of serious structural damage extremely remote and the degree of vertical compartmentation provided sufficiently limits the spread of fire in the structures but that the spread of smoke requires attention from a life safety standpoint (PONYA 1976)." The consultant reported that "…either of the two fire protection options provided for under Local Law 5 would provide a good level of occupant life safety within the World Trade Center complex, provided that whichever is selected is supplemented by certain additional measures." The consultant provided a series of recommendations to supplement either the compartmentation option or the sprinklering option.

The Port Authority initially decided to adopt the compartmentation option in response to Local Law 5. The summary of the January 1976 report on the *Fire Safety of the World Trade Center* lists the following actions to be implemented to enhance the fire safety of the WTC towers (PONYA 1976):

1. The openings between floors of telephone closets, which was a source of fire spread during the February 13, 1975, fire should be

> closed. This work has been accomplished to prevent any reoccurrences of a similar condition.
>
> 2. In addition, the Port Authority will proceed with the compartmentation option of Local Law 5, including all of its requirements for fire alarm, communications, and stairway pressurization.
>
> 3. Sprinklering of all storage rooms, janitor closets, mail rooms and file rooms in the central core of each floor.
>
> 4. Building additional sprinkler capacity and provisions for extension of a sprinkler system to any area of such usage requiring it in the event of an occupancy change.
>
> 5. Equipping those doors which are normally kept open to the corridor system, such as doors at consumer service areas, with electromagnetic 'hold open' devices which would be activated by smoke detectors to close the doors.
>
> 6. Providing fail-safe automatic door closers, arranged to close upon activation by smoke detectors, for the overhead rolling fire doors separating the below-grade truck dock from the elevator lobby.
>
> 7. Developing an optimum mode of operation of the building air-conditioning system to remove smoke from the central core compartments without contaminating adjacent areas.

Thus, while the Port Authority initially chose to implement the compartmentation option, it also chose to provide "for extension of sprinkler system to any area of such usage requiring it." According to the 1993 joint report written by the NYC Fire Commissioner and Commissioner of Buildings, in the 1980s the Port Authority began "a program to fully sprinkler the tower buildings (Rivera and Rinaldi 1993)." The report goes on to state that by March 1993 sprinklering was " nearly complete in tower 2 and 85 percent complete in tower 1." The report also included a table that summarized "the major system requirements of Local Laws 5/73 and 16/84 with conditions in place when the 1993 explosion occurred."

The tenant alteration guidelines issued in 1998, contained the following requirement and information (PANYNJ 1998):

> All tenant spaces shall be sprinklered. Except for a few areas, most tenant floors in The World Trade Center are provided with wet-pipe sprinkler systems. New tenants normally require a new sprinkler system. For renovations of existing spaces, modifications to the existing system are normally needed to comply with any new partition configuration.

Because Local Law 16 required that business occupancies taller than 100 ft be sprinklered, WTC 7 was sprinklered during the original construction.

Section 6 of Local Law 5 adopted by New York City in 1973, required the subdivision of unsprinklered space in new office occupancies and in existing offices over 100 ft in height by fire rated partitions.

Local Law 5 was challenged in the courts and was eventually upheld, although the original compliance dates were amended by Local Law 86 (1979) so that full compliance was required by February 7, 1988.

10.4.3 Smoke Management

New York City has historically had fewer requirements for active smoke control than many other codes and has required passive techniques such as venting of shafts and openable skylights in stairways in the local laws amending the NYC Building Code. For high-rise buildings there is a requirement for a smoke purge system to be used manually by the fire department to remove smoke after the fire is extinguished and for the ability to pressurize corridors with 100 percent fresh air (NYC Building Code Sec. 504.15(c)). Pressurized stairways are not required in sprinklered buildings. These features of WTC 1 and WTC 2 were confirmed in a March 1993 joint report from the fire and buildings departments on compliance with LL 5/73 and LL 16/84 (Rivera and Rinaldi 1993). For details of the smoke management systems see NIST NCSTAR 1-4D.

10.5 DESIGN AND CONSTRUCTION OF FIRE SAFETY AND EGRESS SYSTEMS

10.5.1 Construction Classification

No contemporaneous documentation has been found that provides the rationale for the decision to select Class 1B for the WTC towers. This decision, however, appears to have been made by the architect-of-record on the basis of economics. In a 1987 memorandum on the subject of fire rating of the WTC buildings, the following statement was included (Feld 1987):

> For office buildings there is no [underline is in the original document] economic advantage in using Class 1A Construction, and ER&S [Emery Roth & Sons] used Class 1B Construction for the WTC Towers and Plaza Buildings which are Occupancy Group "E" (Business) with a fire index of 2 hours.

An interoffice memorandum between staff of the general contractor written in 1969 is the only contemporaneous document found to date that refers to the classification of the WTC towers (Bracco 1969). The following statement is included in that memorandum:

> The WTC towers would be classified, by our interpretation of the code, as occupancy Group E, Business; Construction Group 1, Non-combustible; and Construction Classification 1-B (since there are no area or height limitations applicable).

10.5.2 Occupancy Group

As stated above, the primary occupancy group was Group E (Business) with the Windows on the World space in WTC 1 being Group F (Assembly). While there was a Port Authority cafeteria on the 44th floor, employee cafeterias not open to the public are specifically exempted from assembly classification because they do not increase occupant load and are only used intermittently. Incidental mercantile spaces such as

news stands and coffee bars at the concourse level are also exempt from reclassification in most building codes.

10.5.3 Compartmentation of WTC 1 and WTC 2

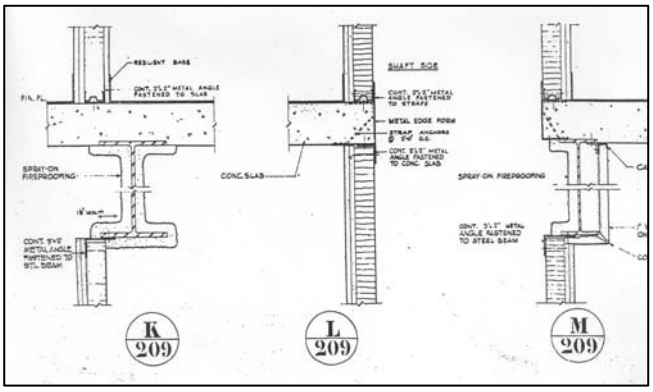
Due to their innovative structural design, WTC 1 and WTC 2 featured large, open office spaces devoid of columns. Tenants could (and often did) utilize open plan office layouts that allowed impressive views of the Manhattan skyline from the perimeter windows.

The NYC Building Code and Port Authority practice required partitions to separate tenant spaces from each other and from common spaces, such as the corridors that served the elevators, stairs and other common spaces in the building core. Fire rated partitions are intended to limit fire spread on a floor and to prevent spread of fire in one tenant space to another. Partitions separating tenant space from exit access corridors were permitted to be 1 h, although the PANYNJ specified them to be 2 h, allowing dead ends to extend to 100 ft (rather than 50 ft with 1 h partitions), which allowed more flexibility in tenant layouts. Partitions separating tenant spaces (so-called demising walls) were required to be 1 h (see Sec. 9.2.5). Enclosures for vertical shafts, including stairways and transfer corridors, elevator hoistways, and mechanical or utility shafts were required to be of 2 h fire rated construction. Protection of vertical shafts was intended to limit the spread of fire and smoke from floor to floor.

Another influence on compartmentation of the buildings was the adoption of Local Law 5 (1973) amending the NYC Building Code. While it did not legally apply to the buildings, PANYNJ policy was to follow the NYC Building Code requirements voluntarily. Local Law 5 (1973) required compartmentation of unsprinklered spaces in existing office buildings over 100 ft in height "having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located," to be subdivided by 1 h fire separations into spaces or compartments not to exceed 7,500 ft^2. Floor areas could be increased up to 15,000 ft^2 if protected by 2 h fire resistive construction and smoke detectors. Regardless of the floor area, compartmentation is not required when complete sprinkler protection is provided (LL 5, Section 6)

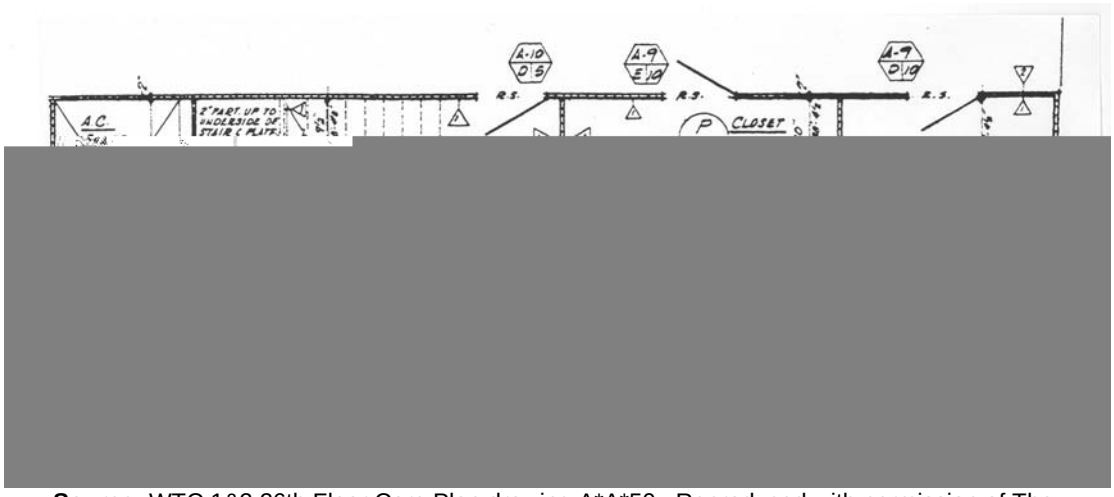
Shortly after the adoption of LL 5 (1973), the PANYNJ began to add the required compartmentation as a part of new tenant layouts as evidenced by several tenant alteration contracts at this time. Following the 1975 fire, a fire safety consultant report recommended to the PANYNJ that the buildings be retrofit with sprinklers to address possible smoke problems, and the PANYNJ realized that this would also obviate the need for compartmentation and permit the unobstructed views for which the buildings were known. The decision to sprinkler left the arrangement again with the only required partitions being those separating tenant spaces from each other and from exit access corridors or common spaces in the core, and with shaft enclosures.

A large number of detail drawings were provided for attaching the planks to various ceiling constructions (A*A* 209 through A*A*212, see Fig. 10–5). Finish layers were either one or two layers of ½ in. gypsum board (moisture resistant was specified in some locations). Two layers on one side were specified in locations where the other side was a shaft or other unoccupied space, and two layers on one side with a single layer on the other was specified where both sides were in occupied spaces. The required number of layers was indicated on construction drawings (e.g., A*A*20, A*A* 50) by the numbers 1 or 2 in triangles (see Fig. 10–6).



Source: WTC 1&2 drawing A*A*209. Reproduced with permission from The Port Authority of New York and New Jersey.

Figure 10–5. Typical finish details.



Source: WTC 1&2 26th Floor Core Plan drawing A*A*50. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 10–6. Stairway detail at 26th floor.

The 1978 edition of the Gypsum Association (GA) Fire Resistance Design Manual lists several, similar shaft wall constructions utilizing 2 in. gypsum layers consisting of two 1 in. gypsum core board panels with "metal channels on long edges." The GA Manual lists shaft walls of a single 2 in. metal edged plank (WP7015) having a 1 h fire rating, a single 2 in. metal edged plank with one layer of Type X gypsum board on the unexposed side (WP7112) having a 2 h fire rating, and a single 2 in. metal edged plank with two layers of Type X gypsum board on the unexposed side (WP 7575) having a 3 h fire rating.

Partitions separating tenant spaces from other tenant spaces on the same floor were constructed of two layers of 5/8 in. Type X gypsum board on each side of steel studs, and ran slab to slab. This construction is commonly recognized as a 2 h fire separation. Above the ceiling, penetrations for ducts or to allow for return airflow were fitted with rated fire dampers to preserve the fire rating. This construction was not used in the original design but was specified later by the PANYNJ as tenant spaces were altered.

Interior partitions not separating spaces occupied by different tenants were constructed of single or double layers of 5/8 in. Type X gypsum board on each side of steel studs and ran from the slab to the suspended ceiling but not above. Double layers of gypsum board were used when the tenant desired additional sound attenuation. These partitions were not required to be fire rated and did not utilize fire rated doors. However, a single layer of 5/8 in. Type X gypsum board on each side of steel studs (16 in. on center) is generally considered to have a 1 h fire rating, and two layers of 5/8 in. Type X gypsum on each side of steel studs (16 in. on center) is considered to have a 2 h fire rating. For a ceiling high partition to be considered as having a fire rating, the ceiling itself would have to be rated as well. The ceiling system used throughout these buildings was not fire rated.

10.5.5 Tenant Separation Walls

Section C26-504.3(a) of the 1968 NYC Building Code required that tenant spaces be separated "by fire separations having at least the fire resistance rating prescribed in Table 5–1, but in no case less than 1 h, and shall continue through any concealed spaces of the floor or roof construction above." The Port Authority chose to stop tenant (demising) partitions (walls separating spaces occupied by different tenants) at the bottom of the suspended ceiling and use 10 ft strips of 1 h rated ceiling on either side of the partition (Solomon 1969). The general contractor stated in a letter to the Port Authority "…we have been unable to find any precedent for the fire rated ceiling 10' on either side of the demising partitions beyond the one you described from your construction experience on Port Authority hangers [sic] (Endler 1969)."

In a code compliance evaluation report written in 1997, it was stated "Tenant demising partitions, including separations from the public corridor, do not in all cases meet the requirement of being built to the slab above (Coty 1997)." The author of the report recommended that: "Generally, this condition has been and will continue to be remediated as a requirement of new tenant alterations. However, it is recommended that the Port Authority develop and implement a survey program to ensure that this remediation process occurs as quickly as possible."

The tenant alteration guidelines issued in 1998 required that tenant partitions have a 1 h fire rating, and the standard details for fire rated partitions indicated a continuous fire barrier from top of floor to bottom of slab (PANYNJ 1998). There were no requirements in the codes or in the PANYNJ guidelines for partitions wholly within tenant spaces.

10.5.6 Egress Systems

The primary egress system for the office spaces was the three stairways located in the building core. These included two 44 in. (designated A and C) and one 56 in. wide (designated B) stairs which provided exactly the code required capacity for an occupant load of 390 per floor (39,000 ft^2 net at 100 ft^2 per person). The layout within the building core was consistent with the building code requirements for maximum travel distance (200 ft unsprinklered, 300 ft sprinklered) and, while the separation was consistent with New York City requirements (15 ft and later 30 ft), it was short of the more common requirements found in all current building codes (one half the diagonal of the space served if unsprinklered, or one-third the diagonal if sprinklered) on some of the floors where the transfer corridors brought the stair access closer together.

The NYC Building Code uses the older "units of exit width" method for specifying exit capacity. Each 22 in. unit of exit width in an office stair provides the capacity for 60 people. Thus, each 44 in. stair provides for 120 people and the 56 in. stair provides 2½ units, or 150 people, for a total occupant load per floor of 390. Also, the PANYNJ made a design decision to use 2 h corridor walls to permit longer dead ends (100 ft rather than the 50 ft limit if the walls had been the minimum 1 h rating) to provide additional flexibility in tenant layouts. For a detailed description of the stairways, see NIST NCSTAR 1-7.

10.5.7 Elevators

There were 99 passenger elevators and 7 freight elevators in each tower, arranged in three vertical zones to move occupants in stages to skylobbies on the 44th and 78th floors. The elevators were arranged as express (generally larger cars that moved at higher speeds) and local elevators in an innovative system first introduced in WTC 1 and WTC 2. There were eight express elevators from the concourse to 44 and ten express elevators from the concourse to 78 as well as 24 local elevators per zone, which served groups of floors in those zones. There were seven freight elevators, only one of which served all floors. All elevators had been upgraded to incorporate firefighter emergency operation consistent with ASME A17.1 and Local Law 5 (1973). See also NIST NCSTAR 1-7.

10.5.8 Active Systems

Fire Alarm Systems

Consistent with practice at the time, the original fire alarm system in WTC 1 and WTC 2 was a manual system with four smoke detectors on each tenant floor, positioned to monitor smoke entering the HVAC returns and arranged to stop the fans and prevent smoke circulation to non-fire areas. Local Law 5 (1973) included retroactive requirements for fire alarm systems and emergency voice communication systems in business occupancies over 100 ft in height. Subsequently, such systems were installed in WTC 1 and WTC 2 with the required fire command center located in the underground parking garage where it was destroyed by the blast in the 1993 bombing rendering most fire safety features inoperable. Following the 1993 bombing, the fire command stations were relocated to the tower building lobbies with a third monitoring location in the Port Authority offices. The lobby location (within sight of the elevators) is specified in the NYC Building Code for fire command centers required in high-rise buildings. There are no code requirements for off-site monitoring of fire alarm systems in this occupancy. For a detailed description of the towers' fire alarm system on September 11, 2001, and prior systems back to the original, see NIST NCSTAR 1-4C.

Fire Sprinkler Systems

After the passage of Local Law 5, the Port Authority implemented a program to retrofit sprinklers and to offer tenants the option of sprinklering or compartmentation consistent with Local Law 5 provisions. Sprinklering of WTC 1 and WTC 2 was undertaken in three phases: Phase 1 was the sprinklering of below grade spaces completed with the original construction. Phase 2 was begun after Local Law 5 was adopted and included the installation of sprinkler risers and other infrastructure, and the installation of sprinklers in corridors, storage rooms, lobbies, and smaller tenant spaces for tenants not selecting the compartmentation option. Phase 3 involved sprinklering the remaining tenant spaces, initially as tenants changed, and later on negotiated schedules. This process was underway when, in 1984, Local Law 16

was adopted, which required sprinklers in high-rise buildings, including new offices and new or existing hotels. Following the settlement of legal challenges to LL 5 (1973), LL 84 (1979) changed the effective date for compliance with LL 5 (1973) to February 8, 1988. By the new date, high-rise office buildings had to either be subdivided in accordance with the compartmentation requirement or sprinklered. A 1997 report states that there were four floors and the skylobbies (all in WTC 1) left to be sprinklered, and that the installation of sprinklers at these floors was underway (Coty 1997). In an October 1999 report, it is stated that sprinklering of the tenant floors was completed and sprinklering of the skylobbies was "currently underway" (PANYNJ 1999).

The sprinkler system in the towers was a high-quality, state-of-the-art system with a few features following New York City practice that differed from practice in the rest of the country. An example of the quality is the decision by the PANYNJ to install separate risers rather than to use the existing standpipes as was permitted. An example of New York City practice is the use of manually operated fire pumps and a so-called "standpipe telephone system" to communicate with the pump operator. Most codes and standards require automatic fire pumps. On September 11, 2001, the fire department was unable to deploy operators to the pumps, so they were not used. Since the risers were breached by the aircraft impact, the lack of pumps may have been inconsequential. For a detailed description of the towers sprinkler system see NIST NCSTAR 1-4B.

Smoke Management

The towers were originally constructed with vents in elevator and utility shafts in accordance with NYC Reference Standard RS 18-1. In addition, smoke detectors were installed at each of the four return vents on each floor to stop fans and prevent recirculation of smoke.

Later, LL 5 (1973) Section 7 (revised by LL 86, Sec. 2) added a requirement for smoke shafts (new) or pressurized stairways (existing) with an exemption for fully sprinklered buildings. The 1976 decision to sprinkler the towers relieved the need to add stair pressurization.

Local Law 16 (1984) Section 53 contained requirements for segregation of ventilation systems and a smoke purge capability. These were addressed through the design and installation of an active system of smoke management that provided a manually activated smoke purge and pressurization of corridors with 100 percent outside air. These systems are described in detail in NIST NCSTAR 1-4C.

Chapter 11
MAINTENANCE AND MODIFICATIONS TO FIRE SAFETY SYSTEMS

The Port Authority of New York and New Jersey (PANYNJ or Port Authority) was very conscientious in providing guidance to tenants about their use of space in the World Trade Center (WTC) buildings. The Port Authority published tenant alteration manuals that detailed how tenant space could be fitted. There were manuals for interfacing with the building fire alarm system, the building fire sprinkler system, and other special systems installed in the buildings. National Institute of Standards and Technology (NIST) located at least partial copies of most of these manuals.

When a tenant space was remodeled, such as to accommodate the needs of a new tenant, the process was for the tenant to hire an architect or interior designer to design the space, following the tenant alteration manual. If the tenant occupied less than an entire floor, they could opt to have the PANYNJ handle most of the modifications through their existing contracts, or they could contract independently as the larger tenants generally did. Creation or movement of interior partitions often required moving of sprinkler heads or fire detectors. Also, whenever the suspended ceiling was pulled the PANYNJ required that the sprayed fire-resistive material be inspected and upgraded (if needed) after the other trades had finished and before the ceiling was reinstalled. The PANYNJ office reviewed and approved plans at the start of a tenant project and conducted inspections prior to the tenant moving in.

Whenever work was done in the buildings, a project number was assigned by the PANYNJ under which all contracts, drawings, and correspondence were filed. These numbers are of the format W(yy)-1234 (where yy is the year initiated and 1234 is a 4 digit number). The reports include these numbers as reference for individual projects, and files retained by the PANYNJ are identified by these numbers.

The PANYNJ also conducted numerous inspections and condition surveys which were beyond any requirements in New York City and other codes and practices, and generally implemented corrective action to address problems identified.

11.1 LOCAL LAWS 5 (1973) AND 16 (1984)

In general, buildings are governed by the building code in force at the time the building permits are issued, except in the rare case of the adoption of retroactive requirements. Local Laws (LLs) 5 (1973) and 16 (1984) were adopted after completion of WTC 1 and WTC 2 but did contain some retroactive provisions. However, the PANYNJ chose to implement virtually all of the provisions of LL 5 (1973) and LL 16 (1984), which drove most of the modifications to the fire and life safety systems that occurred over the life of the buildings. These modifications included the complete sprinklering of the buildings and several upgrades to the fire alarm system.

Several requirements in LL 5 (1973) were retroactive to existing office buildings over 100 ft in height. These included evacuation drills and planning, fire safety directors and wardens, and requirements for re-entry from stairs every four floors with signs in the stairs identifying re-entry floors. Provisions regarding compartmentation requirements for unsprinklered spaces, smoke and heat venting, sprinklers in

showrooms, permitting standpipes to be used as sprinkler risers, fire alarm and voice communication systems with a fire command center, and one elevator serving every floor supplied with emergency power that can be used by the fire department were also included. LL 16 (1984) extended retroactive provisions for sprinklers, fire alarm and communication systems (with fire command center), a fire service elevator connected to emergency power, and exit lighting and signage, to most occupancy types. LL 16 (1984) added construction class 1C (sprinklered high rise) and removed the compartmentation requirement added by LL 5 (1973), since these buildings were now required to be sprinklered.

11.2 CODE COMPLIANCE SUMMARY FOLLOWING THE 1993 BOMBING

In the aftermath of the 1993 bombing, the exemption of PANYNJ facilities from regulation under the NYC Building Code was once more being questioned. The Fire Commissioner and Commissioner of Buildings co-authored a report on the state of various properties in New York City that were exempt from City oversight (Rivera and Rinaldi 1993). They recommended that the States of New York and New Jersey enact legislation making all Public Benefit Corporations, including the Urban Development Corporation and The PANYNJ, subject to the New York City building regulations. The City had even drafted such legislation and submitted it to Albany in 1975 (Rivera and Rinaldi 1993, Attachment I). They report that as of the date of their report the legislation had not been enacted.

The Rivera and Rinaldi report includes a summary of code compliance at the WTC, including the history of code compliance discussions between City departments and PANYNJ, and that "the trend in recent years has been towards cooperation," citing the sprinklering of the towers (Rivera and Rinaldi 1993, page 6). The report goes on to say that, "since its compliance with fire code requirements was dependent upon economic and design feasibility, the PA[NYNJ] agreed to comply with selected provisions of the code, but has not fully done so. Moreover, it was difficult for the Fire Department to monitor code compliance by the WTC because the WTC consistently asserted its legal exemption from local law. Fire officials relied on persuasion and negotiation to gain compliance." (Rivera and Rinaldi 1993, page 6).

Regarding compliance at the time of the explosion, Rivera and Rinaldi report that "a preliminary review by the NYC Department of Buildings generally indicates that the WTC complies with the specific provisions of Local Law 5/73 and Local Law 16/84, or provides acceptable equivalent systems." (Rivera and Rinaldi 1993, page 7) They go on to say that the WTC exceeds the requirements of these local laws in several areas, including emergency power, smoke purge, and corridor pressurization. They cite the fire alarm system as a "major departure" from the requirements of the local laws because each building does not have its own fire command station, they have only one pull station per floor, and they do not provide public address to all areas on all floors. These deficiencies were addressed by the PANYNJ as discussed in NIST NCSTAR 1-4C. Several newly discovered deficiencies regarding occupant egress provisions are also mentioned (Rivera and Rinaldi 1993, page 10).

The position of the PANYNJ was summarized in a statement by Stanly Brezenhoff, Executive Director PANYNJ before the New York City Council, Committee on Housing and Buildings on March 26, 1993 (Rivera and Rinaldi 1993, Attachment F). On page 8 of his statement, Brezenhoff states that the PANYNJ has a "tradition of designing for high standards of structural integrity, and our policy of voluntarily meeting or even exceeding code requirements." Brezenhoff goes on to give examples of meeting or exceeding building code standards for structural integrity such as,

- The towers have three stairs for fire egress, rather than two required by code
- The towers comply with or exceed code provisions controlling fire protection of structural members, floors and partitions, and enclosure of shafts
- The office floors can support 100 lb/ft^2, twice the code requirement
- The towers were designed for wind speeds approximately twice those in the code.

11.3 WTC DUE DILIGENCE STUDY OF NOVEMBER 22, 1996

In late 1996, the PANYNJ contracted with Rolf Jensen & Associates (RJA) and Jaros, Baum & Bolles (JB&B) to conduct a study of code compliance at the WTC buildings. These reports, along with issues identified by the World Trade Department of PANYNJ, were summarized in a report dated October 15, 1999 (PANYNJ 1999). This study appears to be related to the Memorandum of Understanding between PANYNJ and the New York City Department of Buildings which provides for oversight by professionals licensed to practice in New York State reporting to PANYNJ with these reports available for review by the City.

Of particular interest is the division of the items identified in the report into categories:

- Category A was non-conforming code items which will remain as such or for which no plans will be prepared to accommodate the code,
- Category B was non-conforming items which have been remedied, or are currently in progress,
- Category C was non-conforming code items whose remediation plans are currently being prepared or will be prepared in the near future, and
- Category D was items of policy, business, leases, repair, and operations (RJA report only).

Items in Category A included the issue of the discharge of Stairways A and C on the mezzanine level when the Code required exit stair discharge to a level "opening onto a public way." This was resolved by an agreement between the PANYNJ and the NYC Department of Buildings that the Plaza was like a public way, and the Concourse was an "underground street." Also in this category is the issue of exit stair venting.

Category B included structural fireproofing, which was "judged adequate" by RJA providing that all floors in both towers were sprinklered and re-fireproofing "to the appropriate thickness for a 2 h rating" was continued. The 1997 RJA report (which is Attachment A to PANYNJ 1999) actually states, "… the protection provided by the automatic sprinkler systems will mitigate the fact that the towers' structural steel fireproofing fall somewhat short of that required to provide a 2 h rating." The RJA report also states that it is their understanding that the PANYNJ "has been currently been [sic] installing and will continue to install 1½ in. thick steel fireproofing based on UL Design No. G508."

This category also includes the topic "remediating tenant separation walls and public corridor walls to conform to code requirements." Here the RJA report states that "Tenant demising partitions, including separations from the public corridor, do not in all cases meet the requirement of being built to the slab above."

Items also in this category that were mentioned by Rivera and Rinaldi as major departures from the local laws with regard to the fire alarm system included the lack of individual fire command stations for each building, additional manual stations and public address speakers needed.

Category C included mechanical rooms with doors directly into egress stairs (which is expressly prohibited), location of standpipe hose stations on some floors (as the stairways move closer together the standpipe connection may exceed the 145 ft distance limit to any point on a floor), and egress issues at the Mall and B-1 levels.

The JB&B report identified firestopping (at penetrations of fire rated assemblies such as pipes passing through floors) in Category C as a general issue in the towers. Their report also identified a number of electrical safety issues throughout the complex.

Category D included smoke control on the PATH mezzanine to prevent smoke from reaching the Mall, formal responsibility for overseeing code conformance for both base building and Tenant projects, and the lack of a Certificate of Occupancy for the buildings.

Chapter 12
WTC 7 FUEL SYSTEM

World Trade Center (WTC) 7 was constructed and owned by Silverstein Properties (Silverstein) on land owned by the Port Authority of New York and New Jersey (Port Authority). It was built and operated by Silverstein as a Port Authority tenant alteration. Many of the tenants conducted critical business operations in the building and required uninterruptible power to prevent the loss of information or operational continuity in the event of a power failure. Backup power was provided by diesel generators located in the mechanical spaces of the building. These generators were designed to start automatically in the event of an interruption of the utility supply. The total generator capacity and quantity of fuel stored in the building was sized to tenant needs.

12.1 CODE REQUIREMENTS

Design and installation of the WTC 7 emergency power and associated fuel systems was consistent with the 1968 New York City (NYC) Building Code. The base system was installed in 1987 with modifications occurring in 1990, 1994, and 1999. Over the period 1987 to 1999, the NYC Building Code provisions discussed below were not changed, so all systems were installed to the same requirements. Some of the key code provisions for the construction and location of fuel storage tanks, piping, and controls are discussed here, and additional details are contained in NIST NCSTAR 1-1A.

12.1.1 Tanks (27-828 and 27-829)[50]

All tanks must be fabricated of steel and coated to prevent corrosion. Minimum thicknesses are specified by tank diameter for storage tanks and for so-called "day tanks" (60 gal or 275 gal). Large storage tanks (up to 20,000 gal) may be buried inside or outside the building or on the lowers floor of the building with protection related to the tank capacity. For example, tanks from 550 gal to 1,100 gal must be enclosed in 2 h fire rated, noncombustible construction and tanks larger than 1,100 gal in 3 h construction.

Tanks on floors above the lowest floor are limited to 275 gal and one such tank per story. These "day tanks" must be surrounded by a concrete curb or steel pan with the capacity to hold twice the volume of the tank in the event of a leak. The curb or pan must be provided with a float switch to sound an alarm and shut off the transfer pump in case of tank failure. Appropriate controls (generally a float switch in the day tank) must be provided to transfer fuel from the storage tanks to the day tank through a transfer pump and piping, with only one such transfer pump and piping network per day tank.

12.1.2 Piping (27-830)[37]

Piping from transfer pumps to day tanks is required to be enclosed in a shaft of 4 in. thick concrete or masonry with a 4 in. clearance to the fuel pipe. Horizontal offsets may be enclosed in a steel sleeve two

[50] Sections of the NYC Building Code in which these requirements are found. These provisions are found in the subchapter on "Heating and Combustion Equipment."

(pipe) sizes larger and enclosed in 2 h fire rated construction. The spaces between the fuel pipe and sleeve or shaft must lead to an open sight drain or an open sump so leaks can be detected.

12.1.3 Power Systems Designs

National Institute of Standards and Technology (NIST) located and reviewed specifications and drawings for each of the emergency power systems. Some of the fuel risers were installed in existing shafts containing other utilities. The NYC Building Code requires that pipe shafts containing piping from the transfer pump to storage tanks above the lower floors not be penetrated by or contain other piping or ducts (27-830(f)(5)). Correspondence relating to the system for the Mayor's Office of Emergency Management shows that this system was reviewed and inspected by the New York City Fire Department (FDNY), a list of needed corrections was produced, and each item was initialed as the corrections were verified.

12.2 BASE BUILDING SYSTEM

The initial base emergency power system was installed in 1987, and consisted of two 900 kW generators and a 275 gal day tank located on floor 5. Main fuel storage was in two 12,000 gal tanks buried under the loading dock on the south side of the building. The tanks were double wall fiberglass[51] with leak detectors between the walls.

Fuel was transferred by one of the two pumps through a 2 in. supply line in an existing shaft containing other utilities, near the west bank of passenger elevators. The transfer pump was controlled by a float switch in the day tank with a low (pump on) and a high (pump off) position. An alarm would be sounded if the fuel level in the day tank fell below the low level or went above the high level. The day tank was located within a 550 gal pan fitted with an alarm and another pump cutoff. The vent for the day tank terminated outside the south wall.

The 2 in. fuel lines were encased in a second pipe covered with 2 in. of calcium silicate to provide the required 2 h fire rating. Pipe supports were located approximately 10 ft apart, and inspection plugs were provided approximately 50 ft apart. Mechanical equipment rooms were sprinklered (ordinary hazard group I), and the fuel pump room was sprinklered (ordinary hazard group III). The generator area on floor 5 was not sprinklered.

12.2.1 Modifications to System

From 1990 to 1999, four major modifications (additions) were made to the base emergency power system. These modifications are summarized in Table 12–1. Of significance are the 1990 modification (Salomon Brothers) that required a pressurized fuel supply system, because a day tank already existed on floor 5, and the 1999 modification (Mayors' Office of Emergency Management) that required a separate 6,000 gal tank on the first floor. Figure 12–1 is a schematic of the locations of the various components of the base system and the four major modifications.

[51] While the NYC Building Code requires steel tanks, effective in November 1985 the U.S. Environmental Protection Agency required (40CFR280) that all new underground fuel storage tanks be double wall fiberglass and that any steel tanks older than 20 years be replaced by double wall fiberglass.

For the Salomon Brothers system, the transfer pumps were powered from the output of the generators. In the event of a failure of utility power, all nine generators were started automatically to ensure that if any of the nine did not start there would be enough power. Once the generators were up to speed, the control system would shut down those that were not needed, but these could be restarted later if power demand increased. There was enough fuel and residual pressure in the lines to start the generators and to run them for a few minutes, but once running, the fuel pumps were powered to supply fuel. As long as any one generator was running, the pumps ran at full capacity.

Table 12–1. Summary of modifications to base emergency power system in WTC 7.

Year	Day Tank/Generator	Storage Tank	Piping	Comments
1990	No day tank permitted since base design included one on floor 5/nine generators on floor 5, 1,750 kW combined capacity	Two 6,000 gal next to base tanks.	Two 2½ in. pipes in separate rated shaft	50 psi pressurized fuel system
1994	50 gal/125 kW on floor 9; generator room sprinklered	Used existing base tanks	1¼ in. in new 2 h rated dedicated shaft	New transfer pump connected to existing storage tanks
1994	275 gal/350 kW on floor 8; generator room sprinklered	Used existing base tanks	2 in. in same dedicated shaft as above	New transfer pump connected to existing storage tanks
1999	275 gal/three 500 kW on floor 7; smoke detectors in generator room	6,000 gal on floor 1, in 4 h rated enclosure; gaseous (clean) fire suppression system; space below tank sprinklered	10 gauge conduit in 2 h rated enclosure	Storage tank kept filled from base storage tanks.

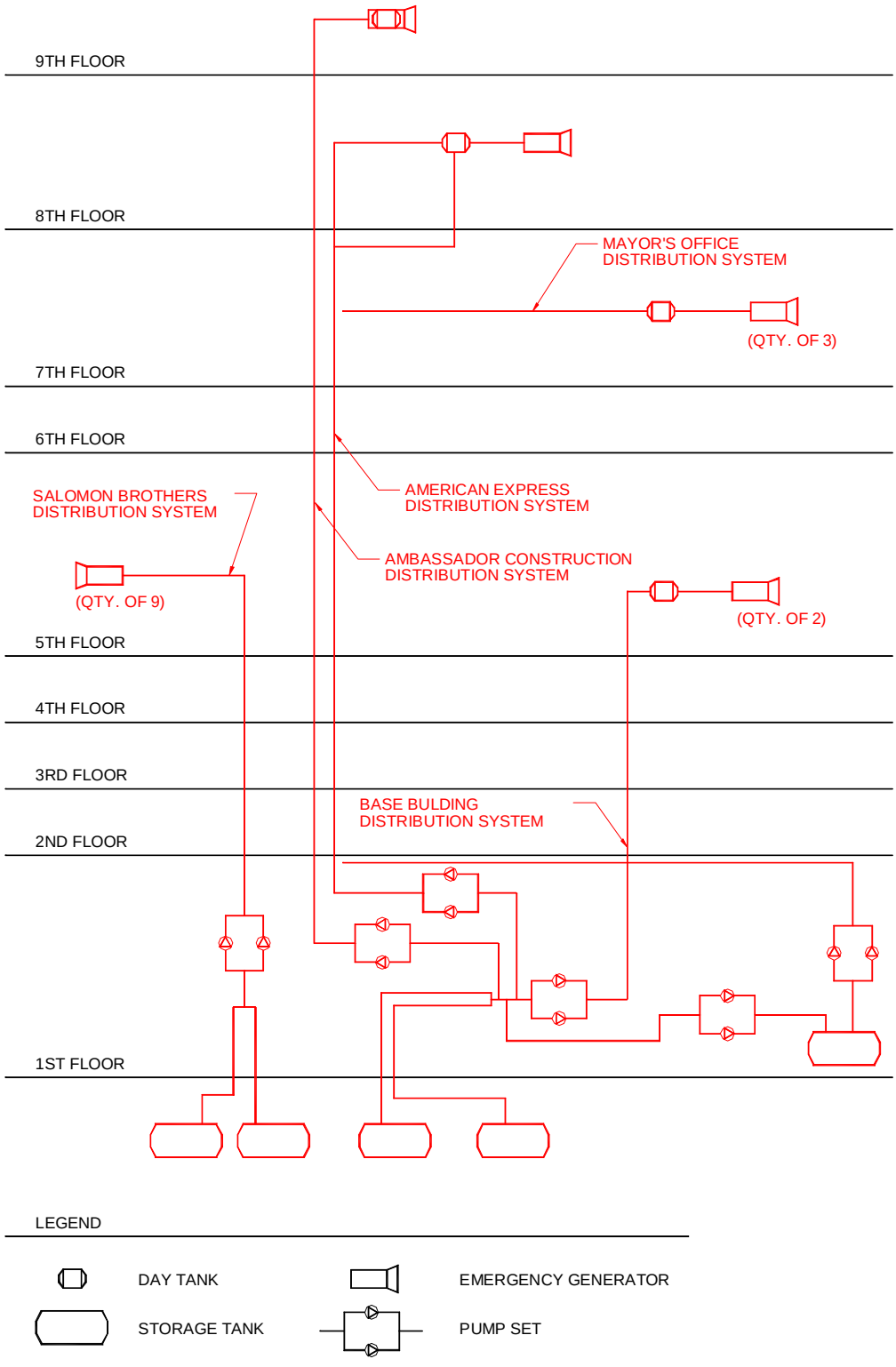


Figure 12–1. Section plan showing the final locations of the fuel oil distribution components.

12.2.2 Ambassador Modification

The Ambassador modification to the base system was performed in 1994. A new transfer pump set (145 gph at 100 psi) was installed and connected to the existing main storage tanks. A new 1¼ in. supply riser was located in a new 2 h shaft dedicated for the fuel distribution system, constructed of 4 in. masonry and located at the south end of the center bank of passenger elevators. The line ran to a single 125 kW generator with a 50 gal day tank mounted in a 100 gal basin on the 9th floor. Controls and alarms were the same as the base system. The transfer pipes were the same double wall design and, outside the masonry shaft, were covered with a 2 h vermiculite. The area of the generator on the 9th floor was sprinklered. No design criteria were located, but the pipe sizes for the entire 9th floor are consistent with a light hazard pipe schedule design.

12.2.3 American Express Modification

At about the same time in 1994, American Express installed a system to supply their operations. Another new pump set rated 170 gph (at 100 psi) was installed on the first floor and was tapped into the existing base system pipes and tanks. Another 2 in. supply pipe ran in the same masonry shaft used for the Ambassador system to a 275 gal day tank and a single 350 kW generator on the 8th floor. Controls and alarms were the same as the base system. The 8th floor generator room was protected with sprinklers designed to light hazard criteria.

12.2.4 Mayor's Office of Emergency Management (OEM) Modification

In 1999, the Mayor's Office of Emergency Management was constructed on the 7th floor. This system differed from the others because the specifications were to provide an independent source of power for full operations for at least one week, requiring the installation of a new, 6,000 gal storage tank and three 500 kW generators fed from a single 275 gal day tank on the 7th floor. The main storage tank was located on the 1st floor of the building in an existing storage room adjacent to the elevators. The room was modified by installing a raised structure on which the tank was installed, enclosed in 4 h masonry (8 in. concrete masonry unit) construction.

A new fill pump set rated 2,000 gph at a design pressure of 125 psi was located in the 1st floor pump room along with a transfer pump set rated 700 gpm at a design pressure of 125 psi. The 6,000 gal OEM tank was kept filled from the two 12,000 gal base system tanks by means of the fill pump. The 1st floor tank room was protected with an Intergen suppression system with the space below the tank still sprinklered (high hazard). The 7th floor generator room was not sprinklered but was protected by smoke detectors connected to the building alarm system.

12.2.5 Salomon Brothers Emergency Power System

In 1990 Salomon Brothers installed a system to provide emergency power to their trading floor that was independent from the other systems in the building. The Salomon Brothers system involved two 6,000 gal tanks identical to and buried adjacent to the base system tanks under the loading dock on the south side of the building. Salomon Brothers had a contract with a fuel delivery service who always

maintained the tanks full.[52] Therefore, both tanks likely contained 6,000 gal of fuel on September 11, 2001.

The system utilized nine generators on the 5th floor with a combined capacity of 1,750 kW. Seven cooling fan sets (four fans per set) were installed to provide cooling and combustion air to the generators. Three fan sets were installed on the north end of the east wall and four fan sets on the north end of the west wall. There were exhaust louvers on the south end of the west wall. These fans were arranged to come on when the generators were running.

Since there was already a 275 gal day tank on the 5th floor associated with the base system, the New York City (NYC) Building Code did not permit another tank on that floor. The Salomon Brothers system was designed with a pressurized fuel system without a storage tank near the generators. Two 70 gpm at 50 psi total head pumps were located in a separate enclosure in the existing fire pump room (not in the fuel pump room with the other transfer pumps). A double supply and return pipe (each 2½ in. covered in 2 in. of calcium silicate) were run in a separate shaft to the 5th floor where the pipes ran outside the mechanical room to the generators in three groups. At the end of the pipe run, where the fuel supply pipe ended and the fuel return pipe began, there was a valve box containing a backpressure regulator, gauges, and a by-pass line. This liquid tight valve box was mounted to the underside of the floor slab for the 6th floor near generator #1.

The transfer pumps were powered from the output of the generators. In the event of a failure of utility power, all nine generators were started automatically. This is to ensure that if any did not start there would be enough power. Once up to speed, the control system would shut down generators that were not needed, but they could be restarted later if demand increased. There was enough fuel and residual pressure in the lines to start the generators and to run them for a few minutes, but once running, the fuel pumps were powered to supply fuel. As long as any one generator was running, the pumps ran at full capacity.

The system also included cooling fan units (each consisting of four fans) with three units (rated 30,000 cfm per fan, 12 fans) installed in the northeast corner of the 5th floor near generators 1 through 4, six units (rated 38,000 cfm per fan, 24 fans) in the northwest corner near generators 8 and 9, and exhaust louvers in the southwest corner near generators 5 through 7. The fans were powered from the generators and ran whenever the generators were running. They brought outside air into the building and across the generators.

12.3 POSSIBLE FAILURE MODES

Fuel oil piping systems like these are fairly common and are used to operate diesel generators and oil fired furnaces in many applications. The systems generally use day tanks at the appliance kept filled from storage remote tanks through transfer pumps and piping. The pipe-in-pipe design used in WTC 7 is quite robust and reliable in preventing leaking fuel from escaping the system.

At the time WTC 7 was designed and built there were no seismic design requirements for buildings in New York City much less for piping systems. More recent research into the failure of fire sprinkler

[52] Interview with Mike Catalano, maintenance person for Salomon Brothers, who was responsible for these systems.

systems in earthquakes has resulted in seismic design requirements for critical piping systems in seismic zones. The research on sprinkler systems has shown the need for lateral bracing to prevent the failure of the piping systems due to differential movement between the pipes and the building in an earthquake.

A working hypothesis is that the impact sustained by WTC 7 from the collapse of WTC 1 resulted in fractures in the fuel piping system (both the fuel pipe and the containment pipe) especially at the point where the pipes entered the valve box, which was rigidly mounted to the underside of the floor slab. With the base system and all of the modifications thereto, such a fracture would result in a small leak of residual fuel in the pipes at the point of the fracture. A fracture of the pipe at the valve box would release fuel under pressure that, if ignited, could produce a spray fire and/or a pool fire very near column 79.

Rupture of a day tank would release more fuel, but it would be contained by the overflow pan. Not until the generators ran for long enough to drain the day tank to its low fuel level and bring on the transfer pumps would additional fuel and pressure in the transfer lines cause a more significant fuel leak. Depending on the number of generators connected to the day tank, this would require several hours.

The Salomon Brothers pressurized system is different. If the supply or return pipes were fractured along with the containment pipe and the generators started, the fuel pipes would be continuously pressurized, and any leak would continue until the storage tanks were empty as long as any one generator was running.

NIST reviewed the report of an environmental contractor (Langan 2002) hired in the months after the collapse of WTC 7 to recover remaining fuel and to mitigate any environmental damage from the Salomon Brothers tanks. The Salomon Brothers tanks were damaged and appeared to be empty, " … Neither the UST's (underground storage tanks) nor their associated piping contained any residual petroleum product. No residual free product or sludge was observed in either UST."

The tanks were installed on a concrete slab over existing silty sand. A layer of bedding gravel on the slab provided a foundation for the tank. Examination of the gravel below the tanks and the sand below the slab showed some fuel contamination but none was observed in the organic marine silt/clay layer below. Also, the sand and soil below the slab was continuous below the adjacent base system tanks, which contained a total of 24,000 gal of fuel. Thus, it is likely that a fuel leak in any of the tanks would result in fuel contamination in this soil.

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Chapter 13
FINDINGS

13.1 GENERAL

Finding 1: The NYC Department of Buildings reviewed the WTC tower drawings in 1968 and provided comments to the PANYNJ concerning the plans in relation to the 1938 NYC Building Code. The architect-of-record submitted to the PANYNJ responses to those comments, noting how the drawings conformed to the 1968 NYC Building Code. All six comments made by the NYC Department of Buildings dealt with egress issues, but none questioned the large occupant loads for Windows on the World in WTC 1 or Top of the World in WTC 2.

Finding 2: In 1993, the PANYNJ and the NYC Department of Buildings entered into a memorandum of understanding that restated the PANYNJ's long-standing stated policy to ensure that its facilities in the City of New York meet and, where appropriate, exceed the requirements of the NYC Building Code. The agreement also provided specific commitments to the NYC Department of Buildings regarding procedures to be undertaken by the PANYNJ to ensure that buildings owned or operated by the PANYNJ are in conformance with the Building Standards contained in the NYC Building Code. Some salient points included in this agreement and the 1995 enhancement to the agreement are:

- Each project would be reviewed and examined for compliance with the Code.
- All plans would be prepared, sealed, and reviewed by New York State licensed professional engineers or architects.
- The PANYNJ engineer or architect approving the plans would be licensed in the State of New York and would not have assisted in the preparation of the plans.
- The person or firm performing the review and certification of plans for WTC tenants may be the same person or firm providing certification that the project had been constructed in accordance with the plans and specifications unless the proposed alteration would "change the character of the occupancy group under paragraph 27-237 of the New York City Building Code which would have been applicable to such space had such space been located in a privately owned building."
- Deviations from the Code, acceptable to the PANYNJ, would be submitted to the NYC Department of Buildings for review and concurrence. Disagreements between the PANYNJ and the NYC Department of Buildings over such deviations from the Code would be referred to the Port Authority Board of Commissioners for resolution.

Finding 3: While the PANYNJ entered into agreements with the NYC Department of Buildings in the 1990s with regard to conformance of PANYNJ buildings constructed in New York City to the NYC Building Code and sought review and concurrence as required by the agreements, the PANYNJ was not required to yield, and appears not have yielded, approval authority to New York City. The PANYNJ was

created as an interstate entity "body corporate and politic," under its charter, pursuant to Article 1 Section 10 of the U.S. Constitution permitting compacts between states, and like many other nongovernmental and quasi-governmental entities in the United States is not subject to building and fire safety code requirements of any governmental jurisdiction.

Finding 4: State and local jurisdictions do not require retention of documents related to the design, construction, operation, maintenance, and modifications of buildings, with few exceptions. These documents are in the possession of building owners, contractors, architects, engineers, and consultants. Such documents are not archived for more than about 6 to 7 years, and there are no requirements that they be kept in safe custody physically remote from the building throughout its service life. In the case of the WTC towers, the PANYNJ and its contractors and consultants maintained an unusually comprehensive set of documents, a significant portion of which had not been destroyed in the collapse of the buildings but could be assembled and provided to the investigation. In the case of WTC 7, several key documents could not be reviewed since they were lost in the collapse of the building.

Finding 5: Consistent with the practice at the time the (code) architect was responsible for specifying the fire protection and designing the egress system in accordance with the prescriptive provisions of the building code. The architect and owner engaged the services of structural engineers to perform the structural design and to ensure that his/her design was properly implemented. At that time the fire protection engineering profession was not sufficiently mature to require the same standard of care employed with the structural design. There is no reason to believe that the involvement of a fire protection engineer at that time would have resulted in any differences in the design or performance of the fire protection systems. However, the technical base and sophistication of the practice of fire protection engineering today is well advanced of where it was then. Today, particularly when designing a building employing innovative features, the involvement of a fire protection engineer in a role similar to the structural engineer, and under the overall coordination of the Design Professional in Responsible Charge is central to the standard of care. Further, when designing the structure of selected tall buildings or selected other buildings to resist fires, or evaluating the fire resistance of such structures, it is essential for the structural engineer and the fire protection engineer to jointly provide the needed standard of care.

13.2 STRUCTURAL SAFETY

Applicable Building Codes

Finding 6: Although not required to conform to NYC codes, the PANYNJ adopted the provisions of the proposed 1968 edition of the NYC Building Code, more than three years before it went into effect. The proposed 1968 edition allowed the PANYNJ to take advantage of less restrictive provisions and of technological advances compared with the 1938 edition, which was in effect when design began for the WTC towers in 1962. The 1968 code:

- Changed partition loads from 20 psf to one based on weight of partitions per unit length (that reduced such loads for many buildings including the WTC buildings); and
- Permitted wind tunnel tests using models to establish design values for the wind load.

Many of these newer requirements, instituted in the 1968 NYC Building Code, are contained in current model codes and building regulations.

Structural Integrity

Finding 7: Building codes lack explicit structural integrity provisions to mitigate progressive collapse. Federal agencies have developed guidelines to mitigate progressive collapse and routinely incorporate such requirements in the construction of new federal buildings. The United Kingdom incorporates such code requirements for all buildings. New York City adopted by rule in 1973 a requirement for buildings to resist progressive collapse under extreme local loads. The rules, which were adopted after the WTC towers were built but before WTC 7 was built, applied specifically to buildings that used precast concrete wall panels and not to other types of buildings.

Finding 8: Building Codes lack minimum structural integrity provisions for the means of egress (stairwells and elevator shafts) in the building core that are critical to life safety. In most tall buildings the core is designed to be part of the vertical gravity load carrying system of the structure. However, in many of those buildings, especially in regions where earthquakes are not dominant, the core may not be part of the lateral load carrying system of the structure. Thus, the core may be designed to carry only vertical gravity loads with no capacity to resist lateral loads, i.e., overturning moment and shear loads. In such situations, the structural designer may prefer the use of partition walls over structural walls in the core area to reduce building weight. The decision to have the core carry a specified fraction of the lateral design loads or be made part of a dual system to carry lateral loads, each of which would enhance the structural integrity of the core if structural walls were used, is left to the discretion of the structural engineer. Alternatively, stairway/elevator cores built with concrete or reinforced concrete block, which are not part of the lateral load carrying system, may be able to provide sufficient structural integrity if they meet, for example, ASTM E1996-03, or other more appropriate test for impact resistance. In the case of the WTC towers, the core had 2 h fire-rated partition walls with little structural integrity and the core framing was required to carry only gravity loads. Had there been a minimum structural integrity requirement to satisfy normal building and fire safety considerations, it is conceivable that the damage to stairways, especially above the floors of impact, may have been less extensive.

Finding 9: Standards and code provisions for conducting wind tunnel tests and for the methods used in practice to estimate design wind loads from test results do not exist. Building codes allow the determination of wind pressures from wind tunnel tests for use in design. Such tests are frequently used in the design of tall buildings. Results of two sets of wind tunnel tests conducted for the WTC towers in 2002 by independent commercial laboratories as part of insurance litigation, and voluntarily provided to NIST by the parties to the litigation, show large differences, of as much as about 40 percent, in resultant forces on the structures, i.e., overturning moments and base shears. Independent reviews by a NIST expert on wind effects on structures and a leading engineering design firm contracted by NIST indicated that the documentation of the test results did not provide sufficient basis to reconcile the differences. Wind loads were a major governing factor in the design of structural components that made up the frame-tube steel framing system.

13.3 FIRE SAFETY

Applicable Building Codes

Finding 10: Although not required to conform to NYC codes, the PANYNJ adopted the provisions of the proposed 1968 edition of the NYC Building Code, more than three years before it went into effect. The

1968 edition allowed the PANYNJ to take advantage of less restrictive provisions compared with the 1938 edition that was in effect when design began for the WTC towers in 1962. The 1968 code:

- Eliminated a fire tower[53] as a required means of fire department access;
- Reduced the number of required stairwells from 6 to 3 and the size of doors leading to the stairs from 44 in. to 36 in. (by increasing stairway and door capacity allowances);
- Reduced the required fire rating of the shaft walls in the building core from 3 h to 2 h; and
- Permitted a 1 h reduction in fire rating for all structural components (columns from 4 h to 3 h and floor framing members from 3 h to 2 h) by allowing the owner/architect to select Class 1B construction for business occupancy and unlimited building height.

Many of these newer requirements, instituted in the 1968 NYC Building Code, are contained in current codes.

Finding 11: In 1993, the PANYNJ adopted a policy providing for implementation of fire safety recommendations made by local government fire departments after a fire safety inspection of a PANYNJ facility and for the prior review by local fire safety agencies of fire safety systems to be introduced or added to a facility. Later that year, the PANYNJ entered into an agreement with FDNY which reiterated the policy adopted by the PANYNJ, recognized the right of FDNY to conduct fire safety inspections of PANYNJ properties in the City of New York, provided guidelines for FDNY to communicate needed corrective actions to the PANYNJ, ensured that new or modified fire safety systems are in compliance with local codes and regulations, and required third-party review of such systems by a New York State licensed architect or engineer.

Standard Fire-Resistance Tests

Finding 12: Code provisions with detailed procedures to analyze and evaluate data from fire resistance tests of other building components and assemblies to qualify an untested building element do not exist. Based on available data and records, no technical basis has been found for selecting the sprayed fire-resistive material (SFRM) used (two competing materials were under evaluation) or its thickness for the large-span open-web floor trusses of the WTC towers. The assessment of the fireproofing thickness needed to meet the 2 h fire rating requirement for the untested WTC floor system evolved over time:

- In October 1969, the PANYNJ directed the fireproofing contractor to apply ½ in. of fireproofing to the floor trusses.
- In 1999, the PANYNJ issued guidelines requiring that fireproofing be upgraded to 1½ in. for full floors undergoing alterations.

[53] A fire tower (also called a smoke-proof stair) is a stairway that is accessed through an enclosed vestibule that is open to the outside or to an open ventilation shaft providing natural ventilation that prevents any accumulation of smoke without the need for mechanical pressurization.

- Unrelated to the WTC buildings, an International Conference of Building Officials (ICBO) Evaluation Service report (ER-1244), re-issued June 1, 2001, using the same SFRM recommends a minimum thickness of 2 in. for "unrestrained steel joists" with "lightweight concrete" slab.

Finding 13: Code provisions that require the conduct of a fire resistance test if adequate data do not exist from other building components and assemblies to qualify an untested building element are needed. Instead, several alternate methods based on other fire-resistance designs or calculations or alternative protection methods are permitted with limited guidance on detailed procedures to be followed. Both the architect-of-record (in 1966) and the structural-engineer-of-record (in 1975) stated that the fire rating of the floor system of the WTC towers could not be determined without testing. NIST has not found evidence indicating that such a test was conducted to determine the fire rating of the WTC floor system. The PANYNJ has informed NIST that there are no such test records in its files.

Finding 14: Use of the "structural frame" approach, in conjunction with the prescriptive fire rating, would have required the floor trusses, the core floor framing, and perimeter spandrels in the WTC towers to be 3 h fire-rated, like the columns for Class 1B construction in the 1968 NYC Building Code. Neither the 1968 edition of the NYC Building Code which was used in the design of the WTC towers, nor the 2001 edition of the code, adopted the "structural frame" requirement. The "structural frame" approach to fire resistance ratings requires structural members, other than columns, that are essential to the stability of the building as a whole to be fire protected to the same rating as columns. This approach, which appeared in the Uniform Building Code (a model building code) as early as 1953, was carried into the 2000 International Building Code (one of two current model codes) which states: "The structural frame shall be considered to be the columns and the girders, beams, trusses and spandrels having direct connections to the columns and bracing members designed to carry gravity loads." The WTC floor system was essential to the stability of the building as a whole since it provided lateral stability to the columns and diaphragm action to distribute wind loads to the columns of the frame-tube system.

Finding 15: A technical basis to establish whether the construction classification and fire rating requirements in modern building codes are risk-consistent with respect to the design-basis hazard and the consequences of that hazard is needed. The fire rating requirements, which were originally developed based on experience with buildings less than about 20 stories in height, have generally decreased over the past 80 years since historical fire data for buildings suggested considerable conservatism in those requirements. However, for tall buildings, the likely consequences of a given threat to an occupant on the upper floors are more severe than the consequences to an occupant, say, on the first floor. It is not apparent how the current height and area tables in building codes consider the technical basis for the progressively increasing risk to an occupant on the upper floors of tall buildings that are much greater than about 20 stories in height where access by firefighters without the availability of firefighter elevators is limited by physiological factors. The maximum required fire rating in current codes applies to any building more than about 12 stories in height. There are no additional categories for buildings above, for example, 40 stories and 80 stories, where different building classification and fire ratings requirements may be appropriate, recognizing factors such as the time required for stairwell evacuation without functioning elevators (e.g., due to power failure or major water leakage), the time required for first responder access without functioning elevators, the presence of sky lobbies and/or refuge floors, and limitations on the height of elevator shafts. The 110-story WTC towers, initially classified as Class IA based on the 1938 NYC Building Code, were classified as Class 1B before being built to take advantage

of the provisions in the 1968 edition of the code. This re-classification permitted a reduction of 1 h in the fire rating of the components (columns from 4 h to 3 h and floor framing members from 3 h to 2 h).

Fire Performance of Structures

Finding 16: Rigorous field application and inspection provisions and regulatory requirements to ensure that the as-built condition of the passive fire protection, such as SFRM, conforms to conditions found in fire resistance tests of building components and assemblies is needed. For example, provisions are not available to ensure that the as-applied average fireproofing thickness and variability (reflecting the quality of application) is thermally equivalent to the specified minimum fireproofing thickness. In addition, requirements are not available for in-service inspections of passive fire protection during the life of the building. The adequacy of the fireproofing of the WTC towers posed an issue of some concern to the PANYNJ over the life of the buildings, and the availability of accepted requirements and procedures for conducting in-service inspections would have provided useful guidance

Finding 17: Structural design does not consider fire as a design condition, as it does the effects of dead loads, live loads, wind loads, and earthquake loads. Current prescriptive code provisions for determining fire resistance of structures—used in the design of the WTC towers and WTC 7— are based on tests using a standard fire that may be adequate for many simple structures and for comparing the relative performance of structural components in more complex structures. A building system with 3 h rated columns and 2 h rated girders and floors could last longer than 3 h or shorter than 2 h depending upon the performance of the structure as a 3-dimensional system in a real fire. The standard tests cannot be used to evaluate the actual performance (i.e., load carrying capacity) in a real fire of the structural component, or the structure as a whole system, including the connections between components. Performance-based code provisions and standards are not available for use by engineers, as an alternative to the current prescriptive fire rating approach, to (1) evaluate the system performance of tall-building structures under real fire scenarios, and (2) enable risk consistent design with appropriate thickness of passive protection being provided where it is needed on the structure. Standards development organizations, including the American Institute of Steel Construction, have initiated development of performance-based provisions to consider fire effects in structural design.

Finding 18: Detailed procedures to select appropriate design-basis fire scenarios to be considered in the performance-based design of the sprinkler system, compartmentation, and passive protection of the structure are needed. The standard fire in current prescriptive fire resistance tests is not adequate for use in performance-based design. While the NFPA 5000 model building code contains general guidance on design fire scenarios (the IBC Performance Code contains no such guidance), the details of the scenarios are left to the fire engineer and regulatory official. The three major scenarios that are not considered adequately are: frequent but low severity events (for design of sprinkler system), moderate but less frequent events (for design of compartmentation), and a maximum credible fire (for design of passive fire protection on the structure). The maximum credible fire scenario for passive protection of structures would assume that the sprinkler system is compromised or overwhelmed and that there is no active firefighting, as is explicitly considered for US Department of Energy facilities. These building-specific representative fire scenarios are similar in concept, though not identical, to the approach used in building design where the performance objectives and design-basis of the hazard are better defined (e.g., a two-level design that includes an operational event with a 10 percent probability of occurrence in 50 years and a life safety event with a 2 percent probability of occurrence in 50 years). The design-basis fire hazards

for the WTC towers and WTC 7 are unknown, and it is difficult to evaluate the performance of the fire protection systems in these buildings under specific fire scenarios.

Finding 19: Code provisions to ensure that structural connections are provided the same degree of fire protection as the more restrictive protection of the connected elements are needed. The provisions that were used for the WTC towers and WTC 7 did not require specification of a fire-rating requirement for connections separate from those for the connected elements. It is not clear what the fire rating of the connections were when the connecting elements had different fire ratings and whether the applied fireproofing achieved that rating.

Finding 20: A technical basis to establish whether the minimum mechanical and durability related properties of SFRM are sufficient to ensure acceptable in-service performance in buildings is needed. While minimum bond strength requirements exist, there are no serviceability requirements for such materials to withstand typical shock, impact, vibration, or abrasion effects over the life of a building. There are existing testing standards for determining many of these properties, but the technical basis is insufficient to establish serviceability requirements. Knowledge of such serviceability requirements is relevant to determine the post-impact fireproofing condition of the WTC towers.

Finding 21: Validated and verified tools for use in performance-based design practice to analyze the dynamics of building fires and their effects on the structural system that would allow engineers to evaluate structural performance under alternative fire scenarios and fire protection strategies are needed. Existing tools are either too simplified to adequately capture the performance of interest or too complex and computationally demanding and lack adequate validation. While considerable progress has been made in recent years, significant work remains to be done before adequate tools are available for use in routine practice. NIST has had to further develop and validate existing tools to investigate the fire performance of the WTC towers and WTC 7.

Compartmentation and Sprinklers

Finding 22: Building fire protection is based on a four-level hierarchical strategy comprising detection, suppression (sprinklers and firefighting), compartmentation, and passive protection of the structure.

- Detectors are typically used to activate fire alarms and notify building occupants and emergency services.
- Sprinklers are designed to control small and medium fires and to prevent fire spread beyond the typical water supply design area of about 1,500 ft^2.
- Compartmentation mitigates the horizontal spread of more severe but less frequent fires and typically requires fire-rated partitions for areas of about 7,500 ft^2. Active firefighting measures also cover up to about 5,000 ft^2 to 7,500 ft^2.
- Passive protection of the structure seeks to ensure that a maximum credible fire scenario, with sprinklers compromised or overwhelmed and no active firefighting, results in burnout, not overall building collapse. The intent of building codes is also for the building to withstand local structural collapse until occupants can escape and the fire service can complete search and rescue operations.

Compartmentation of spaces is a key building fire safety requirement to limit fire spread. The WTC towers initially had 1 h fire-rated partitions separating tenants (demising walls) that extended from the floor to the suspended ceiling, not the floor above (the ceiling tiles were not fire rated). Over the years, these partitions were replaced with partitions that were continuous from floor to floor (separation wall) as required by the 1968 NYC Building Code. Some partitions had not been upgraded by 1997, and a consultant recommended to the PANYNJ that it develop and implement a survey program to ensure that the remediation process occurred as quickly as possible. It appears that with few exceptions, nearly all of the floors not upgraded were occupied by a single tenant, and it is not clear whether separation walls would have mattered in terms of meeting the 1968 code. The PANYNJ adopted guidelines in 1998 that required such partitions to provide a continuous fire barrier from top of floor to underside of slab.

Finding 23: Building codes typically require 1 h fire-rated tenant separations but do not impose minimum compartmentation requirements (e.g., 13,000 ft^2) for buildings with large open floor plans to mitigate the horizontal spread of fire. This is the case with both the 1968 NYC Building Code, which did not require sprinklers in occupied spaces on or above the ground floor, and the 2001 NYC Building Code, which requires sprinklers in Group E (Business) buildings over 100 feet in height. The sprinkler option was chosen for the WTC towers in preference to the compartmentation option in meeting the subsequent requirements of Local Law 5 adopted by New York City in 1973. Thus, if there was only one tenant on a WTC floor there would be no horizontal compartmentation requirement. Conversely, if there were a large number of tenants on a WTC floor, it would be highly compartmented with separation walls. The affected floors in the WTC towers were mostly open—with a modest number of perimeter offices and conference rooms and an occasional special purpose area. Some floors had two tenants and those spaces, like the core areas, were partitioned (slab to slab). Photographic and videographic evidence confirms that even non-tenant space partitions (such as those that divided spaces to provide corner conference rooms) provided substantial resistance to fire spread in the affected floors. For the duration of about 50 min to 100 min prior to collapse of the WTC towers that the fires were active, the presence of undamaged 1 h fire-rated compartments may have assisted in mitigating fire spread and consequent thermal weakening of structural components.

Finding 24: State and local building regulations are needed that require installation of sprinklers in existing buildings on a reasonable time schedule, not as an option in lieu of compartmentation. Functioning sprinklers can provide significant improvement in safety for most common building fires and prevent them from becoming large fires. NYC promulgated local laws in 1973 and 1984 to encourage installation of sprinklers in new buildings and is now considering a law to require sprinklers in existing buildings. The WTC towers were fully sprinklered by 2001, about 30 years after their construction. Sprinklering of the tenant floors in the WTC towers was completed by October 1999, while sprinklering of the skylobbies was still underway at that time. The sprinkler system was installed in three phases. Phase 1 was completed during initial building construction and included the sub-grade areas. Phase 2 was completed in 1976, in compliance with Local Law 5, and included sprinklering the corridors, storage rooms, lobbies, and certain tenant spaces. Phase 3 was begun in 1983 and completed in 2001 and resulted in fully sprinklering the buildings.

Finding 25: Modern building codes allow a lower fire rating for structural elements when a building is sprinklered. This trade-off provides an economic incentive to encourage installation of sprinklers. Sprinklers provide better intervention against small and medium fires, fires which are more likely to occur than a WTC disaster, as long as the water supply is not compromised and there is redundant technology in

place. The required technical basis is not available to establish whether the "sprinkler trade-off" in current codes adequately considers fire safety risk factors such as: (1) the complementary functions of sprinklers and fire-protected structural elements, (2) the different fire scenarios for which each system is designed to provide protection, and (3) the need for redundancy should one system fail. It is noteworthy that the British Standards Institution has established a group to review all the sprinkler trade-offs contained in their standards. No such formal review has yet been initiated in the United States. Although the classification and fire rating of the WTC towers did not take advantage of the sprinkler-tradeoff since such provisions were not contained in the 1968 NYC Building Code, had such provisions existed, they would have permitted a lower fire rating for many WTC building elements.

Use of Elevators in Emergencies

Finding 26: With a few special exceptions, building codes in the United States do not permit the use of fire-protected elevators for routine emergency access by first responders or as a secondary method (after stairwells) for emergency evacuation of building occupants. The use of elevators by first responders would additionally mitigate counterflow problems in stairwells. While the United States conducted research on specially protected elevators in the late 1970s, the United Kingdom along with several other countries that typically utilize British standards have required such "firefighter lifts," located in protected shafts, for a number of years. Without functioning elevators (e.g., due to a power failure or major water leakage), first responders carrying gear typically require about a minute per floor to reach an incident using the stairs. While it is difficult to maintain this pace for more than about the first 20 stories, it would take a first responder about an hour to reach, for example, the 60th floor of a tall building if that pace could be maintained. Such a delay, combined with the resulting fatigue and physical effects on first responders that were reported on September 11, 2001, would make firefighting and rescue efforts difficult even in tall building emergencies not involving a terrorist attack. Each of the WTC towers had 106 elevators, and WTC 7 had 38 elevators. By code, the elevators could not be used for fire service access or occupant egress during an emergency since they were not fire-protected, nor were they located in protected shafts. The elevators were equipped through normal modernization with fire service recall. Most were damaged by the aircraft impacts; though prior to the impact in WTC 2 the elevators were functioning and contributed greatly to the much faster initial evacuation rate in WTC 2.

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Chapter 14
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PANYNJ (Port Authority of New York and New Jersey). 1999. World Trade Center – Code Compliance Evaluation, October 15 (WTCI-161-P).

Rivera and Rinaldi. 1993. Report on Fire and Building Codes and the Jurisdiction and Compliance of Federal, State, State Authorities and Foreign Government Buildings, Carlos M. Rivera, Fire Commissioner and Rudolph J. Rinaldi, Commissioner of Buildings, March 25.

Robertson, Leslie, and See, Saw-Teen. 1987. Preliminary Design of High-Rise Buildings, Chapter 11, Building Structural Design Handbook, Richard White and Charles Salmon, editors, John Wiley & Sons, New York, NY.

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SHCR (Skilling, Helle, Christiansen, & Robertson). 1967. Viscoelastic Damping Units, The World Trade Center Report No. DU-3 (WTCI-1006-L).

Simiu, Emil, and Scanlan, Robert H. 1996. *Wind Effects on Structures*, John Wiley & Sons, Inc, New York, NY.

Solomon, Joseph H. (Emery Roth & Sons). 1975. Letter to Malcolm P. Levy (General Manager, World Trade Center Operations), February 18.

Sullivan, Richard C. 1964. New Concept in Vertical Transport, *Westsider*, 29, Fall.

UBC (Uniform Building Code). 1988. Uniform Building Code, International Conference of Building Officials, Whittier, CA.

UL (Underwriters' Laboratories). 2001. Fire Resistance Directory 2001, Underwriters Laboratories, Inc. Northbrook, IL 60062.

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Appendix A
SUPPORTING DOCUMENTS FOR CHAPTER 1

This appendix contains the supporting documents that are referenced in Chapter 1 of this report. All of the documents contained in this appendix are reproduced with permission of The Port Authority of New York and New Jersey. Table A–1 contains a summary of supporting documents and their location within this appendix. The footnote numbers given in the table correspond to those in Chapter 1.

Table A–1. Supporting documents for Chapter 1.

Footnote Number	Document Title	Page(s)
2	Letter dated May 15, 1963, from Malcolm P. Levy (Chief, Planning Division, World Trade Department) to Minoru Yamasaki (Minoru Yamasaki & Associates)	194
3	Letter dated September 29, 1965, from Malcolm P. Levy (Chief, Planning Division, World Trade Department) to Minoru Yamasaki (Minoru Yamasaki & Associates)	195
4	Memorandum dated June 22, 1965, from John M. Kyle (Chief Engineer, PANYNJ) to Malcolm P. Levy (Chief, Planning Division, World Trade Department)	196
5	Memorandum dated January 15, 1987, from Lester S. Feld (Chief Structural Engineer, World Trade Department) to Robert J. Linn (Deputy Director for Physical Facilities, World Trade Department)	197
6	Letter dated February 18,1975, from Joseph H. Solomon (Emery Roth & Sons) to Malcolm P. Levy (Chief, Planning Division, World Trade Department)	199

K40-1

6211 - A1

L. SCHREIER

RECEIVED

THE PORT OF NEW YORK AUTHORITY

111 Eighth Avenue at 15th Street New York 11 NY

ALGONQUIN 5-1000

WORLD TRADE CENTER

Dear Yama:

At a recent meeting with Mr. John Kyle, Chief Engineer, the subject of New York City Code compliance was further amended as follows:

"All consulting engineers and architects working on the World Trade Center have been instructed to comply with the Code in preparing their designs. Questions have arisen, however, in areas where the Code is not explicit. It was agreed that in such cases and, where technological advances make portions of the Code obsolete, the consultants may propose designs based on acceptable engineering practice. All such instances will be called to the attention of The World Trade Center Planning Division. When preliminary designs have been completed, the Chief Engineer will review all design concepts with the appropriate municipal agencies before the consultants proceed with the final design".

Sincerely,

Malcolm P. Levy
Chief, Planning Division

LF:db
cc: Mr. J. Roth (ERS)

(2.1)

6211
R 110-4

THE PORT OF NEW YORK AUTHORITY

111 Eighth Avenue at 15th Street New York NY 10011 CC R 40-1

620-8233

WORLD TRADE CENTER

Malcolm P. Levy
CHIEF, PLANNING DIVISION

Richard C. Sullivan
DIRECTOR

September 29, 1965

Mr. Minoru Yamasaki
Minoru Yamasaki & Associates
1025 East Maple Road
Birmingham, Michigan 48011

Dear Yama:

We have decided to adopt the new Building Code presently existing in second and third draft form for The World Trade Center.

The Roth office is requested to revise floor plans as quickly as possible and on an accelerated basis to comply with the provisions of this code. It is my understanding that the present drawings have been prepared to permit rapid conversion to the new code. Generally the tower core should be redesigned to eliminate the fire towers and to take advantage of the more lenient provisions regarding exit stairs. No other major change to the core should be undertaken without review by this office.

e structural consultants are instructed, by copy of this letter, to r
evise structural design in accordance with the more realistic cr
iteria for partition weight allowance. The majority of interior
partitions, as noted in a previous letter, will consis of reinforce
d gypsum plank.

The Roth office is requested to provide me with the dates on which we can expect revised floor plans and also to indicate any changes in design schedule caused by these instructions.

Sincerely,

Malcolm P. Levy

cc: R. Baum (JBB), J. Loring (JRLA), J. Roth (ERS), J. Skilling and L. Robertson (WSHJ)

Similar letter sent to Mr. Julian Roth (ERS)

MEMORANDUM

PA 90-A
5-63

REFER TO	DATE	NOTED BY	DATE
RETURN TO		FILE	

TO: Malcolm P. Levy, Chief, Planning Div., W.T.C.
FROM: John M. Kyle
DATE: June 22, 1965
SUBJECT: WORLD TRADE CENTER - NEW BUILDING CODE

REFERENCE:

COPY TO: Miss Skehan; Messrs. Tozzoli, Winters

This will confirm my advice that, in view of the more liberal provisions of the proposed new New York City Building Code, I feel we should take advantage of its provisions.

This decision is based on the following:

1. The new code has received thorough review by interested technical groups and representatives of the City and has been modified to meet all major objections.

2. It is scheduled to be officially submitted to the City in September and should be approved well before we construct our buildings.

3. The Commissioner has stated that he favors the approach taken by the Port Authority in using advanced techniques in the design of the World Trade Center. He also stated that the Port Authority is not subject to the provisions of the Building Code.

File

John M. Kyle
Chief Engineer

PORT AUTHORITY OF NY & NJ
OFFICE OF CHIEF ENGINEER OF DESIGN
INFRASTRUCTURE

RECEIVED
NOTED:
REFERRED TO:

M E M O R A N D U M

TO: Robert J. Linn, Deputy Director for Physical Facilities, WTD
FROM: Lester S. Feld
DATE: January 15, 1987

SUBJECT: THE WORLD TRADE CENTER - TOWERS & PLAZA BUILDINGS FIRE RATING PER NYC BUILDING CODE REVISION EFFECTIVE 12-6-68

REFERENCE:
(1) - Memo - M. Levy to File - dated 4-20-65
(2) - Letter - L. Robertson (WSHJ) to M. Levy - dated 4-26-65
(3) - Letter - M. Levy to M. Gerstman (TRCC) - dated 5-14-69
(4) - Office Memo - W. Bracco (TRCC) to J. Endler (TRCC) - dated 5-26-69
(5) - UL Fire Test Report from T. P. Feit - dated 7-26-69
(6) - Letter - A. F. Abbasi (UL) to T. P. Feit (Zonolite) - dated 3-26-70
(7) - Buckslip - V. Dovletian to D. Bais - dated 1-9-87
(8) - Page 4 - Item 1C of Issue A entitled "Office Space Design Guide"

COPY TO: D. Bais, J. Carlock, A. Cracchiolo, V. Dovletian, P. Martinez (ERS)
D. Montalbano, A. Preschle, J. Pugh (LERA), L. Robertson (LERA)
A. Vaccaro - All w/Reference 1 - 8 attached.

1/28 Please review and give me your comments. Tony C.

COPY TO
AGC
LL
AN
VAD
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BE
BT
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POST

1. On January 13, 1987 I contacted Richard Roth, Jr. (ER&S) regarding the subject fire ratings, normally established by the Architect. Mr. Roth referred me to Phil Martinez for the required information.

2. Phil's recollection (since ER&S had given all their WTC tracings to our Planning Division) was as follows:

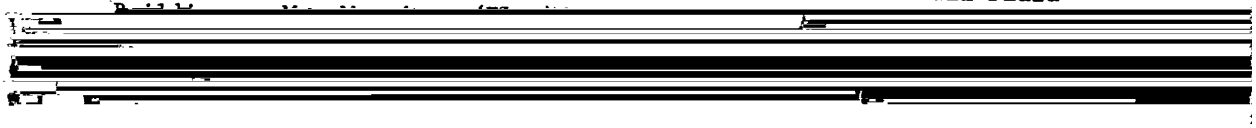
   A. The egress requirement and fire ratings used to design the WTC Towers & Plaza Buildings were in accordance with the provisions of the planned NYC Building Code revisions effective December 8, 1968. Normally fire ratings are not shown on the Architectural Working Drawings or in the General Notes. The fire ratings are given only on the application forms filed with the plans for NYC Building Department Approval. Since the Port Authority is not subject to the NYC Building Code Requirements, no plans or forms were filed.

   B. For office buildings there is no economic advantage in using Class 1A Construction, and ER&S used Class 1B Construction for the WTC Towers and Plaza Buildings which are Occupancy Group "E" (Business) with a fire index of 2 hours. As such, columns must have 3 hour fire rating and floor construction with a 2 hour rating.

3. Please note that Reference #3 by Mal Levy was concurred in by W. Bracco (TRCC) in Reference #4, with regard to Class 1-B Construction cited by Mr. Martinez. In addition, References #1 & #2 (written in 1965) are superseded by References #3 & #4 (written in 1969).

4. For your information and use I have also attached References #5 & #6 on the UL Test of floor construction showing a 3 hour rating. Please note that the UL Test is based on the use of 1½" thick Monokote Fireproofing on joists and ½" thick Monokote on steel deck. Actually - Cafco - Type "D" spray-on was used at the WTC on joists only, in lieu of Monokote. In addition, the UL Test used stone-concrete slab with a thickness of 2' 3/4" over top of corrugated deck, as compared to the 4" lightweight concrete slab used at the WTC.

5. With regard to Reference #7, no joists were used in the floor construction of 3 WTC, 4 WTC, or 5 WTC - rolled beam are used in all Plaza



Lester S. Feld
Chief Structural Engineer
World Trade Department

EMERY ROTH & SONS
850 THIRD AVENUE, NEW YORK, N. Y. 10022 (212) 753-1733

RICHARD ROTH, Sr., F. A. I. A.
HARRY J. HARMAN, A. I. A.
RICHARD ROTH, Jr., A. I. A., R. I. B. A.
JOSEPH H. SOLOMON, A. I. A.

JULIAN ROTH
ADMINISTRATION
ESTELLE BEAL
CONTROLLER
PHILIP MARTINES
CHIEF DRAFTSMAN

February 18, 1975

Mr. Malcolm P. Levy
General Manager
World Trade Center Operations
Port Authority New York, New Jersey
1 World Trade Center
New York, New York 10047

RE: WORLD TRADE CENTER

Dear Mal:

In accordance with the instructions issued by the Port Authority at the start of the project, construction drawings for the World Trade Center were to conform with requirements of the Building Code of New York City, and any variations therefrom were to be called to the attention of the Port Authority for final decision and authorization. This procedure has been followed in production of the contract drawings and, with the exceptions authorized by the Port Authority noted below, the drawings are in accordance with the new Building Code adopted in December, 1968. The Building Department reviewed the tower drawings in 1968 and made six comments concerning the plans in relation to the old code. Specific answers noting how the drawings conformed to the new code with regard to these points were submitted to the Port Authority on March 21, 1968.

We were instructed by the Port Authority to deviate from code with respect to the following areas:

1. Omission of vents from closed shafts. Noted to the Port Authority by letter dated April 20, 1967.

2. Demising partitions to stop at suspended ceiling or bottom of truss instead of running from slab to slab. Noted to the Port Authority by letters dated November 9, 1967 and June 6, 1969 with response on December 12, 1967. Prior instruction on procedure from Port Authority dated January 26, 1966.

3. Omission of fire protected openings on exterior walls with separation of less than 30 feet. Noted to Port Authority by copy of letter to MYA dated January 26, 1966.

4. Treatment of concourse level as "Underground Street" noted by letter to the Port Authority on April 6, 1971, January 11, 1972 and May 7, 1973.

Fire detection and protection requirements specified for the World Trade Center meet or exceed Building Code requirements prior to the adoption of Local Law #5. Most other office towers in the City of New York meet the minimum code requirements:

A. Telephone system for Fire Department use connecting pump room and gravity tank room with all floors. A six inch gong provided at permanent telephone at pump room, first floor and gravity tank room. Telephone jacks at all other floors protected by break glass boxes.

B. Standpipe signalling device: an eight inch gong located in the pump room and every 10 floors in the elevator shaft; an approved closed circuit strap key enclosed in a sheet metal box at each telephone station for fire department use.

The Building Code permits the use of louvered doors on toilet rooms, janitor and electric closets located in 1 hour rated corridors. There is no size limit specified for the louver, but the Board of Standards and Appeals permits louvers of 2 square feet in 3/4 hour rated doors (which are required in 1 hour rated partitions). Up until about 1968 most office buildings had 1 hour minimum rated enclosures and louvered doors in telephone closets and sleeves or small slots through the floor. Since 1968, about 25 percent still have louvers in the doors. In more recent buildings the floor openings have been slabbed over.

Since corridor construction is required by code to be 1 hour rated, it follows that louvered doors were acceptable in tele-

phone closets. Corridor partitions in the Trade Center Towers, however, were designed to meet 2 hour rated construction at the request of the Port Authority, to forestall any problems with dead end limitations in the new code. It would require investigation of individual floor tenant layouts to determine if the dead end limitation of 50 feet for 1 hour construction has been exceeded.

The original contract drawings, dated 7/31/67 and the Contract Bid Sets dated 12/18/67 and 2/9/68 indicate 2 hour rated enclosures for the telephone closets with louvers in a FPSC, 1-1/2 hour label door. The hollow metal door specification written in 1967 and received by the Port Authority on 10/24/67 called for fusible link dampers on louvers in labeled doors. Letters to the Port Authority dated 8/23/67 and 9/6/67 incated that variances had been obtained for omission of dampers and requested instruction regarding this advice. The requirement for dampers was deleted from the final draft of the specification reviewed by the P.A. in May, 1968. Re quirement to meet provisions of underwriter's labs, B.S.A. and Building Department was retained, however, for doors with F.P.S.C. and hourly ratings.

Based on Port Authority comments on drawings received 4/17/69 and pursuant to a letter from the Port Authority to Tishman Construction Company dated 4/28/69 instructing that such changes be made, the wall of the telephone closet was changed to 1 hour rated construction on 5/23/69 and the door was changed to F.P. with a 1-1/2 hour rating. Since the telephone closet was no longer a shaft with a 2 hour rated enclosure, all floor openings left for future installation of cables had to be firestopped. This admonition was reiterated in a letter to the Port Authority dated June 25, 1973.

Please inform us if any additional information is desired.

Sincerely,

EMERY ROTH & SONS

Joseph H. Solomon

JOSEPH H. SOLOMON

JHS:am
CC: Mr.R. Monti, Chief Engineer/ PA

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Appendix B
SUPPORTING DOCUMENTS FOR CHAPTERS 2 AND 3

This appendix contains the supporting documents that are referenced in Chapters 2 and 3 of this report. All of the documents contained in this appendix are reproduced with permission of The Port Authority of New York and New Jersey. Table B–1 contains a summary of supporting documents and their location within this appendix. The footnote numbers given in the table correspond to those in Chapters 2 and 3.

Table B–1. Supporting documents for Chapter 3.

Footnote Number	Document Title	Page(s)
13	Memorandum of Understanding Between the New York City Department of Buildings and the PANYNJ 1993 (WTCI-160-P)	204
14	Supplement to Memorandum of Understanding Between the New York City Department of Buildings and the PANYNJ 1995 (WTCI-113-P)	208
15	Original letter dated January 25, 1968 from Joseph H. Solomon (Emery Roth & Son) to Malcolm P. Levy (General Manager, World Trade Center Operations). Illegible copy received from PANYNJ.	212
15	Letter dated January 25, 1968, from Joseph H. Solomon (Emery Roth & Son) to Malcolm P. Levy (General Manager, World Trade Center Operations) reconstructed by NIST.	214

THE PORT AUTHORITY OF NY & NJ

One World Trade Center
New York, New York 10048

Law Department

Jeffrey S. Green
General Counsel

Lawrence S. Hofrichter, Chief
Finance Division
(212) 435-6220
(201) 961-6600 x6220

November 5, 1993

THE PORT AUTHORITY OF N.Y. & N.J.
TENANT CONSTRUCTION REVIEW UNIT
RECEIVED
NOV 09 1993
NOTED
REFERRED TO

Charles G. Sturcken, Deputy General Counsel
The New York City
Department of Buildings - Executive Offices
60 Hudson Street
14th Floor
New York, New York

Dear Mr. Sturcken:

Enclosed please find a fully executed original of the Memorandum of Understanding between the Port Authority and the New York City

Walter M. Frank
Deputy Chief, Finance Division
Law Department

Enclosures

cc: William H. Goldstein, Deputy Executive Director, Capital Programs

bcc: J.S. Green, P.S. Cooper (51N), A.A. DiNome (68S), E.J. Fasullo (72S), L.S. Hofrichter, F.J. Lombardi (72S), C.J. Maikish (35E), A.J. Raiola, S.T. Van de Walle

MEMORANDUM OF UNDERSTANDING BETWEEN THE NEW YORK CITY DEPARTMENT OF BUILDINGS AND THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY

This Memorandum shall govern the relationship between the New York City Department of Buildings (the "Department") and the Port Authority of New York and New Jersey (the "Port Authority"), both parties entering into this agreement with the intention to establish procedures to be followed by the Port Authority for any building construction project ("Project"), to be undertaken by the Port Authority or any of its tenants at buildings owned or operated by the Port Authority and located in the City of New York (the "City), to assure conformance of Projects at such buildings with the standards set forth in the New York City Building Code (the "Code").

While the facilities of the Port Authority, an agency of the States of New York and New Jersey, are not technically subject to the requirements of local building codes, the long-standing policy of the Port Authority has been to assure that its facilities meet and, where appropriate, exceed Code requirements.

The purpose of this Memorandum is not only to restate that long-standing policy as part of an understanding with the City but to provide specific commitments to the Department, as the agency of the City responsible for assuring compliance with the Code, regarding procedures to be undertaken by the Port Authority for any Project at its facilities in the City to assure that the buildings owned or operated by the Port Authority within the City are in conformance with the Building Standards contained in the Code.

Accordingly, the Department and the Port Authority hereby agree as follows:

1. Port Authority Review. To assure conformance with the building standards set forth in the Code at the time of the design and construction of any Project, the Port Authority shall, in the case of each Project, thoroughly review and examine all plans in connection with such Project for conformance with the building standards set forth in the Code. Plans prepared for Projects to be undertaken by Port Authority tenants shall be prepared and sealed by a New York State licensed professional engineer or architect retained or employed by tenant; plans prepared for Projects to be undertaken by the Port Authority shall be prepared by a New York State licensed professional engineer or architect employed or retained by the Port Authority. The Port Authority's examination of plans shall be conducted by New York State licensed architects and engineers retained or employed by the Port Authority. The Port Authority engineer or architect approving the plans for any Project from the standpoint of Code conformance shall be a New York State licensed architect or engineer who shall not have assisted in the actual preparation of such plans.

2. Project File. The Port Authority shall maintain a file (the "Project File") for each Project which file shall at all times contain the most recently

prepared drawings, plans and any other documents required in connection with the review of the Project from the standpoint of Code conformance. In the case of any Project being effectuated by a tenant of the Port Authority (a "Tenant Project") such file shall also include the Tenant Alteration Application prepared by the Tenant. In the case of any project administered by a line department of the Port Authority, such file shall include any construction application prepared in connection with such Project. The Line Departments of the Port Authority are currently its World Trade, Aviation, Interstate Transportation, Port, and Regional Development Departments.

3. Project Certification. For each Tenant Project, the Port Authority shall require the Tenant to obtain the certification of a New York State licensed architect or engineer that such Project was constructed in accordance with the approved plans and specifications for such Project. For any Project effectuated by the Port Authority, the Chief Engineer or his successor in duties shall certify that the Project was constructed in accordance with the approved plans and specifications for the Project. Certifications for each Project shall be maintained in the Project File.

4. Copies of Project File. The Department may at any time request the Port Authority to provide it with a copy of any Project File and the Port Authority shall promptly provide a copy of the Project File to it.

5. Variances. The Port Authority shall promptly advise the Department of any Project approved by the Chief Engineer of the Port Authority which involves, in the judgment of the Chief Engineer of the Port Authority or his successor in duties, a variance from the clear requirements of the Code. In the event that the Department disagrees with the manner in which questions of Code conformance have been or are proposed to be dealt with in connection with such Project, it may so advise the Authority. The Port Authority shall seek expeditiously to resolve the matter. Any matter of Code conformance in connection with such Project which the Department believes involves an unacceptable variance from the requirements of the Code shall be subject to the further review of the Port Authority Board of Commissioners. The Commissioners shall be advised of the Department's views on the matter.

6. Inspections and Surveys. The Port Authority shall continue to conduct or cause to be conducted all building inspections, during both construction and post-construction periods, required under the Code. In addition, the Port Authority will continue to perform structural integrity inspections on a cyclical basis for all of its structures located in the City.

7. Port Authority Responsibility. As indicated above, the purpose of this Agreement is to set forth certain basic understandings between the Department and the Port Authority. It is understood, however, that the Port Authority with its tenants shall continue to bear the responsibility for life safety in buildings at its facilities and nothing in this Agreement is intended to impose any obligations of inspection or review on the Department. The Department shall refer back to the Chief Engineer of the Port Authority any requests for

information or interpretation which it may receive from tenants of the Port Authority with respect to any Project.

8. No Personal Liability. No Commissioner, officer, agent or employee of the Port Authority or the Department shall be held personally liable under any provision of this Agreement or because of its execution or attempted execution or because of any breach or alleged breach thereof.

IN WITNESS WHEREOF, the parties hereto have caused this instrument to be signed, sealed and attested.

ATTEST:

Secretary

DATE: 11/3/93

THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY

By: Stanley Brezenoff
Executive Director

ATTEST:

FRANK M. SCHWARTZ
Notary Public, State of New York
No. 41-4632586
Qualified in Queens County
Commission Expires January 31, 19 95

DATE: 10/28/93

THE NEW YORK CITY DEPARTMENT BUILDINGS

By: Stewart D. O'Brien
Acting Commissioner

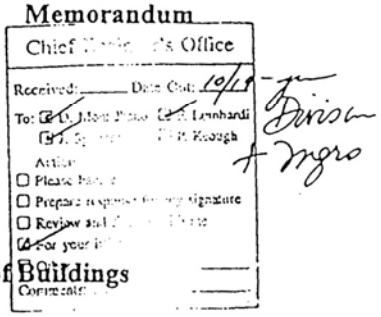
Frank M. Schwartz

3

THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY
Commercial Litigation Division (68E)

Memorandum

OCT 18 AM : 02



TO: Lysa Meduri, Acting Secretary
FROM: Walter M. Frank
DATE: October 16, 1995
SUBJECT: **Transmittal of Letter Agreement - NYC Department of Buildings**

Copy to: J. Green, N. Chanfrau, P. Cooper, W. Goldstein, H. Henschel, F. Lombardi

Transmitted for the official records of the Port Authority is a Letter Agreement between the Port Authority and the New York City Department of Buildings providing for a change to the recent Supplement to the Basic Memorandum of Understanding between the Department and the Port Authority in connection with the Port Authority's Tenant Self-Certification Program at the World Trade Center.

Walter M. Frank
Deputy Chief
Commercial Litigation Division

WMF:gk

Encl.

THE PORT AUTHORITY OF NY & NJ

One World Trade Center
New York, N.Y. 10048

William H. Goldstein
Deputy Executive Director/
Capital Programs
(212) 435-8415
(201) 961-6000 x8415

September 15, 1995

Honorable Joel A. Miele, Sr., Commissioner
Department of Buildings
City of New York
60 Hudson Street
New York, New York 10013

Dear Commissioner Miele:

As you know, the Port Authority of New York and New Jersey (the "Port Authority") and the New York City Department of Buildings (the "Department") recently executed a supplement (the "Supplement") to the Memorandum of Understanding between the Department and the Port Authority to provide that the Port Authority's tenant at the World Trade Center could, in lieu of any review by the Port Authority, use New York State licensed architects or engineers meeting qualifications to be established by the Port Authority to: (A) prepare and review such tenant's plans for the construction of any project and certify that such plans conform with the building standards set forth in the New York City Building Code and (B) certify that such project has been constructed in accordance with the approved plans and specifications for such project.

As you also know, the Supplement provides that the person or firm performing the review and certification described in (A) above shall not be the same person or firm providing the certification described in (B) above. A copy of the Supplement is attached.

This letter will-confirm the agreement of the Port Authority and the Department that, notwithstanding the last sentence of paragraph 1 of the Supplement, a single licensed consultant may make both certifications described in (A) and (B) of such paragraph, except where the alteration would change the character of the occupancy group under paragraph 27-237 of the New York City Building Code which would have been applicable to such space had such space been located in a privately owned building.

If the foregoing meets with your approval, please be good enough to sign this letter on behalf of the Department where indicated below and return one of the originals to me. In light of the fact that three originals of the Supplement were furnished to the Department, we have, for your record purposes, executed in total four originals of this letter.

Very truly yours,

William H. Goldstein
Deputy Executive Director
Capital Programs

THE NEW YORK CITY DEPARTMENT OF BUILDINGS

AGREED

BY: _____
Commissioner

SUPPLEMENT TO MEMORANDUM OF UNDERSTANDING
BETWEEN THE NEW YORK CITY DEPARTMENT OF
BUILDINGS AND THE PORT AUTHORITY OF NEW
YORK AND NEW JERSEY

In November, 1993 the New York City Department of Buildings (the "Department") and the Port Authority of New York and New Jersey (the "Port Authority") entered into the attached Memorandum of Understanding (the "Memorandum") establishing certain procedures for the purpose of helping to assure conformance of construction projects to be undertaken at buildings owned or operated by the Port Authority in New York City with the standards set forth in the New York City Building Code.

Recently, the Department implemented its own optional plan review system providing for professional certifications of applications and plans and subsequent construction work falling under its jurisdiction.

The purpose of this Supplement to the Memorandum is to provide under the Memorandum for the adoption by the Port Authority of a procedure under which any Port Authority tenants at the World Trade Center may utilize New York State licensed architects or engineers to certify, in lieu of any review by the Port Authority, that (i) the tenant's construction plans are in conformance with the standards set forth in the New York City Building Code, and (II) construction has been performed in accordance with such plans, it being understood that the persons making the certifications described in (i) and (II) shall not be the same.

Accordingly, the Department and the Port Authority hereby agree that the Memorandum is amended as follows:

1. Professional Certification. Notwithstanding anything to the contrary in the Memorandum, the Port Authority may, in lieu of any reviews or certifications by the Port Authority provided for in the Memorandum, provide procedures pursuant to which its tenants at the World Trade Center may utilize New York State licensed architects or engineers meeting qualifications to be established by the Port Authority to (A) prepare and review such tenant's plans for the construction of any project and certify that such plans conform with the building standards set forth in the New York City Building Code and (B) certify that such project has been constructed in accordance with the approved plans and specifications for such project. The person or firm performing the review and certification described in (A) above shall not be the same person or firm providing the certification described in (B) above.

2. Other Provisions. Except as provided herein, all the terms and conditions of the Memorandum shall remain in full force and effect.

3. No Personal Liability. No Commissioner, officer, agent or employee of the Port Authority or the Department shall be held personally

liable under any provision of this Supplement or because of its execution or attempted execution or because of any breach or alleged breach thereof.

IN WITNESS WHEREOF, the parties hereto have caused this Instrument to be signed, sealed and attested.

ATTEST:

THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY

By:

DATE: 6/2/95

WITNESS:

FRANK M. SCHWARTZ
Notary Public, State of New York
No. 41-4632586
Qualified in Queens County
Commission Expires Jan. 31, 19 97

THE NEW YORK CITY DEPARTMENT OF BUILDINGS

By:
Commissioner

DATE: 6/1/95

COPY

EMERY ROTH & SONS
PRU THIRD AVENUE
NEW YORK, N. Y. 10022

January 23, 1958

Mr. Malcolm P. Levy, Chief
Planning & Construction Division
The World Trade Center
The Port of New York Authority
111 Eighth Avenue
New York, New York

Re: The World Trade Center
Building Department Review

Dear Mal:

We have reviewed the comments submitted by Commissioner Ferro with regard to conformance of the World Trade Center with the Building Code. The Tower plans adhere to the Proposed Building Code with respect to all five points noted.

1. The Proposed Code provides for a stair capacity of 60 persons per 22 inch unit of width. Each Tower floor has two 3'-8" stairs (two units each) and one 4'-6" stair (two and one half units) for a total of 6½ units. The stairs, therefore have a capacity of 390 persons per floor. The largest floor area is about 36,500 square feet net on the 106th floor. At one person per hundred square feet, there will be 365 persons per floor; well within the permissible maximum.

2. The maximum travel distance from the most remote corner of the upper floors to a stair is about 140 feet. The Proposed Code permits a maximum travel distance of 200 feet in a fireproof building in Occupancy Group Classification E (business).

3. No fire tower is required under the Proposed Code.

January 25, 1968

Mr. Malcolm P. Levy, Chief

Planning and Construction Division

The World Trade Center

111 Eighth Avenue

New York, New York

Re: The World Trade Center Building Department Review

Dear Mal,

We have reviewed the comments submitted by Commissioner Ferro with regard to conformance of the World Trade Center with the Building Code. The Tower plans adhere to the Proposed Building Code with respect to all five points noted.

1. The Proposed Code provides for a stair capacity of 60 persons per 22 inch unit of exit width. Each Tower floor has two 3' 8" stairs (two units each) and one 4' 8" stair (two and one half units) for a total of 6 ½ units. The stairs, therefore, have a capacity of 390 persons per floor. The largest floor area is about 36,500 square feet net on the 106th floor. At one person per hundred square feet, there will be 365 persons per floor, well within the permissible maximum.
2. The maximum distance ---corner of the --- is about 140---. The Proposed Code permits a maximum travel distance of 200 feet in an unsprinklered building in occupancy group classification E (business).
3. No fire tower is required under the Proposed Code.
4. All cellar stairs are completely enclosed in two hour fire-rated masonry construction as required by the Proposed Code. Each cellar stair is contained in a continuous enclosure leading directly to the street, the street floor lobby, or the Concourse floor landing to the street. The Concourse floor is considered as an underground street in accordance with the interpretation made by the Port Authority.
5. The cellar stairs that are to be used for tenant storage are less than ten percent of the total area of the building. In accordance with the Proposed Code, therefore, they are treated the same as office building with regard to egress requirements.

The garage spaces are limited to storage of cars with a maximum tank capacity of 26 gallons. There will be no servicing of cars or dispensing of fuel. All garage areas will be sprinklered. The Proposed Code limits the maximum distance to stairs for this type of garage to 150 feet without distinction to garages above or below grade. The World Trade Center is in conformance with these requirements.

Cordially,

Signed by Joseph H. Solomon

Emory Roth & Sons

NIST NCSTAR 1-1A

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Design and Construction of Structural Systems

David A. Fanella
Arnaldo T. Derecho
S. K. Ghosh

NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

NIST NCSTAR 1-1A

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Design and Construction of Structural Systems

David A. Fanella
Arnaldo T. Derecho
S. K. Ghosh
S. K. Ghosh Associates, Inc.

September 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

Disclaimer No. 1

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Disclaimer No. 2

The policy of NIST is to use the International System of Units (metric units) in all publications. In this document, however, units are presented in metric units or the inch-pound system, whichever is prevalent in the discipline.

Disclaimer No. 3

Pursuant to section 7 of the National Construction Safety Team Act, the NIST Director has determined that certain evidence received by NIST in the course of this Investigation is "voluntarily provided safety-related information" that is "not directly related to the building failure being investigated" and that "disclosure of that information would inhibit the voluntary provision of that type of information" (15 USC 7306c).

In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

Use in Legal Proceedings

No part of any report resulting from a NIST investigation into a structural failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a; as amended by P.L. 107-231).

National Institute of Standards and Technology National Construction Safety Team Act Report 1-1A
Natl. Inst. Stand. Technol. Natl. Constr. Sfty. Tm. Act Rpt. 1-1A, 166 pages (September 2005)
CODEN: NSPUE2

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ABSTRACT

This report describes the provisions that were used to design and construct World Trade Center 1, 2, and 7. Included is a summary of the major provisions in the codes and standards together with the loads and load combinations that were used to design the buildings. Methods used to proportion structural members and other components of the buildings are also discussed, as well as tests that were performed to support the design. It is shown that the loads that were used to design the members were at least equal to those prescribed in the applicable codes and standards, and that the methods used to proportion the structural members followed the requirements in the applicable material design standards available at that time.

Also included in this report are the innovative systems, technologies, and materials that were used in the buildings, and the Port Authority's acceptance procedures for such items. Fabrication and inspection requirements at the fabrication yard and inspection protocol during construction are discussed. Also covered are the details of the deviations to contract documents that were granted by the Port Authority, including the justifications for those deviations.

The information contained in this report is based on documents and structural drawings that were acquired from the following locations: (1) the offices of the Port Authority of New York and New Jersey in Newark, New Jersey, and New York City and (2) the National Institute of Standards and Technology in Gaithersburg, Maryland. Paper, microfilm, and electronic versions of these documents were obtained from these locations. Appendixes to this report include copies of referenced documents.

Keywords: Analysis, codes, construction, design, fabrication, innovative systems, inspection, loads, load combinations, materials, standards, tests, deviations, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

3M	Minnesota Mining and Manufacturing Company
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ASTM	ASTM International
AWS	American Welding Society
CSU	Colorado State University
JFK	John F. Kennedy (Airport)
KKE	Karl Koch Erecting Company
LERA	Leslie E. Robertson Associates
NIST	National Institute of Standards and Technology
NPL	National Physical Laboratory
PANYNJ	Port Authority of New York and New Jersey
PDM	Pittsburgh-Des Moines Steel Company
PONYA	Port of New York Authority
PPG	Pittsburgh Plate Glass
SHCR	Skilling, Helle, Christiansen, & Robertson
TRCC	Tishman Realty & Construction Company
WSHJ	Worthington, Skilling, Helle, & Jackson
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

°F	degrees Fahrenheit
cps	cycles per second
ft	foot
ft^2	square foot

ft^3	cubic foot
in.	inch
kip	a force equal to 1,000 pounds
ksi	1,000 pounds per square inch
lb	pound
m	meter
m/s	meters per second
min	minute
mph	miles per hour
pcf	pounds per cubic foot
plf	pounds per linear foot
psf	pounds per square foot
psi	pounds per square inch
s	second

PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

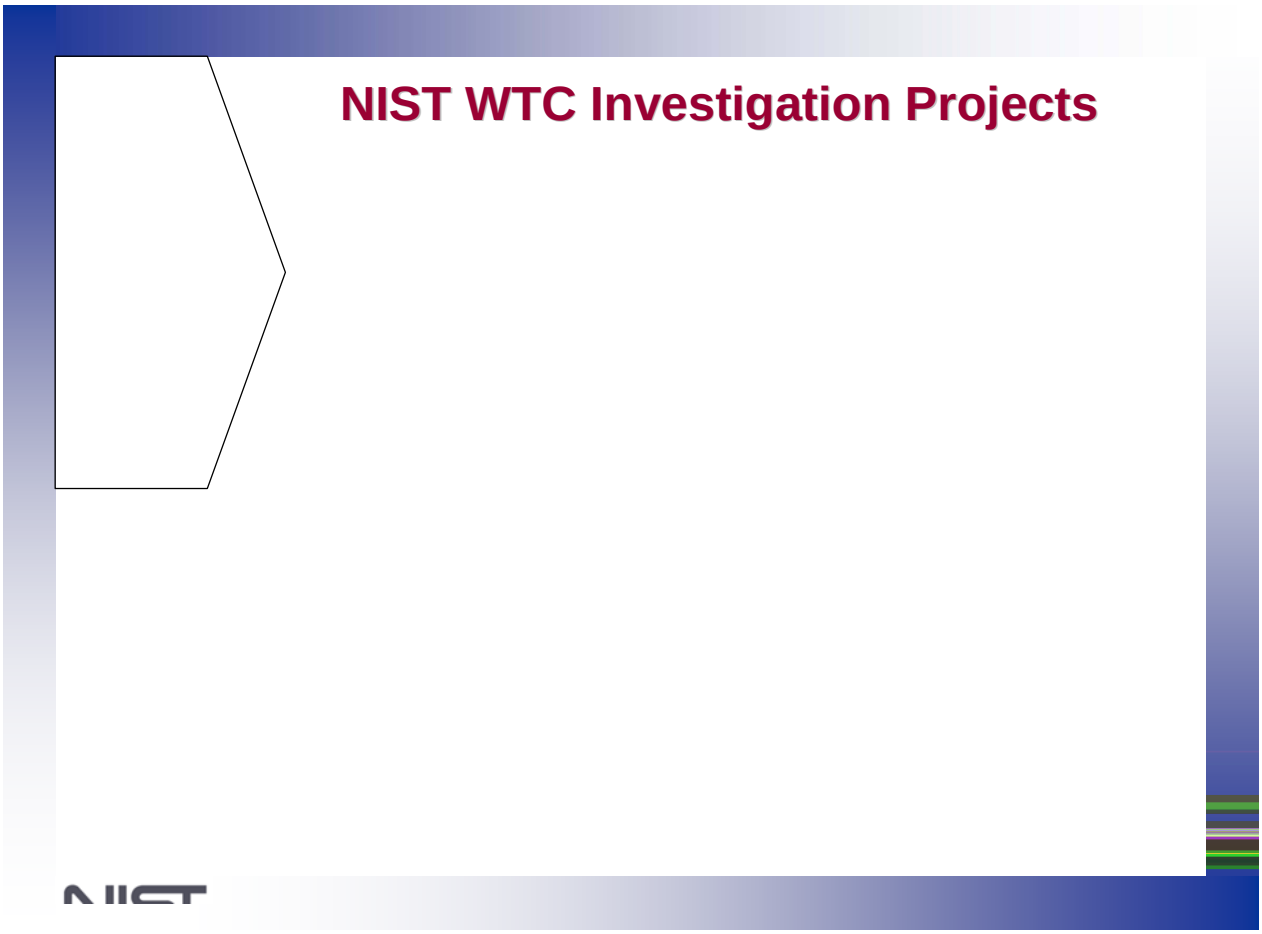
NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.


NIST WTC Investigation Projects

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

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EXECUTIVE SUMMARY

E.1 OVERVIEW

This report contains a summary of the requirements that governed the design and construction of World Trade Center (WTC) buildings 1, 2, and 7. It includes specific information related to the following items: (1) Provisions used to design and construct the buildings; (2) Tests performed to support the design; (3) Criteria that governed the design of the vertical and lateral load resisting systems and the hat-truss systems; (4) Methods used to proportion structural members and other components of the buildings; (5) Innovative systems, technologies and materials, and acceptance procedures used by Port Authority of New York and New Jersey (PANYNJ); (6) Details of variances to contract documents granted by PANYNJ; (7) Fabrication and inspection requirements at the fabrication yard; and (8) Inspection protocol during construction. Documents and structural drawings that were used to accomplish these tasks were acquired from the following locations: (1) the offices of the PANYNJ in Newark, New Jersey, and New York City and (2) the National Institute of Standards and Technology in Gaithersburg, Maryland. Paper, microfilm, and electronic versions of the documents were obtained from these locations. Due to the physical condition of some of the documents, certain portions of some of the documents were illegible. Such items are noted throughout this report. Appendixes to this report include copies of referenced documents.

E.2 PROVISIONS USED TO DESIGN AND CONSTRUCT THE BUILDINGS

E.2.1 WTC 1 and WTC 2

Minoru Yamasaki & Associates and Worthington, Skilling, Helle & Jackson (WSHJ), the architectural and structural engineering firms, respectively, for the project, were instructed by the Port of New York Authority (Port Authority or PONYA) in May of 1963 to prepare their designs for WTC 1 and WTC 2 in accordance with the New York City Building Code. At that time, the 1938 edition of that Code was in effect. In September of 1965, the Port Authority instructed the consultants to revise their designs for WTC 1 and WTC 2 to comply with the second and third drafts of the new New York City Building Code that was under development. The new Code was adopted on December 6, 1968.

Design criteria for WTC 1 and WTC 2 were established for structural members located inside the core area and outside the core area. The design dead loads and live loads specified in the design criteria were greater than or equal to corresponding design loads in the 1968 edition of the New York City Building Code. Live load reduction requirements given in the design criteria were equal to or more stringent than Code requirements.

Wind forces on the towers were determined based on a series of wind tunnel tests that were conducted at the Colorado State University (CSU) and the National Physical Laboratory (NPL), Teddington, Middlesex, United Kingdom. Such tests were permitted by the Code to determine wind pressures in lieu of those tabulated in the Code. Design shear forces and overturning moments on the exterior columns and spandrel beams due to the wind forces were computed at each floor level from data obtained from the wind tunnel tests.

According to the 1968 edition of the New York City Building Code, structural steel members were to be designed and detailed in accordance with the requirements in the 1963 edition of the American Institute of Steel Construction (AISC) *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings*, with some modifications.

The allowable stress method in the 1963 AISC *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings* was used to proportion the exterior columns and spandrels for the combined effects of axial compression, bending moment, and shear due to gravity and wind forces. Composite floor trusses that were used outside of the core area and the truss s at connections as the core aea aned to proportiocolumns were

E.3.1 Exterior Wall Panel Tests

Scale model tests were performed at the University of Western Ontario to determine elastic load-deflection characteristics of typical exterior wall panel units along the height of the building. One of the main goals of this test program was to determine how the overall stiffness of the wall panels changed as changes were made in the columns, spandrels, and stiffeners that made up the wall panels.

A subassembly of a wall panel was tested, which, according to the researchers, was chosen for its simplicity, flexibility, and low cost. Models were built to a scale of one-quarter of full size and were fabricated from sheets of thermoplastic polymer. The forces that were applied to the test models simulated the forces acting on a unit of the actual wall panel.

Deflections and rotations were measured during the tests, and the shear stiffness of a unit was determined by dividing the load by the deflection. A number of conclusions from these tests, such as the thickness and depth of the spandrel increases the shear stiffness of the wall panel, were reported to WSHJ.

E.3.2 Wind Tunnel Tests

Wind tunnel tests were part of a four-pronged wind program that was developed by WSHJ for WTC 1 and WTC 2. The elements of this program were:

- Meteorological Program
- Wind-Tunnel Program
- Structure Damping Program
- Physiological Program

One of the goals of the meteorological program was to determine the variation of extreme wind speed with respect to direction at the WTC site. Data from five different sources were examined to help accomplish this. A statistical model for estimating extreme wind velocity was developed, and it was reported that the agreement between the observations based on the data from the fivm stations and the theoretical distribution was satisfactory.

Wind tunnel tests were conducted at the CSU and the NPL located in Teddington, Middlesex, United Kingdom. Tests were conducted on single-tower and twin-tower configurations subject to uniform and turbulent flow.

Over 2,000 tests were conducted at CSU to study the behavior of rigid and aeroelastic models. The directions chosen for the wind tunnel testing of the models of lower Manhattan corresponded to the most turbulent (southeast direction over Brooklyn) and the least turbulent (southwest over open water) directions. These two directions were simulated in the wind tunnel. It was found that the models of both towers oscillated in the wind due to vortex shedding, gust buffeting, and wake buffeting under certain combinations of key variables in the tests.

Two hundred tests were performed at CSU to study the effect of tower spacing on the response of the buildings. It was concluded that the "as planned" spacing was satisfactory.

Part of the purpose of the aeroelastic tests performed at CSU was to provide a comparison between the results obtained from the CSU and NPL aeroelastic tests. According to the report by WSHJ, the results from these two locations were in good qualitative and quantitative agreement. In general, these tests indicated that large lateral deflections at the top of the buildings occurred transverse to the direction of the wind for wind velocities in the range of 125 mph to 130 mph for angles of incidence within approximately 10 degrees of normal to a building face.

Tests were also conducted at CSU on the southeast and southwest models of lower Manhattan subjected to turbulent flow conditions. Similar to the other tests, the most severe oscillations were transverse to the wind and occurred with the wind blowing within a small range of angles on either side of the normal to a building face.

Pressures were measured at various points on the model based on an equivalent design wind velocity of approximately 98 mph. The equivalent design wind velocity was defined as the mean wind velocity averaged over a 20 min period at a height of 1,500 ft above the ground and based a 50-year return period. An averaging process was used to determine average pressure coefficients on the towers in the two principal directions. Shear force and overturning moment coefficients were determined from these average pressure coefficients. As discussed above in Sec. E.2.1, these coefficients were used to design the exterior columns and spandrels.

No documentation was found on the structure damping program or the physiological program.

E.3.3 Damping Unit Tests

Two programs were carried out to test certain important properties of the damping units that were used in WTC 1 and WTC 2. The purpose of the damping units was to supplement the tubular steel frame in limiting wind-induced oscillations to levels below human perception. The Minnesota Mining and Manufacturing Company (3M), the manufacturer of the damping units, conducted one series of tests, and Dr. S. Crandall conducted the other set of tests at the Massachusetts Institute of Technology. The main goal of these tests was to verify the mechanical and physical properties of the damping units that were given in the specifications.

WSHJ produced a report that compared the results from the two test programs. Major differences occurred with respect to the ultimate shear strength of the damping units. According to the tests conducted by 3M, the shear strength of the units was satisfactory with respect to the design parameters, whereas, the tests conducted by Crandall showed that about twenty percent of the damping units would be near or over the ultimate shear strength, which implies that they would fail in shear. According to the WSHJ report, the reason for this discrepancy may have been due to the differences in the test set up used in the two programs.

E.3.4 Floor Truss Tests

Full-scale flexural tests were performed on the floor trusses used in WTC 1 and WTC 2, in accordance with the design specifications. A minimum of one test was required for each of the 23 different types of floor trusses designated in the design drawings. The Laclede Steel Company, the manufacturer of the floor trusses, performed all of the tests. Results were found for one of the floor truss shipments in May 1969, which included a comparison of the design deflection (camber) versus the measured deflections from the tests for various target loads.

Tests were also performed on the shear knuckles (i.e., the floor truss diagonals that extended above the top chord and embedded in the concrete slab). These knuckles acted like shear studs, which made the floor trusses and concrete slab act in a composite manner. The Laclede Steel Company performed all of the transverse and longitudinal shear knuckle tests. Results from these tests showed that the shear strengths of the knuckles embedded in concrete were well above the allowable values assumed in design.

The Laclede Steel Company also conducted tests to verify the horizontal and vertical design loads for two welded connections between the 32 in. deep floor trusses and the 24 in. deep bridging trusses. Average measured failure loads for both types of connections were equal to at least twice the design values.

Two types of tests were performed by the Laclede Steel Company to determine the bearing capacity at the ends of the floor trusses. The bearing strength of the as-designed floor trusses and the bearing strength of repaired bearing ends were both determined. For example, bearing ends were repaired because they were damaged during transportation from the manufacturer. In both cases, it was shown that the bearing capacities of the floor truss ends were greater than the design loads.

E.3.5 Stud Shear Connector Tests

A testing program was established to determine the horizontal shear capacity of 3/4 in. diameter by 4 1/2 in. long stud shear connectors welded through the troughs of Roll Form Type “B” steel deck and embedded in a lightweight aggregate concrete slab. Such tests were required by the 1963 AISC Specifications, since the lightweight aggregate used in the concrete slabs for the WTC buildings did not conform to the ASTM International specification for normal weight aggregates. A work order from the Port Authority was sent to the Fritz Engineering Laboratory at Lehigh University to perform the tests. It has not been possible to locate any results from this testing program. No evidence was found that this system was used in WTC 1 and WTC 2.

E.4 PANYNJ POLICIES AND AGREEMENTS WITH NEW YORK CITY DEPARTMENT OF BUILDINGS

In 1993, a memorandum of understanding was established between the Port Authority and the New York City Department of Buildings. The purpose of this document was to restate the "long-standing" Port Authority policy that its facilities meet or exceed New York City Building Code requirements. Specific commitments were made by the Port Authority to ensure that any building construction project undertaken by the Port Authority or by any of its tenants at buildings owned and operated by the Port Authority would conform to the New York City Building Code. For example, the Port Authority was to thoroughly review and examine all plans for conformance with the requirements of the then-current New York City Building Code. Plans for projects undertaken by Port Authority tenants were to be prepared and sealed by a New York State licensed professional engineer or architect retained by the Port Authority. Also, the Port Authority was to maintain a file containing the most recent drawings, plans, and other documents required in connection with the review of the project for code conformance. Any variances from code requirements on a project were to be reported by the Port Authority to the New York City Department of Buildings, and the Port Authority was required to perform building inspections and structural integrity inspections on a cyclical basis for all of its buildings located in New York City.

A supplement to this agreement was executed in 1995. The supplement added that the design professional responsible for performing the review and certification of plans for WTC tenants must not be the same design professional providing certification that the project had been constructed in accordance with the plans and specifications.

E.5 INNOVATIVE SYSTEMS, TECHNOLOGIES AND MATERIALS, AND ACCEPTANCE PROCEDURES USED BY THE PANYNJ

E.5.1 Innovative Features of the Structural System

The structural system, comprising the lateral-force-resisting as well as the gravity-load-carrying systems, of WTC 1 and WTC 2 towers incorporated several innovative features including the following:

1. The towers represented one of the earliest applications of the framed-tube lateral-force-resisting system to super high-rise buildings.

2. Uniform perimeter column geometry (14 in. by 14 in. cross-section) was maintained over most of the height of the 110-story buildings.

3. Fourteen different specified grades of steel were used to allow the perimeter column geometry to remain uniform throughout the heights of the buildings.

4. Deep spandrel plates were used as beam elements connecting perimeter columns, enabling framed tube action by strapping around the structure.

5. Prefabrication of steel construction was extensively used, through using 3-column-wide by 3-stories-high panels, bolted butt-plate column splices, and high-strength bolted shear connections of the spandrel beams (plates).

6. Specially designed corner panels with chamfered edges were used to facilitate force transfer around the corners of the framed-tubes.

7. Long-span floor trusses were used for the floor systems. Composite action was achieved between the floor trusses and the concrete floor slab by extending the truss diagonals above the top chord into the slab. The concrete floor slab acted as a rigid diaphragm, which distributed the lateral forces to the elements of the tube according to their stiffnesses.

8. Viscoelastic dampers connecting the floor trusses to the perimeter framed tube system were used in each tower to control dynamic response.

9. Extensive wind tunnel testing was performed to establish the lateral wind loads used in the design of the towers.

Except for Items 7 and 8 above, the innovative features were not appraised by acceptance procedures. Tests to support the design innovations were done for Items 5, 7, 8, and 9.

E.5.2 Lateral-Force-Resisting System of WTC 1 and WTC 2

The structural system that resisted lateral loads in WTC 1 and WTC 2 was considered to be a framed-tube system (closely spaced columns and deep spandrel beams). The exterior walls were composed of steel columns and spandrel plates, and were designed to resist the lateral wind forces and a portion of the gravity forces. The welded steel plate box columns were spaced 3 ft-4 in. on center above the 7th floor. The columns and spandrels were shop assembled and welded into 36 ft high by 10 ft wide panels that consisted of three columns and spandrel beams. These panels were erected on site. Below the 7th floor, the columns were spaced 10 ft-0 in. apart, and bracing was used in the core area to increase lateral stiffness.

WTC 1 and WTC 2 were early examples of super high-rise buildings that were designed based on the framed-tube concept. The first application of this type of system was in a concrete apartment building in Chicago that was completed in 1965. Many variations of this system were used subsequently in a number of buildings between the mid-1960s through the early 1970s.

E.5.3 Damping Units

Viscoelastic damping units were part of the structural system in WTC 1 and WTC 2 to supplement the tubular steel frame in limiting wind-induced building oscillations to levels below human perception. This may have been the first application of damping units for this purpose in tall building structures.

The damping units were located between the bottom chords of the floor trusses (and bottom flanges of the beams on certain floors) and the columns of the exterior wall. Approximately 100 dampers were used on each floor from the 7th to the 107th floor in both buildings. As the buildings oscillated from the wind, part of the energy of oscillation was dissipated by shear deformations in the damping units.

As note above, 3M manufactured and tested the damping units for WTC 1 and WTC 2. Working with WSHJ, 3M wrote specifications for the damping units, which included a prototype test program that would measure key parameters related to the performance of the units. The specifications also included a

quality assurance program that contained requirements for both initial and long-term (5-year) acceptance and the test methods that were to be used to determine whether damping units met these requirements. Since this was the first time that this particular type of damping unit was utilized, there was a need to test the units on a long-term basis. No information on the design service life of the damping units could be found.

E.5.4 Floor Trusses

An innovative feature of the floor system used in WTC 1 and WTC 2 outside of the core area was the way that composite action was achieved between the floor trusses and the concrete slab. Truss diagonals were extended above the top chord. This "knuckle" acted like a shear stud, which made the floor truss and concrete slab act in a composite manner.

Working with WSHJ, the Laclede Steel Company, the manufacturer of the floor trusses, wrote specifications for the floor trusses. Requirements were given for materials, fabrication, welding, bolting, and painting. Full-scale tests of the floor trusses, which are described above, were also included in the specifications, as were requirements for quality control and inspection.

E.6 FABRICATION AND INSPECTION REQUIREMENTS AT THE FABRICATION YARD

E.6.1 WTC 1 and WTC 2

Fabrication and inspection requirements were contained in the contracts for the floor trusses, box core columns and built-up beams, members of the exterior wall, and rolled columns and beams. In general, the inspection requirements from the specifications for the various contracts were at a minimum equivalent to those in the New York City Building Code, and in many cases they were more comprehensive and stringent than the corresponding provisions in the Code.

E.6.2 WTC 7

The specification for WTC 7 contained the fabrication and inspection requirements for this project. Structural steel for WTC 7 was to be fabricated in accordance with the applicable requirements in the New York City Building Code, the 1963 AISC *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings*, and other specifications related to bolts, welds, and painting.

The specification also notes that there was a separate contract for testing and inspection. This contract was not found. However, specific requirements for inspection of shop and field welds by a testing agency were located in the specification.

E.7 INSPECTION PROTOCOL DURING CONSTRUCTION

E.7.1 WTC 1 and WTC 2

Karl Koch Erecting Co., the company that performed the structural steel erection work for WTC 1 and WTC 2, developed a quality control and safety program. This program included information on 10 different key areas that were to be addressed during construction.

E.7.2 WTC 7

The WTC 7 specifications contain general erection requirements for fasteners, anchor bolts, column bases, installation, and bracing. No inspection requirements during construction are given in the specifications.

E.8 DEVIATIONS GRANTED BY PANYNJ

The Port Authority approved numerous variances in the fabrication and erection of structural members in WTC 1 and WTC 2. The Office of the Construction Manager at the Port Authority approved deviations to the contract documents after Skilling, Helle, Christiansen, & Robertson (SHCR) (a successor firm established in New York of WSHJ of Seattle, Washington) reviewed the details of the deviations and granted their approval. In many cases, SHCR submitted alternative methods, which were incorporated into the deviations.

The variances that were granted for the structural members and their materials may be categorized into the following groups:

- Deviations relating to fabrication/erection tolerances (box columns, box beams, and floor trusses)
- Deviations relating to defective components (column trees and floor trusses)
- Deviations relating to alternative fabrication/erection procedures (core columns, floor trusses, exterior wall columns, and beam seats)
- Deviations relating to product substitutions (exterior wall)
- Deviations relating to inspection practice (exterior wall and welds).

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Chapter 1
INTRODUCTION

This report contains a summary of the requirements that governed the design and construction of World Trade Center (WTC) buildings 1, 2, and 7. It includes specific information related to the following items:

- Provisions used to design and construct the buildings
- Tests performed to support the design
- Criteria that governed the design of the vertical and lateral load resisting systems and the hat-truss systems of WTC 1 and WTC 2
- Methods used to proportion structural members and other components of the buildings
- Innovative systems, technologies and materials, and acceptance procedures used by the Port Authority of New York and New Jersey (PANYNJ)
- Details of variances granted by PANYNJ
- Fabrication and inspection requirements at the fabrication yard
- Inspection protocols during construction

Documents and structural drawings that were used to accomplish these tasks were acquired from the following locations: (1) the offices of the PANYNJ in Newark, New Jersey, and New York City and (2) the National Institute of Standards and Technology in Gaithersburg, Maryland. Paper, microfilm, and electronic versions of the documents were obtained from these sources. Due to the physical condition of some of the documents, certain portions of some of the documents were illegible. Such items are noted throughout this report.

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Chapter 2
PROVISIONS USED TO DESIGN AND CONSTRUCT THE BUILDINGS

2.1 BUILDING CODES USED IN DESIGN

2.1.1 WTC 1 and WTC 2

In 1963, the Port of New York Authority (Port Authority or PONYA) (whose name changed to the Port Authority of New York and New Jersey in 1972) instructed the architect and consulting engineers to prepare their designs for World Trade Center (WTC) 1 and WTC 2 to comply with the New York City Building Code (hereafter, referred to as the "Code"), although it was not required to comply with this code or any other building code.[1] The Port Authority, as an interstate agency created under a clause of the U.S. Constitution permitting compacts between states with the consent of Congress, was not bound by local codes. While not explicitly stated in the 1963 letter, the 1938 edition of the Code was in effect at that time. In areas where the Code was not explicit or where technological advances made portions of it obsolete, the Port Authority directed the consultants to propose designs "based on acceptable engineering practice," and required them to inform the WTC Planning Division when such situations occurred. When preliminary designs were complete, the Chief Engineer of the Port Authority was to review all design concepts with the appropriate municipal agencies before the consultants were to proceed with the final design. According to correspondence in 1975 from Emery Roth & Sons, the architect-of-record for the WTC project, the New York City Building Department reviewed the design drawings of WTC 1 and WTC 2 in 1968 and "made six comments concerning the plans in relation to the old code."[2] The correspondence goes on to state that specific answers on how the drawings conformed to the new code with regard to these comments were submitted to the Port Authority in March of 1968. These comments and the responses to these comments have not been found.

In 1965, the Port Authority instructed the consultants to revise their designs for WTC 1 and WTC 2 to comply with the second and third drafts of the new Code that was under development, and to undertake any revisions necessary to comply with such provisions.[3] The new edition of the Code became effective on December 6, 1968.

2.1.2 WTC 7

Unlike in the cases of WTC 1 and WTC 2, WTC 7 was designed and constructed as a "Tenant Alteration" project of a consortium comprised of Seven World Trade Company and Silverstein Development Corporation. Section 5A.3 of the project specifications (WTC 7 Project Specifications 1984) required that the structural steel be designed in accordance with the then-current New York City Building Code and the

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[1] Letter dated May 15, 1963 from Malcolm P. Levy (Chief, Planning Division, World Trade Department) to Minoru Yamasaki (Minoru Yamasaki & Associates) (see Appendix A).

[2] Letter dated February 18, 1975 from Joseph H. Solomon (Emery Roth & Sons) to Malcolm P. Levy (Chief, Planning Division, World Trade Department) (see Appendix A).

[3] Letter dated September 29, 1965 from Malcolm P. Levy (Chief, Planning Division, World Trade Department) to Minoru Yamasaki (Minoru Yamasaki & Associates) (see Appendix A).

latest edition of the *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings* published by the American Institute of Steel Construction (AISC 1978). WTC 7 was designed in the mid-1980s, and the 1968 edition of the Code, edited and amended through January 1, 1985, was in effect. It is also noted that references were made on the structural drawings (The Office of Irwin G. Cantor 1983) to specific provisions in the Code. In particular, Note 12 on sheet FS-3 states that inspection requirements for the foundations shall comply with Code Sec. C26-1000 Tables 10-1 and 10-2.

2.2 SUMMARY OF CODE PROVISIONS

This section contains a summary of the structural provisions in the 1968 edition of the Code. As noted above, the design of WTC 1 and WTC 2 was based on these provisions. The 1968 Code also governed the design of WTC 7. Also provided in this section are the criteria used in the design of WTC 1 and WTC 2 and WTC 7. Wherever applicable, differences between the Code provisions and the corresponding design criteria are documented. Only those provisions that relate to the design of these buildings are discussed here. Unless otherwise noted, referenced article and section numbers are from the 1968 edition of the Code.[4]

2.2.1 Loads

Article 9 of the Code contains the minimum loads to be used in the design of buildings and parts thereof. According to C26-900.2, Standards, the minimum dead, live, and wind loads prescribed in Reference Standard RS-9, Loads, are a part of Article 9. In no case was it allowed for the loads used in design to be less than the minimum values contained in that article.

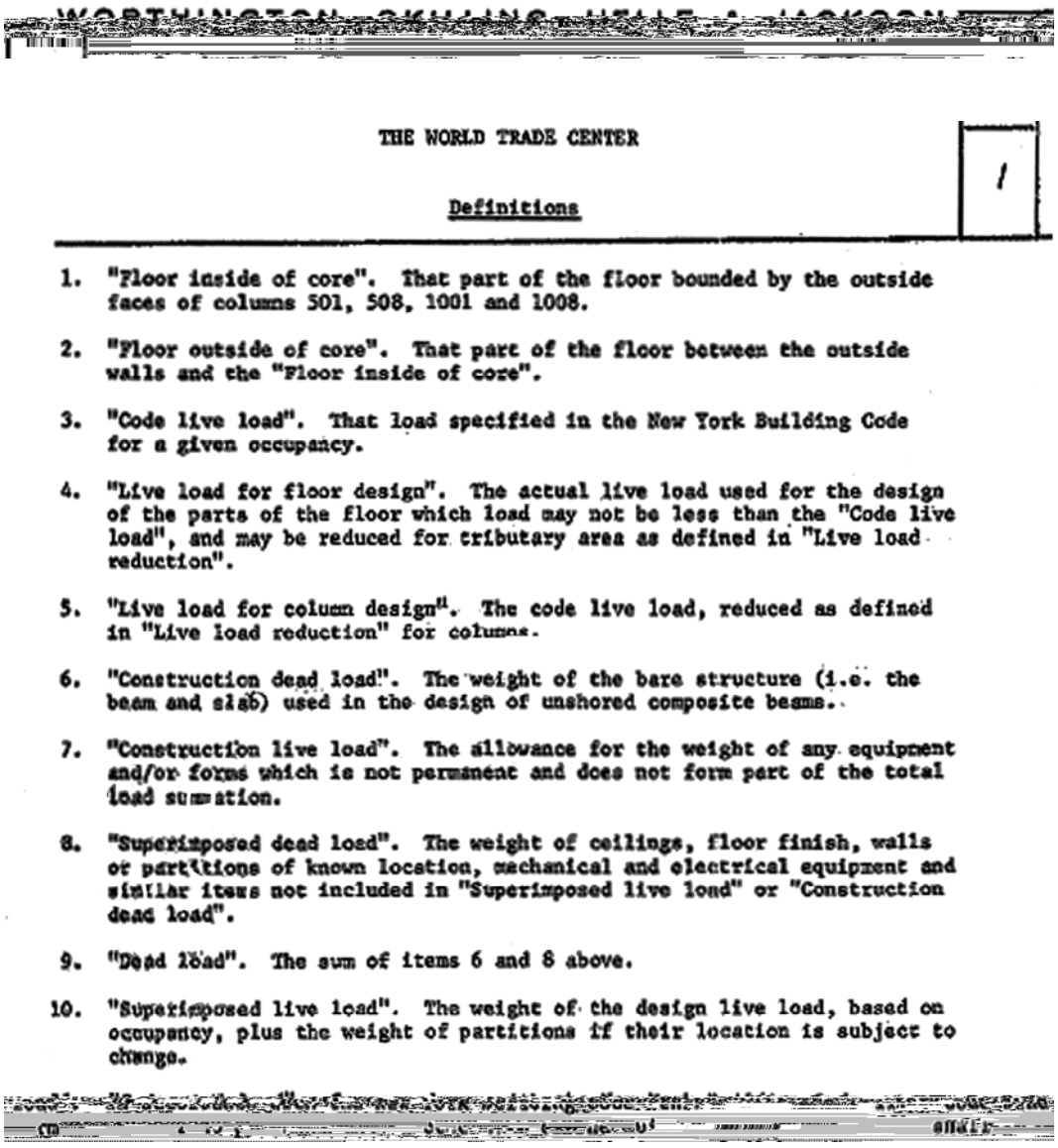
Dead Loads

Code requirements. Dead loads are defined in sub-article 901.0, Dead Loads, as the actual weight of the building materials or construction assemblies to be supported, based on the unit weights provided in Reference Standard RS 9-1, Minimum Unit Design Dead Loads for Structural Design Purposes (C26-901.1). Weights in pounds per square foot (psf) of floor area are listed for various types of (a) walls and partitions, (b) floor finishes and fills, (c) ceilings, (d) roof and wall coverings, (e) floors (wood joist construction), and (f) miscellaneous materials. Actual weights may be determined from analysis or from data in manufacturers' drawings and catalogs, but in no case were the unit weights allowed to be less than those contained in Reference Standard RS 9-1 unless the Building Commissioner approved them.

Weights from service equipment (plumbing stacks, piping, heating, ventilating, and air conditioning, etc.) and partitions were also to be included in the dead load (C26-901.2 and C26-901.3, respectively).

Design criteria for WTC 1 and WTC 2. The unit dead loads specified for the various structural members are contained in the Design Criteria for WTC 1 and WTC 2 (WSHJ 1965a). Different criteria were established for members located inside the core and outside the core. Definitions for member locations in the floor plan, as well as other definitions that are used throughout this report, are shown in Fig. 2–1. Note that the definition for "Code wind load" in Item 11 of this figure is illegible.

[4] In the 2001 edition of the New York City Building Code, "subchapter" is used in place of "article" and "article" is used in place of "sub-article."



THE WORLD TRADE CENTER

Definitions

1

1. "Floor inside of core". That part of the floor bounded by the outside faces of columns 501, 508, 1001 and 1008.

2. "Floor outside of core". That part of the floor between the outside walls and the "Floor inside of core".

3. "Code live load". That load specified in the New York Building Code for a given occupancy.

4. "Live load for floor design". The actual live load used for the design of the parts of the floor which load may not be less than the "Code live load", and may be reduced for tributary area as defined in "Live load reduction".

5. "Live load for column design". The code live load, reduced as defined in "Live load reduction" for columns.

6. "Construction dead load". The weight of the bare structure (i.e. the beam and slab) used in the design of unshored composite beams.

7. "Construction live load". The allowance for the weight of any equipment and/or forms which is not permanent and does not form part of the total load summation.

8. "Superimposed dead load". The weight of ceilings, floor finish, walls or partitions of known location, mechanical and electrical equipment and similar items not included in "Superimposed live load" or "Construction dead load".

9. "Dead load". The sum of items 6 and 8 above.

10. "Superimposed live load". The weight of the design live load, based on occupancy, plus the weight of partitions if their location is subject to change.

12. "Partitions". The weight of movable partitions as specified by the New York Building Code.

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Figure 2–1. Definitions used in design criteria for WTC 1 and WTC 2.

Detailed documentation is given in the Design Criteria (WSHJ 1965a) for the loads used in the design of WTC 1 and WTC 2. In this report, samples from the Design Criteria are shown to illustrate the types of loads that were specified in the various portions of the buildings.

- **Floor inside of core.** The core area in a representative upper floor of WTC 1 and WTC 2 is

partition loads in Reference Standard RS 9-1 may be used in lieu of actual partition weights when partitions are not shown on the plans) are given in the Design Criteria as well (see Fig. 2–3).

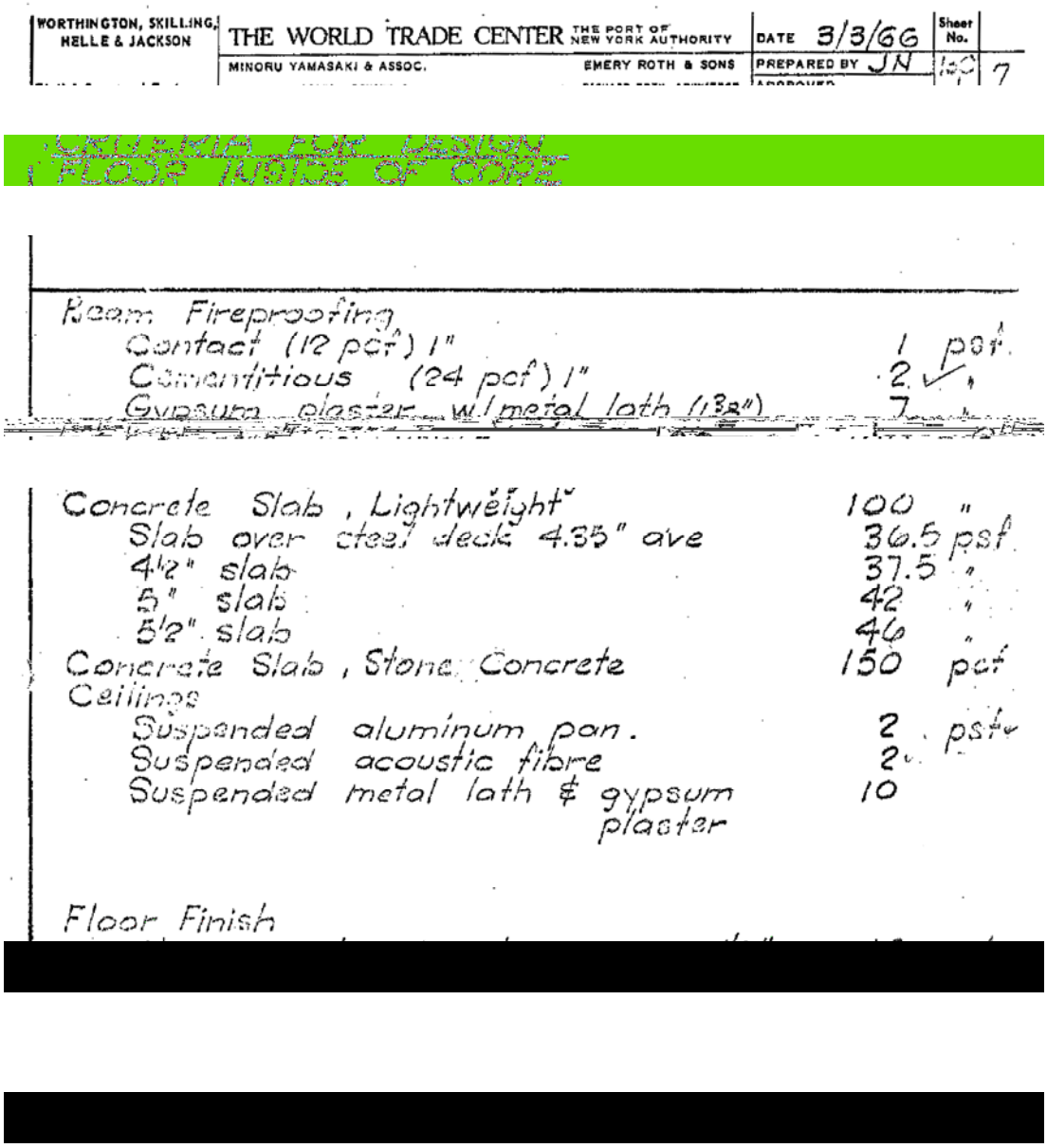

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Figure 2–3. Design criteria for WTC 1 and WTC 2: floor inside of core – unit dead load.

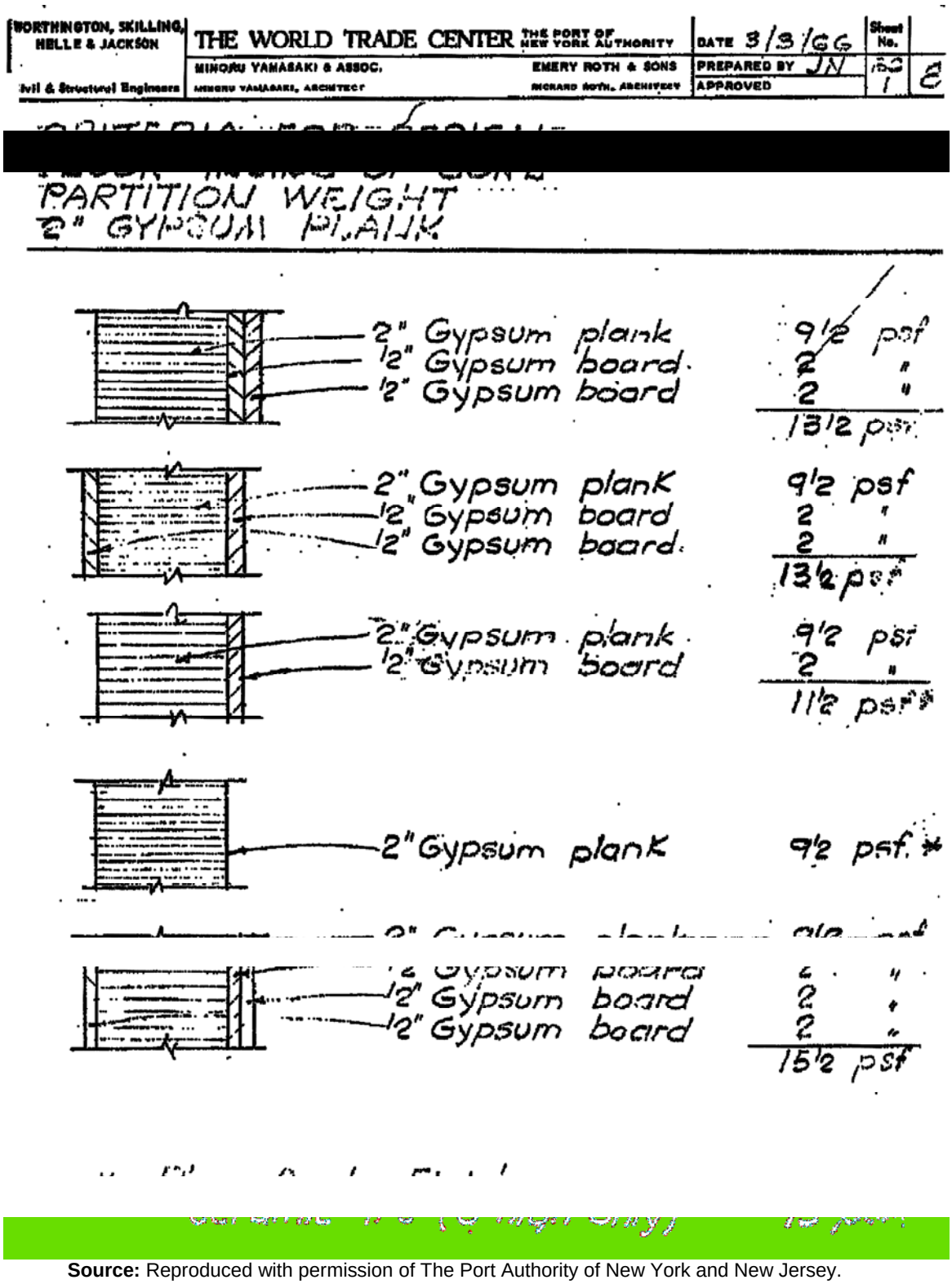

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Figure 2–3. Design criteria for WTC 1 and WTC 2: floor inside of core – unit dead load (continued).

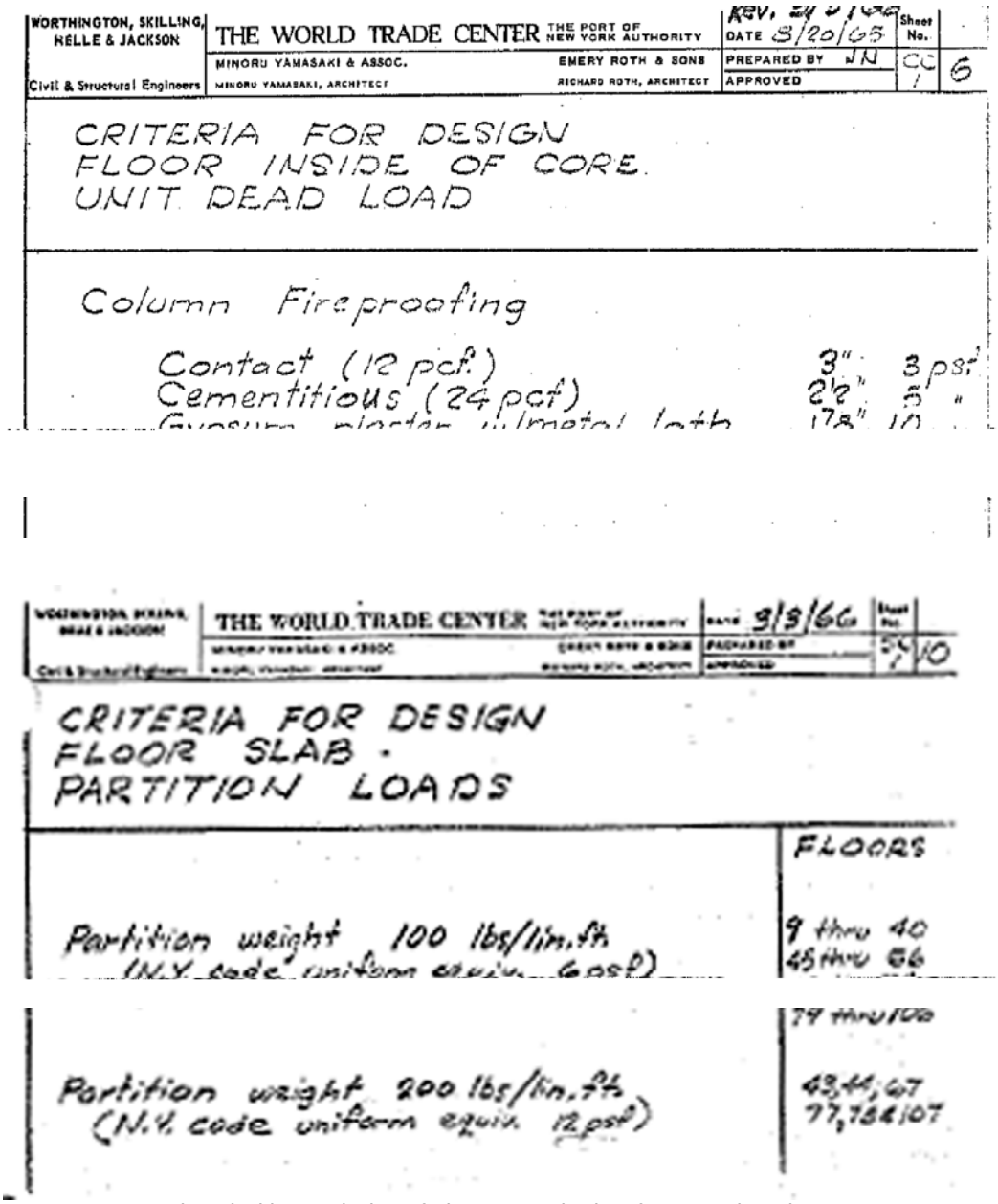

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Figure 2–3. Design criteria for WTC 1 and WTC 2: floor inside of core – unit dead load (continued).

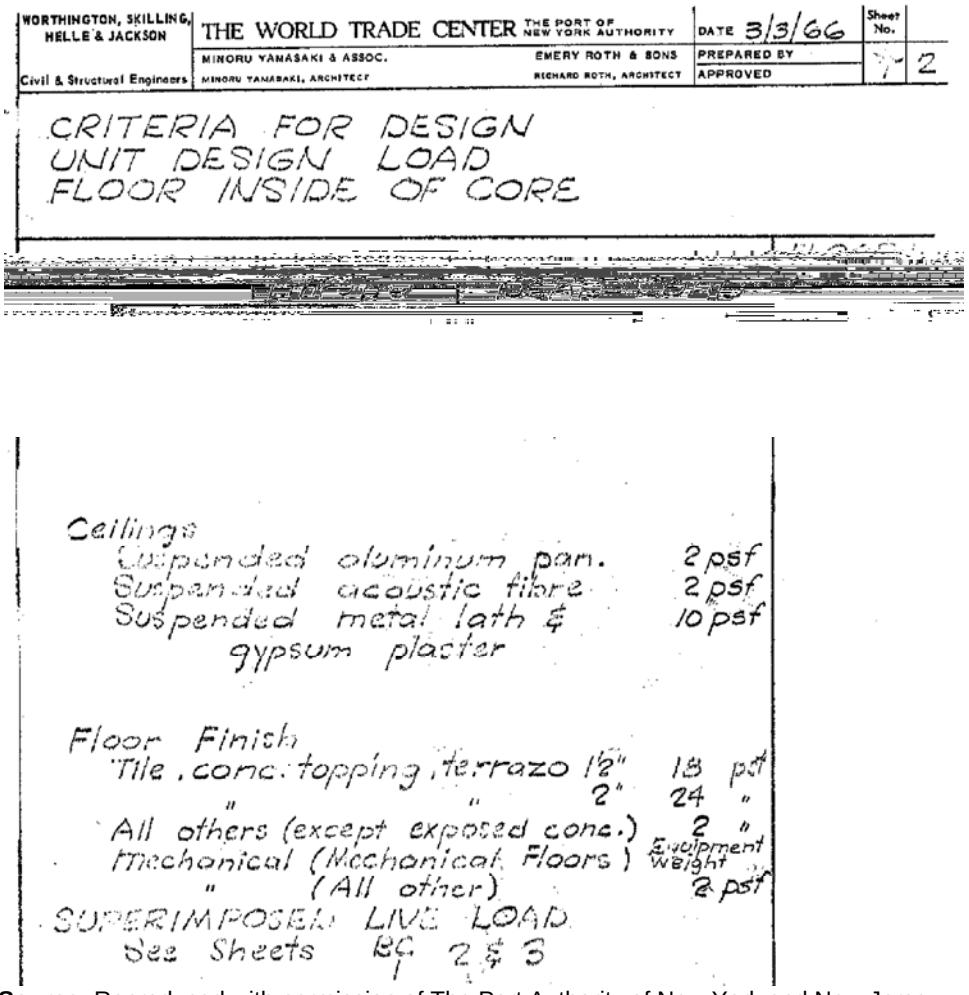

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Figure 2–3. Design criteria for WTC 1 and WTC 2: floor inside of core – unit dead load (continued).

- **Floor outside of core.** Unit dead loads for areas outside of the core area are specified in the Design Criteria with respect to the following structural members: one-way long-span floor trusses, one-way short-span floor trusses, two-way floor trusses, beams on framed floors, bridging, columns, steel deck, and reinforced concrete slabs. The design criteria also changed depending upon the floor level. Figure 2–4 contains sample design criteria for the long-span floor trusses at typical floor levels and for beams on some of the framed floors (i.e., mechanical floors). See WSHJ (1965a) for all of the design criteria. The dead loads in the design criteria for all of the structural members were greater than or equal to the corresponding dead loads prescribed in the Code.

Design criteria for WTC 7. Design load criteria for WTC 7 are summarized in Fig. 2–5. These criteria appear on Sheet S-24, Typical Superstructure Sections and Details, in the structural drawings (The Office of Irwin G. Cantor 1983). Because the actual materials used for the partitions, flooring, and ductwork were not specified, the reasonableness of these design values cannot be ascertained.

YORTHINGTON, SKILLING, HELLE & JACKSON
Civil & Structural Engineers

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MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT

EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT

DATE 8/1/66 — PREPARED BY MR — APPROVED

Sheet No. TF 1 2

FLOORS OUTSIDE OF CORE
LONGSPAN TRUSSES - ONE WAY

		FLOORS
Concrete Slab	36.5 psf.	10 thru 24
Slab Reinf.	1.5 "	26 thru 40
Steel Deck	2.0 "	45 thru 58
Structural Steel	10.0 "	60 thru 66
		68 thru 74
CONSTRUCTION DEAD LOAD =	50.0 psf.	79 thru 91
		93 thru 106
Ceiling	2.0 psf	
Mechanical & Electrical	2.0 "	
Fireproofing	2.0 "	
Floor Finish	2.0 "	
SUPERIMPOSED DEAD LOAD =	8.0 psf	
TOTAL DEAD LOAD (to be used for camber)	58.0 psf.	

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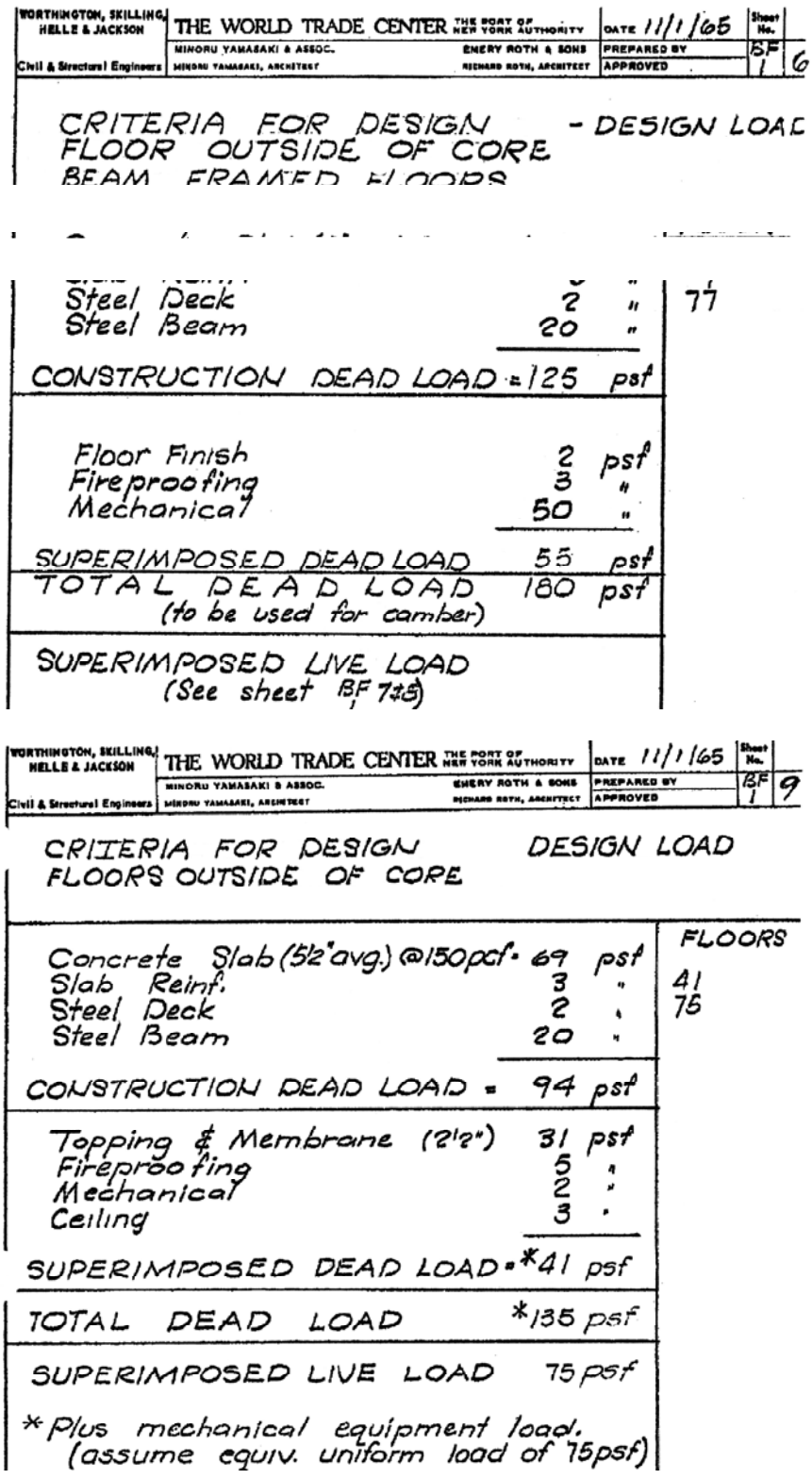
Figure 2–4. Design criteria for WTC 1 and WTC 2: floor outside of core – unit dead load.



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THE WORLD TRADE CENTER — THE PORT OF NEW YORK AUTHORITY
MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT
EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT
DATE 11/1/65 — PREPARED BY — APPROVED
Sheet No. BF 1 6

CRITERIA FOR DESIGN - DESIGN LOAD
FLOOR OUTSIDE OF CORE
BEAM FRAMED FLOORS

Steel Deck	2	"	77
Steel Beam	20	"	
CONSTRUCTION DEAD LOAD =	125	psf	
Floor Finish	2	psf	
Fireproofing	3	"	
Mechanical	50	"	
SUPERIMPOSED DEAD LOAD	55	psf	
TOTAL DEAD LOAD (to be used for camber)	180	psf	
SUPERIMPOSED LIVE LOAD (See sheet BF 7#5)			

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CRIEIRIA FOR DESIGN — DESIGN LOAD
FLOORS OUTSIDE OF CORE

			FLOORS
Concrete Slab (5½" avg.) @150pcf.	69	psf	
Slab Reinf.	3	"	41
Steel Deck	2	"	75
Steel Beam	20	"	
CONSTRUCTION DEAD LOAD =	94	psf	
Topping & Membrane (2½")	31	psf	
Fireproofing	5	"	
Mechanical	2	"	
Ceiling	3	"	
SUPERIMPOSED DEAD LOAD =	*41	psf	
TOTAL DEAD LOAD	*135	psf	
SUPERIMPOSED LIVE LOAD	75	psf	

*Plus mechanical equipment load. (assume equiv. uniform load of 75psf)

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Figure 2–4. Design criteria for WTC 1 and WTC 2: floor outside of core – unit dead load (continued).

LOADING SCHEDULE

AREA / LOAD (PSF)	CONCRETE SLAB	FILL, FINISH, ROOFING	CEILING, DUCTWORK	PARTITIONS	FLOORING	BEAMS, ENCASEMENT, FIREPROOFING	TOTAL DEAD LOAD	LIVE LOAD	TOTAL LOAD
MAIN ROOF, BULKHEAD ROOF	50	10	8			7	75	30	105
8TH-20TH FL. 24TH & 46TH FL	50		5	12		8	75	50	125
21ST-23RD FL.	50		5	12	15	8	90	75	165
7TH FLOOR NORTH SIDE	80		5	12		93	190	50	240
7TH FLOOR SOUTH SIDE	80	38	8	12		27	165	50	215
6TH FLOOR OFFICE SPACE	56		5	12		7	80	50	130
6TH FLOOR SWITCHBOARD ROOM	62	38				55	155	100	255
5TH FLOOR OFFICE SPACE	150	38	5			17	210	50	260
5TH FLOOR MECHANICAL SPACE	150	38	5			17	210	150	360
4TH FLOOR	56	75	5			10	146	100	246
3RD FLOOR NEW CONSTRUCTION	56	75	5			10	146	100	246
3RD FLOOR OVER EXISTING SUBSTATION							240	100	340
2ND FLOOR NEW CONSTRUCTION	56	60	5			10	131	150	281
2ND FLOOR EXISTING SUBSTATION							240	150	390
1ST FLOOR LOBBY	175	90				50	315	100	415
1ST FLOOR EXISTING SUBSTATION							300	225	525

NOTE:
ALL SPECIAL EQUIPMENT LOADS SHALL BE ADDED SEPARATELY TO ABOVE LOADING

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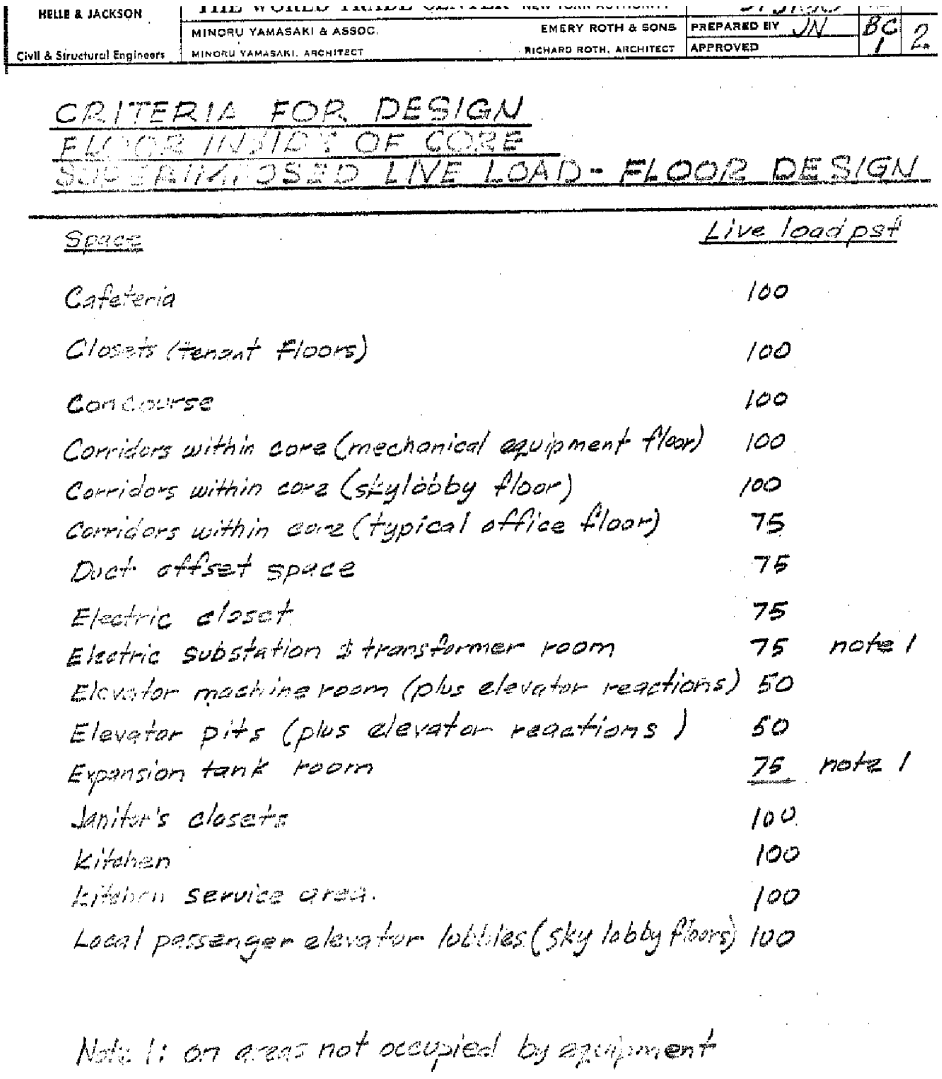
Figure 2–5. Design load criteria for WTC 7.

Live Loads

Code requirements. Requirements for live loads are given in sub-article 902.0, Live Loads, of the Code, with specific requirements for floor live loads given in C26-902.2. Minimum design values for uniformly distributed and concentrated floor live loads for various occupancies are contained in Reference Standard RS 9-2, Minimum Requirements for Uniformly Distributed and Concentrated Live Loads (C26-902.2). For occupancies that are not listed, design live loads are to be determined by the architect or engineer subject to approval by the Building Commissioner. Provisions are also given on how to apply concentrated live loads so as to produce maximum stress.

Design criteria for WTC 1 and WTC 2. Specified live loads are given in the Design Criteria for WTC 1 and WTC 2 (WSHJ 1965a). As in the case of dead loads, different live load criteria were established for members located inside the core and outside the core. Samples from the Design Criteria are shown in this report.

- **Floor inside of core.** Live loads to be used in the design of the beams and the columns in the core area are summarized in Fig. 2–6. As can be seen from the figure, except for Floor 109 and areas occupied by equipment, the design live load varied from 40 psf to 100 psf. A modification to the design criteria for Floor 109 was made in December of 1976, as indicated on the second page of Fig. 2–6. This modification required that the beams on the 109th floors in WTC 1 and WTC 2 be designed for a live load of 150 psf. Also, notes regarding the design criteria for WTC 1 were added in June of 1989. These notes were applicable to the beams in the tenant space inside the core on floors 27 through 40, 60, 61, 68 through 74, and 90 through 105, as indicated on the third page of Fig. 2–6. For all occupancies or use of spaces common to the design criteria and the Code, the live loads in the design criteria were equal to the corresponding live loads prescribed in the Code (which are given in Annex A1 of NIST NCSTAR 1-1B).



HELLE & JACKSON
Civil & Structural Engineers

MINORU YAMASAKI & ASSOC.
MINORU YAMASAKI, ARCHITECT

EMERY ROTH & SONS
RICHARD ROTH, ARCHITECT

PREPARED BY JN
APPROVED

BC 1 2a

CRITERIA FOR DESIGN
FLOOR INSIDE OF CORE
SUPERIMPOSED LIVE LOAD - FLOOR DESIGN

Space	Live load psf	
Cafeteria	100	
Closets (Tenant Floors)	100	
Concourse	100	
Corridors within core (mechanical equipment floor)	100	
Corridors within core (skylobby floor)	100	
Corridors within core (typical office floor)	75	
Duct offset space	75	
Electric closet	75	
Electric substation & transformer room	75	note 1
Elevator machine room (plus elevator reactions)	50	
Elevator pits (plus elevator reactions)	50	
Expansion tank room	75	note 1
Janitor's closets	100	
Kitchen	100	
Kitchen service area	100	
Local passenger elevator lobbies (sky lobby floors)	100	

Note 1: on areas not occupied by equipment

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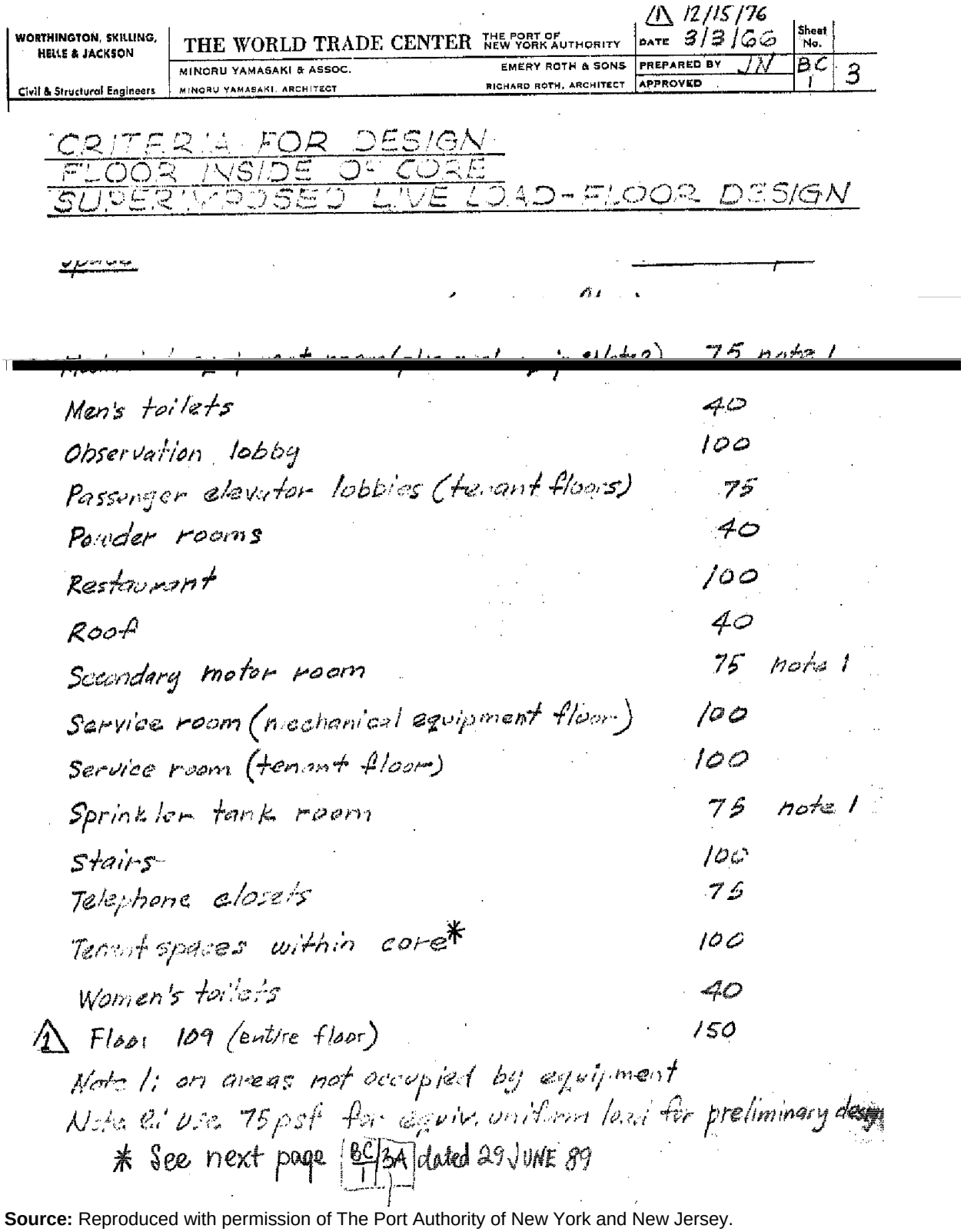
Figure 2–6. Design criteria for WTC 1 and WTC 2: floor inside of core – live load.



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Civil & Structural Engineers

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MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT

EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT

1 12/15/76
DATE 3/3/66
PREPARED BY JN
APPROVED
Sheet No. BC 1 3

CRITERIA FOR DESIGN
FLOOR INSIDE OF CORE
SUPERIMPOSED LIVE LOAD - FLOOR DESIGN

[illegible]	75	note 1
Men's toilets	40	
Observation lobby	100	
Passenger elevator lobbies (tenant floors)	75	
Powder rooms	40	
Restaurant	100	
Roof	40	
Secondary motor room	75	note 1
Service room (mechanical equipment floor)	100	
Service room (tenant floor)	100	
Sprinkler tank room	75	note 1
Stairs	100	
Telephone closets	75	
Tenant spaces within core*	100	
Women's toilets	40	
1 Floor 109 (entire floor)	150	

Note 1: on areas not occupied by equipment
Note 2: use 75 psf for equiv. uniform load for preliminary design
* See next page BC/1 3A dated 29 JUNE 89

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Figure 2–6. Design criteria for WTC 1 and WTC 2: floor inside of core – live load (continued).

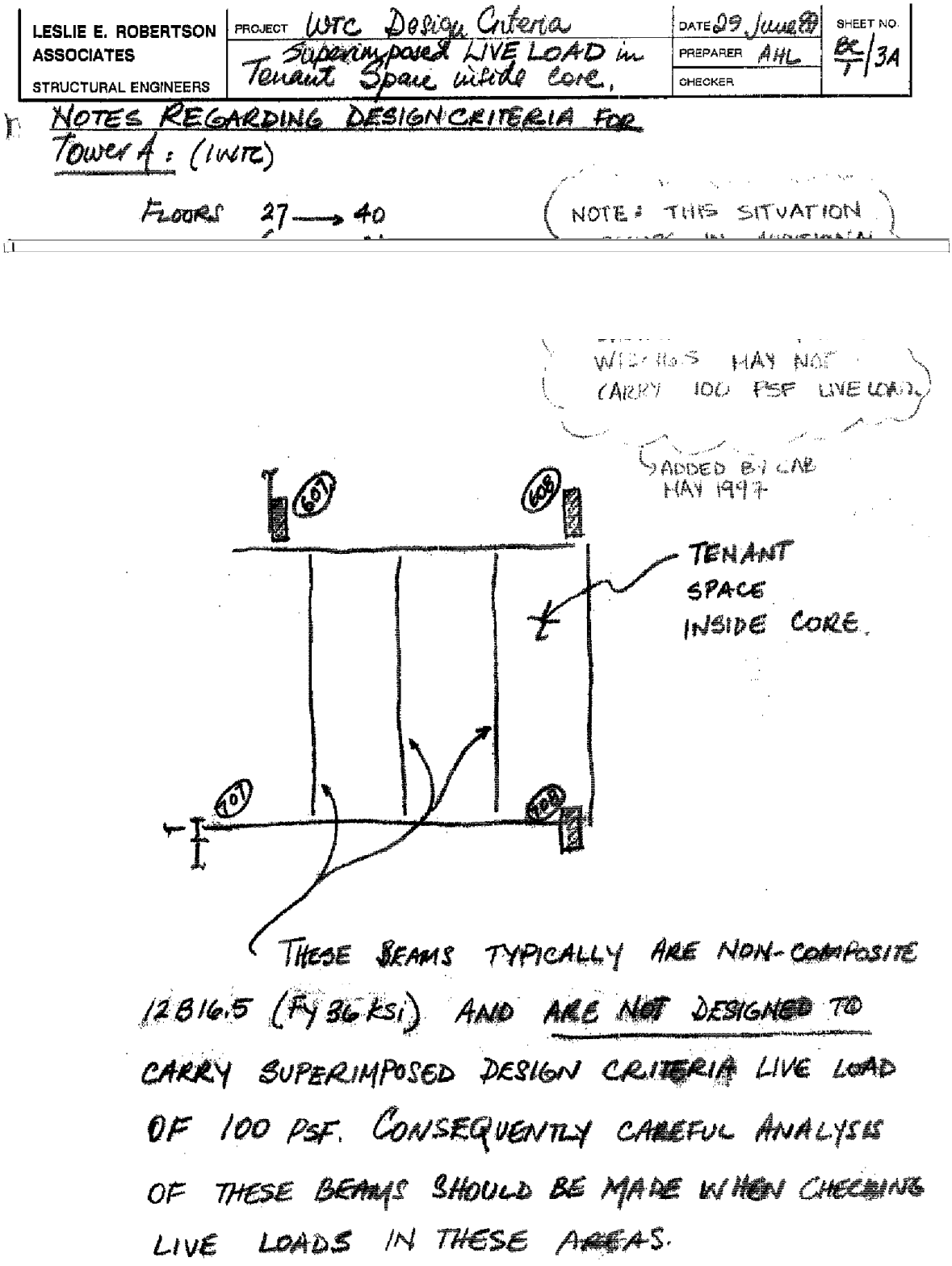

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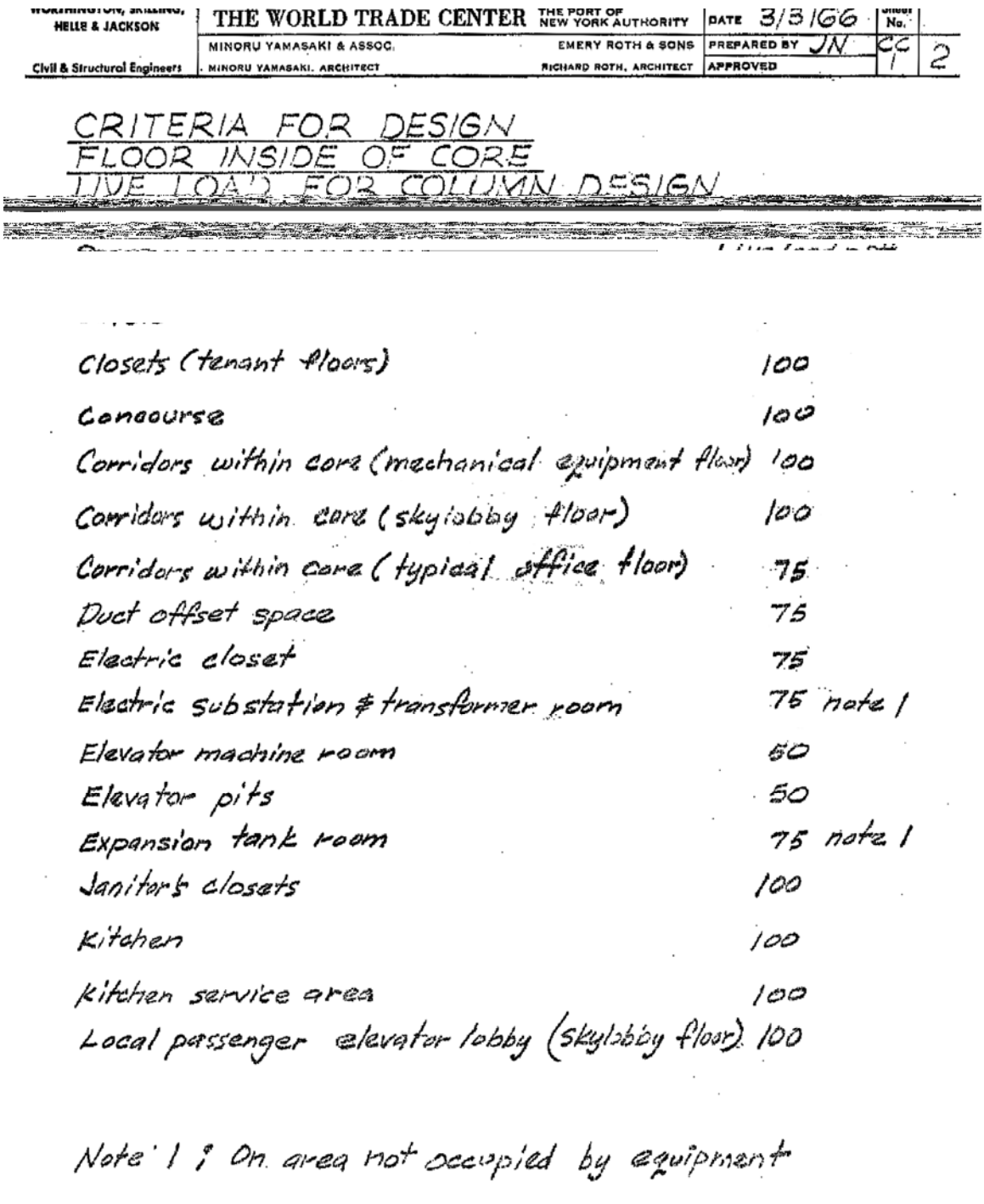
Figure 2–6. Design criteria for WTC 1 and WTC 2: floor inside of core – live load (continued).



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MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT

EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT

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Sheet No. CC 1 2

CRITERIA FOR DESIGN
FLOOR INSIDE OF CORE
LIVE LOAD FOR COLUMN DESIGN

Closets (tenant floors)	100
Concourse	100
Corridors within core (mechanical equipment floor)	100
Corridors within core (skylobby floor)	100
Corridors within core (typical office floor)	75
Duct offset space	75
Electric closet	75
Electric substation & transformer room	75 note 1
Elevator machine room	60
Elevator pits	50
Expansion tank room	75 note 1
Janitor's closets	100
Kitchen	100
Kitchen service area	100
Local passenger elevator lobby (skylobby floor)	100

Note 1 ; On area not occupied by equipment

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Figure 2–6. Design criteria for WTC 1 and WTC 2: floor inside of core – live load (continued).

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Civil & Structural Engineers	MINORU YAMASAKI, ARCHITECT	RICHARD ROTH, ARCHITECT	APPROVED		

CRITERIA FOR DESIGN

FLOOR INSIDE OF CORE

LIVE LOAD FOR COLUMN DESIGN

Space	Live load psf
Main shuttle elevator lobbies (sky lobby floors)	100
Mechanical equipment rooms	75 note 1
Men's toilets	40
Observation lobby	100
Passenger elevator lobbies (tenant floors)	75
Powder rooms	40
Restaurant	100
Roof	40
Secondary motor rooms	75
Service room (mechanical equipment floor)	100
Sprinkler tank room	75 note 1
Stairs	100
Telephone closets	75
Tenant spaces within core	50 + 6 psf partn. note 3
Woman's toilets	40

Note 3: Except floors 67 & 77 use 12 psf

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Figure 2–6. Design criteria for WTC 1 and WTC 2: floor inside of core – live load (continued).

- **Floor outside of core.** Like the unit dead loads, design live loads outside of the core area varied with respect to the floor level. At most floor levels, a design live load of 100 psf was specified for the slabs (see Fig. 2–7 from the Design Criteria). Note that this live load is greater than the 50 psf live load specified in the Code for office occupancies without storage. At mechanical floors 7, 41, 75, and 108, a 75-psf live load was used (also see Fig. 2–4). Figure 2–8 contains sample design criteria for the columns at the floor levels noted in the figure. In this case, live loads specified in the design criteria were equal to the corresponding live loads prescribed in the Code. Design live loads for the floor trusses, which are specified in the Design Criteria, are discussed in the following section on live load reductions.

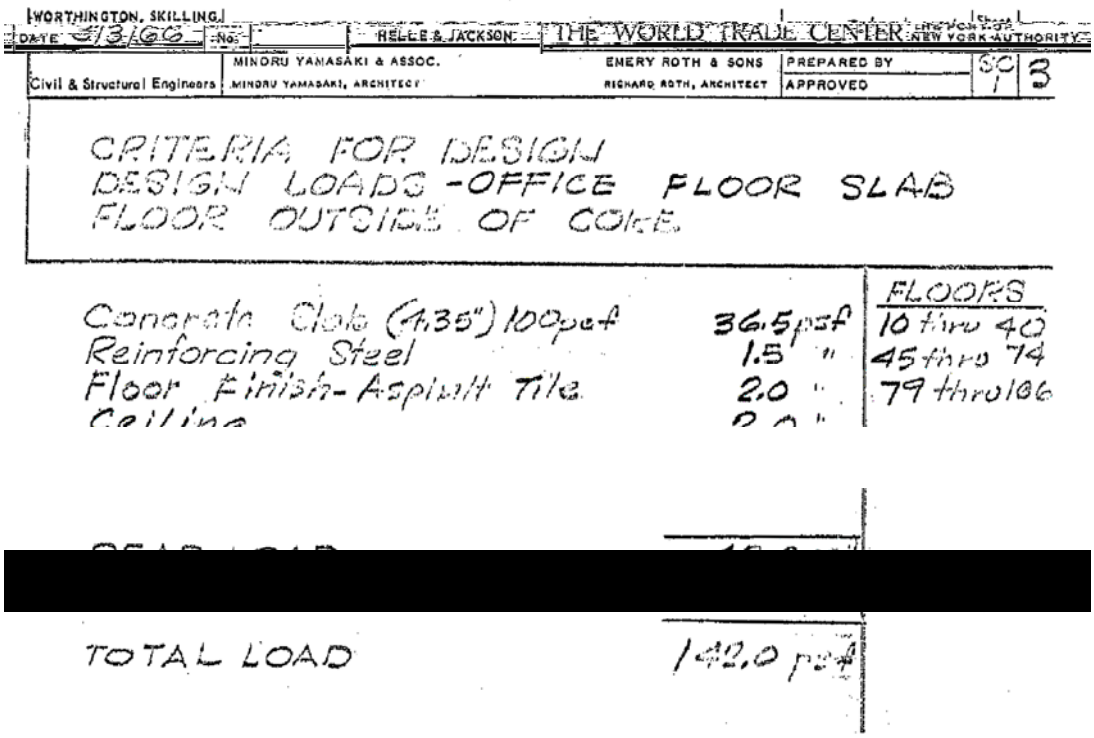

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Figure 2–7. Design criteria for WTC 1 and WTC 2: typical floor slabs outside of core – live load.

Design criteria for WTC 7. As noted previously, design criteria for WTC 7 are summarized in Fig. 2–5. These criteria appear on Sheet S-24, Typical Superstructure Sections and Details, in the structural drawings (The Office of Irwin G. Cantor 1983). For the floor levels where the type of occupancy was noted on Sheet S-24, the live loads in the design criteria were equal to those given in the Code.

Live Load Reduction

In general, building codes allow live loads to be reduced below code-prescribed values, since it is unlikely that an entire floor area will be fully loaded with the design live loads. For example, the probability is small that a column in the lowest floor of a multistory building would have to carry the full code-prescribed live load on all of the supported floors above. The same is true for floor members, such as beams or trusses, that support live loads on only one supported floor: smaller live loads are expected on

members that support larger floor areas. It is important to note that codes generally limit the maximum amount of live load reduction that may be taken on a member (depending on the type of member, the area it supports, and the type of live load) and that live load reduction is not permitted in all situations.

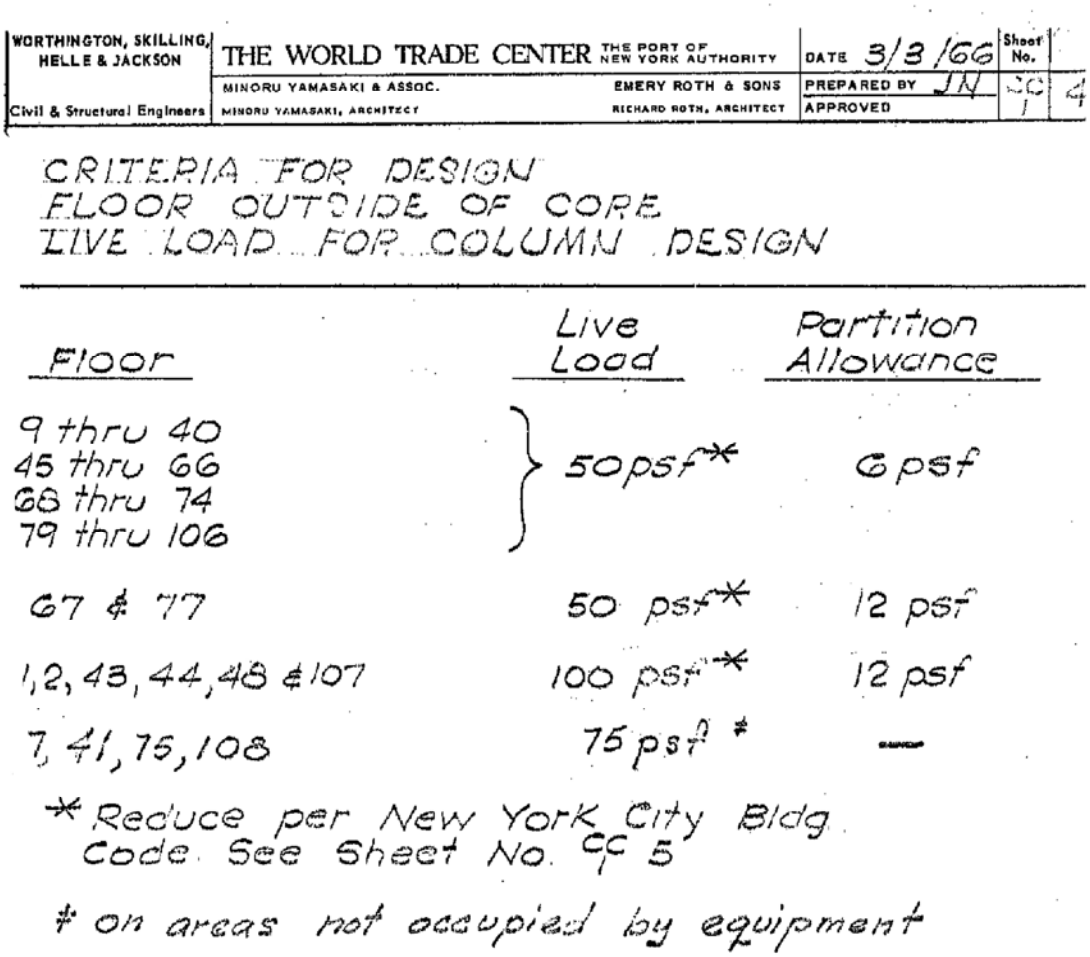

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Figure 2–8. Design criteria for WTC 1 and WTC 2: columns outside of core – live load.

Code requirements. Provisions for live load reduction are contained in sub-article 903.0, Live Load Reduction. According to C26-903.1, live load reduction is not permitted on roofs. The allowable reduced live load for floor members is determined by multiplying the basic live load value from Reference Standard RS 9-2 (see above) by the percentages given in Table 9-1 of the Code, which is reproduced here as Table 2–1. These percentages are a function of the contributory floor area, which is defined in C26-903.3, and the ratio of live load to dead load. Contributory floor areas are computed as follows (C26-903.3):

- For one-way and two-way slabs: product of the shorter span length and a width equal to one-half the shorter span length. Ribbed slabs shall be considered as though the slabs were solid.
- For flat plate or flat slab construction: one-half the area of the panel.

- For columns, girders, or trusses framing into columns: the loaded area directly supported by the column, girder, or truss. For columns supporting more than one floor, the loaded area shall be the cumulative total area of all the floors that are supported.

- For joists and similar multiple members framing into girders or trusses, or minor framing around openings: twice the loaded area directly supported but not more than the area of the panel in which the framing occurs.

Table 2–1. Percentage of live load per the 1968 Code.

Contributory Area (ft^2)	Ratio of Live Load to Dead Load[a]		
	0.625 or less	1	2 or more
149 or less	100	100	100
150–299	80	85	85
300–449	60	70	75
450–599	50	60	70
600 or more	40	55	65

a. For intermediate values of live load/dead load, the applicable percentages of live load may be interpolated.

No live load reduction is permitted (C26-903.2(b)) for members and connections (other than columns, piers, and walls) supporting:

- Floor areas used for storage (including warehouses, library stacks, and record storage);

- Areas used for parking of vehicles; and

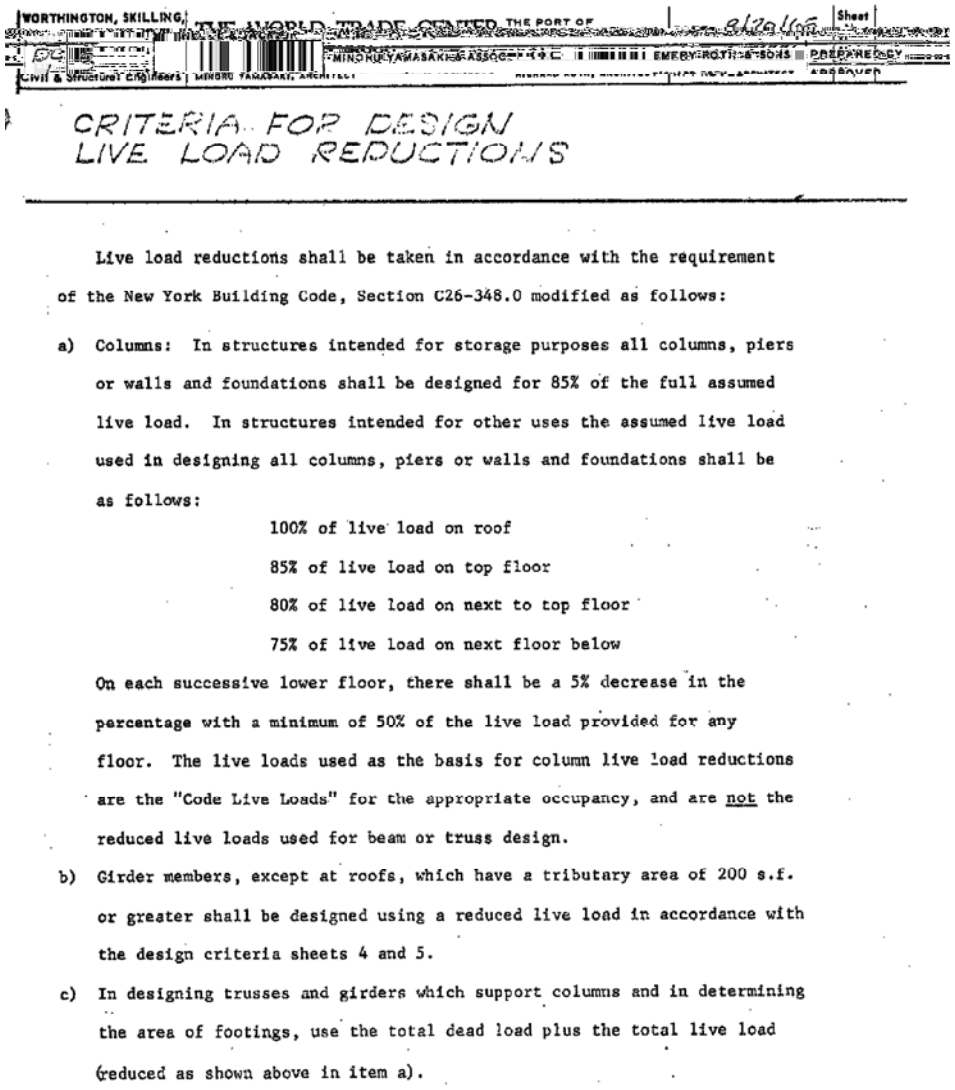
- Areas used as places of assembly, for manufacturing, and for retail or wholesale sales.

The maximum live load reduction is 20 percent for columns, piers, and walls supporting such areas.

Live load reduction is also not permitted for calculating shear stresses at the heads of columns in flat slab or flat plate construction (C26-903.2(c)).

As an alternative procedure, live load reduction for columns, piers, and walls may be taken as 15 percent on the top floor, increased successively at the rate of 5 percent on each successive lower floor, with a maximum reduction of 50 percent. For girders supporting 200 ft^2 or more of floor area, the live load reduction is 15 percent.

Design criteria for WTC 1 and WTC 2. Sample live load reduction criteria from the Design Criteria of WTC 1 and WTC 2 are given in Fig. 2–9 (WSHJ 1965a). According to these criteria, live load reductions were to be determined in accordance with C26-348.0 (note: this is the section number of the live load reduction provisions in the 1938 edition of the Code) subject to the modifications contained in Fig. 2–9. It is important to note that the live load reduction provisions in C26-348.0 of the 1938 Code are the same as the alternative provisions contained in C26-903.2(d) of the 1968 Code, except for the provisions related to permissible reductions for certain types of occupancies, which are more comprehensive and more stringent in the 1968 Code.



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Civil & Structural Engineers ... MINORU YAMASAKI, ARCHITECT ... EMERY ROTH & SONS ... PREFERENCE

CRITERIA FOR DESIGN
LIVE LOAD REDUCTIONS

Live load reductions shall be taken in accordance with the requirement of the New York Building Code, Section C26-348.0 modified as follows:

a) Columns: In structures intended for storage purposes all columns, piers or walls and foundations shall be designed for 85% of the full assumed live load. In structures intended for other uses the assumed live load used in designing all columns, piers or walls and foundations shall be as follows:

100% of live load on roof
85% of live load on top floor
80% of live load on next to top floor
75% of live load on next floor below

On each successive lower floor, there shall be a 5% decrease in the percentage with a minimum of 50% of the live load provided for any floor. The live loads used as the basis for column live load reductions are the "Code Live Loads" for the appropriate occupancy, and are not the reduced live loads used for beam or truss design.

b) Girder members, except at roofs, which have a tributary area of 200 s.f. or greater shall be designed using a reduced live load in accordance with the design criteria sheets 4 and 5.

c) In designing trusses and girders which support columns and in determining the area of footings, use the total dead load plus the total live load (reduced as shown above in item a).

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Figure 2–9. Design criteria for WTC 1 and WTC 2 – live load reduction.

Figure 2–10 shows the percentage of design live load from the Design Criteria that was to be used in the design of beams in the core area, except for tenant areas, on the floors noted in the figure. These percentages were the same as those from the 1968 Code (see Table 2–1 of this report), except in the case where the live load to dead load ratio was 2 or more and the loaded area tributary to the floor member was between 150 ft^2 and 299 ft^2; in this case, the code-prescribed percentage is 85 percent, while the value in the Design Criteria was 90 percent, which is more stringent than the Code requirement.

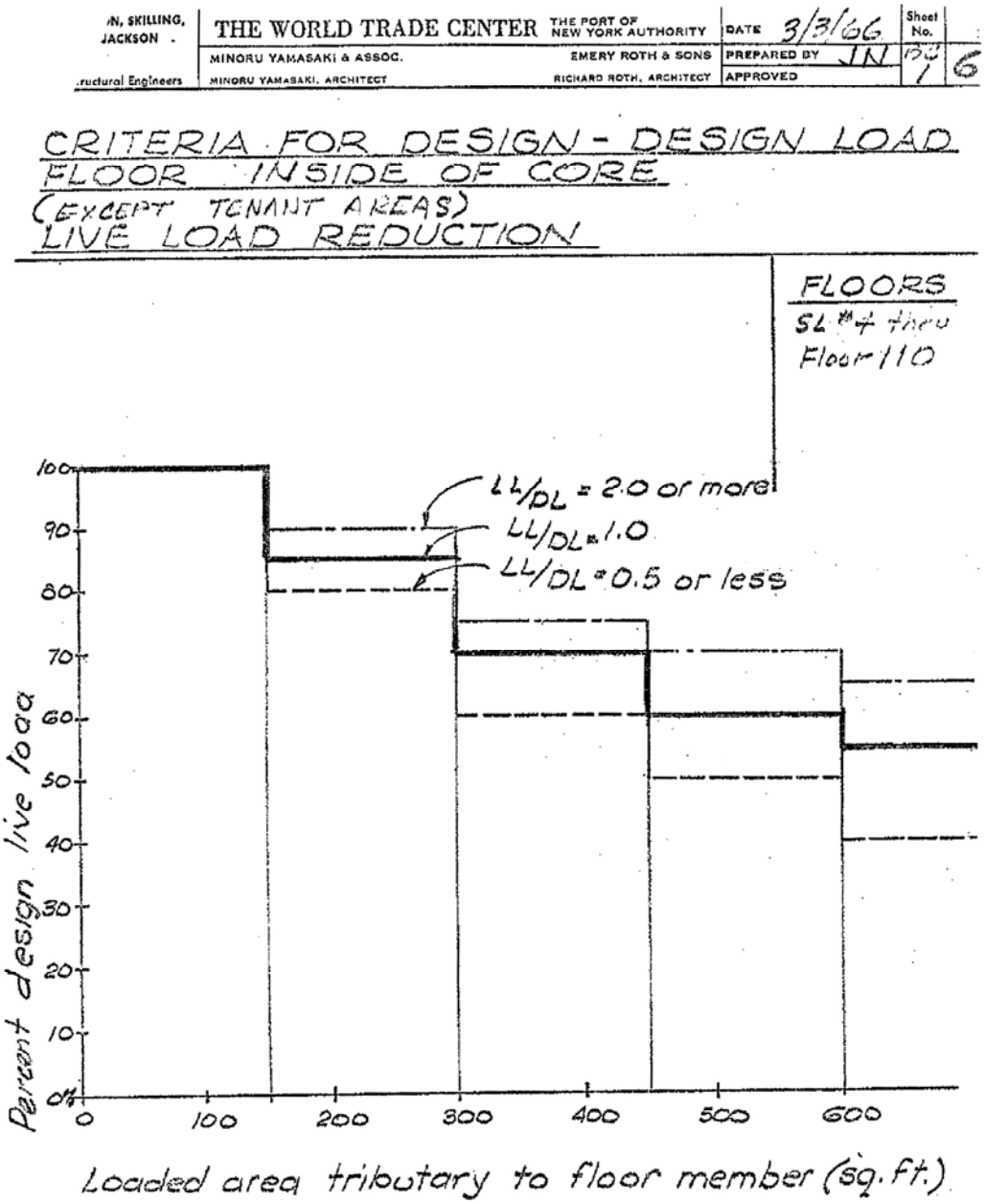

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Figure 2–10. Design criteria for WTC 1 and WTC 2: floors inside of core, except for tenant areas – live load reduction.

Figure 2–11 shows the design live loads from the Design Criteria for the tenant areas inside of the core. The solid line represents the reduced live load that was to be used in the design of the beams; these values were computed in accordance with the live load reduction provisions in the Design Criteria (see Item b in Fig. 2–9). Note that the unreduced live load specified in the Design Criteria for tenant spaces inside the core was 100 psf (see Fig. 2–6), which matches the design live load shown in Fig. 2–11 for tributary areas up to 200 ft^2. No live load reduction was to be taken for beams with tributary areas less than 200 ft^2 in tenant areas Also included in this figure are two other sets of data points: one set represents the reduced live load computed in accordance with the 1968 Code provisions with a live-to-dead load ratio equal to

one (see Table 2–1), and the other set is the Code equivalent uniform load for partitions, which is a constant 6 psf for partition weights up to 100 plf (see Exhibit RS 9-1 in Annex A1 of NIST NCSTAR 1-1B). The Code requires a 50-psf live load in tenant areas (office areas without storage) per Reference Standard RS 9-2 (see Exhibit RS 9-2 in Annex A1 of NIST NCSTAR 1-1B). The 50 psf live load plus the 6 psf partition load is shown in the figure for tributary areas up to 150 ft^2. Figure 2–11 clearly shows that the design live loads specified in the Design Criteria, including live load reduction, were greater than those required by the Code for office areas without storage.

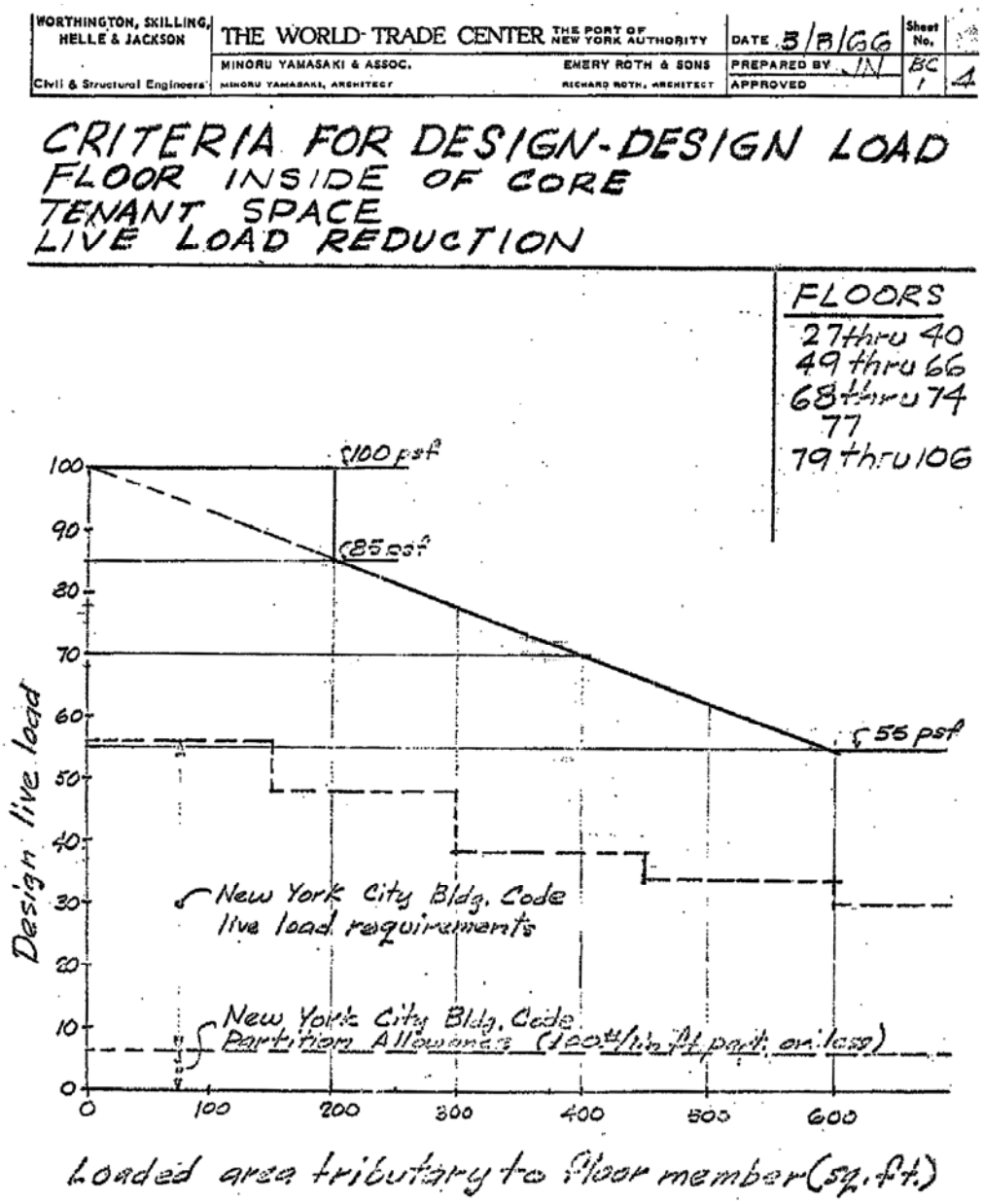

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Figure 2–11. Design criteria for WTC 1 and WTC 2: floors inside of core, tenant areas – live load reduction.

The sheets from the Design Criteria that are shown in Fig. 2–12 give the design dead and live loads for the floor trusses (short-span, long-span, and two-way) outside of the core area for the floors that are noted in the figure. The Design Criteria also specified a live load equal to 100 psf that could act over an area of 6 ft-6 in. by 31 ft-0 in. on any of the long-span or short-span trusses in the system.

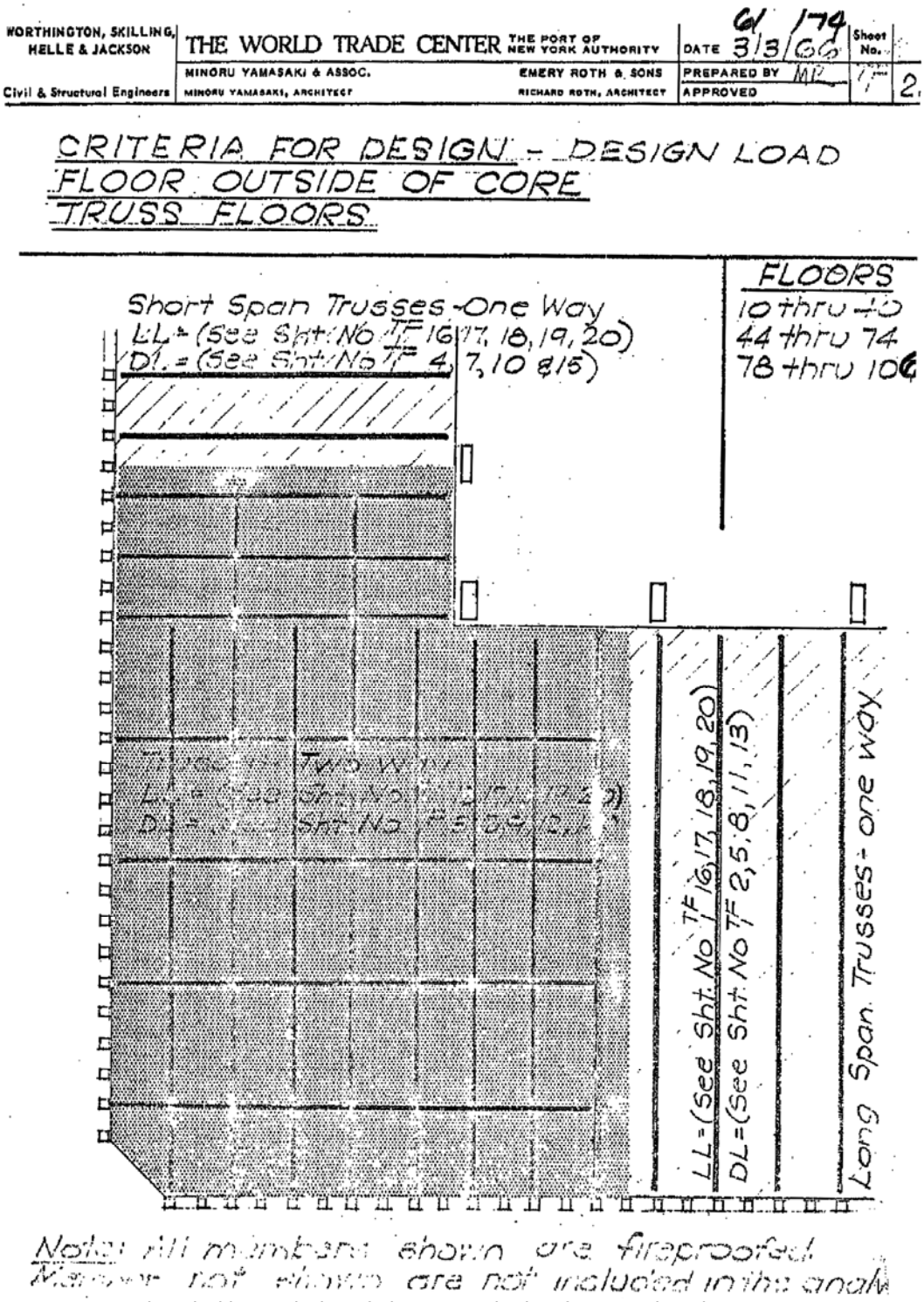

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Figure 2–12. Design criteria for WTC 1 and WTC 2: floors outside of core.

Figure 2–13 is a reproduction of sheet TF 1/16 from the Design Criteria, which shows the design live loads, including live load reduction, on the short-span, long-span, and two-way floor trusses in the area outside of the core for the floor levels that are noted in the figure. Similar criteria were also provided for other floor levels.

The live load reduction criteria for columns outside of the core area are summarized in Fig. 2–14.

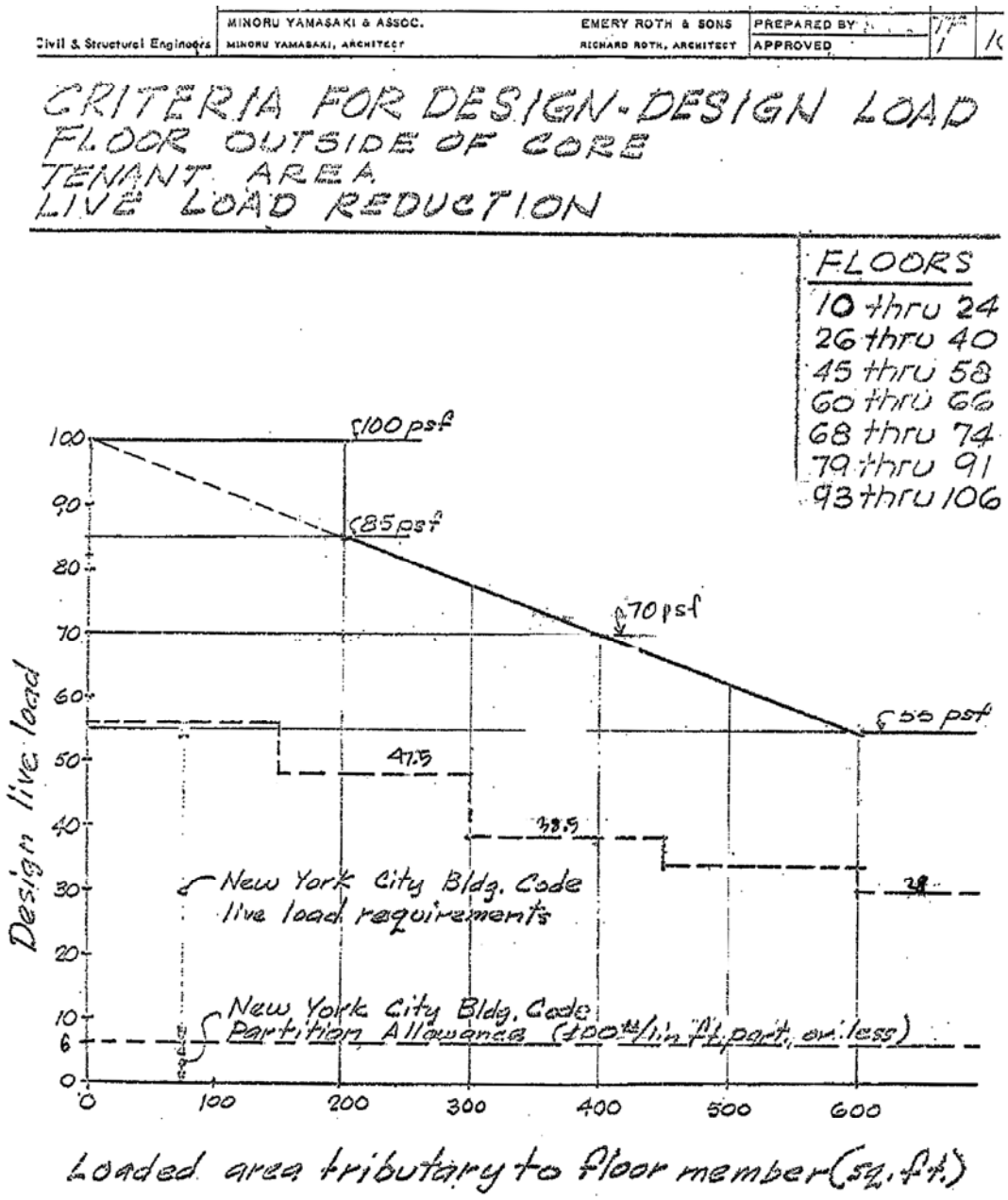

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Figure 2–13. Design criteria for WTC 1 and WTC 2: floors outside of core – live load reduction.

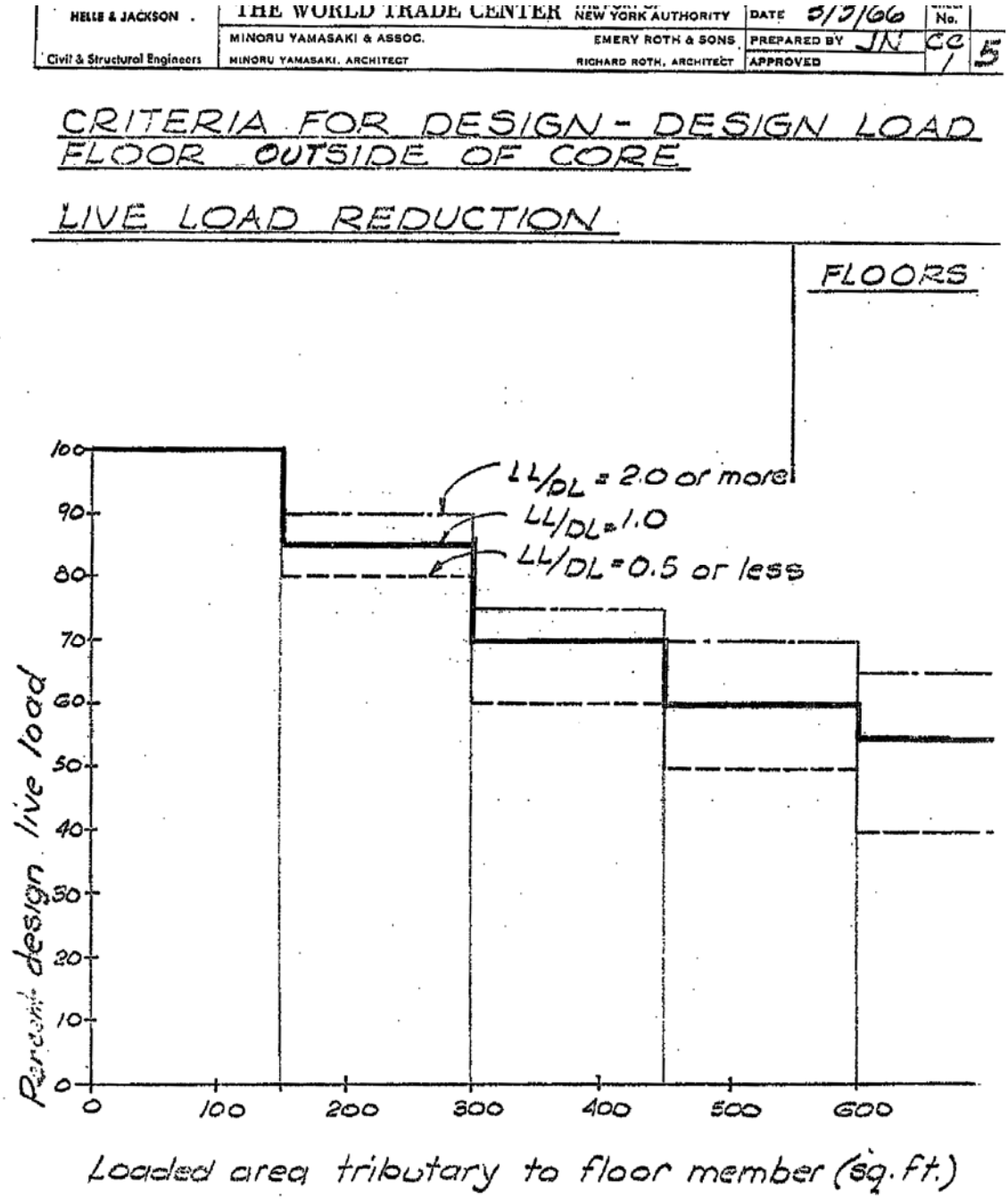

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Figure 2–14. Design criteria for WTC 1 and WTC 2: columns outside of core – live load reduction.

Design criteria for WTC 7. Live load reduction criteria used in the design of the structural members in WTC 7 are not listed on any of the structural drawings. However, the project specifications (WTC 7 Project Specifications 1984) require that WTC 7 be designed in accordance with the NYC Building Code. No documents were found that indicated what live load reduction was used.

Wind Loads

Code requirements. According to sub-article 904.0, Wind Loads, wind forces are computed in accordance with Reference Standard RS 9-5, Minimum Design Wind Pressures. The Code provisions require that wind shall be assumed to act from any direction, and for continuous framing, the effects of partial loading conditions shall be considered. Minimum design wind pressures acting on vertical surfaces are contained in Table RS 9-5-1, which is reproduced here as Table 2–2.

Table 2–2. Design wind pressures on vertical surfaces per the 1968 Code (Table RS 9-5-1).

Height Zone (ft above curb level)	Design Wind Pressure on Vertical Surfaces (psf of projected solid surface)	
	Structural Frame	Glass Panels
0 – 50[a]	15	–
0 – 100	20	30
101 – 300	25	30
301 – 600	30	35
601 – 1000	35	40
Over 1000	40	40

a. Signs and similar construction of shallow depth only.

Table RS 9-5-2 (see Table 2–3) contains the design wind pressures normal to horizontal and inclined surfaces.

Table 2–3. Design wind pressures on horizontal and inclined surfaces per the 1968 Code (Table RS 9-5-2).

Roof Slope	Design Wind Pressure Normal to Surface
30 degrees or less	Either pressure or suction equal to 40 % of the values in Table RS 9-5-1 over the entire roof area.
More than 3 degrees	Windward slope: pressure equal to 60 % of the values in Table RS 9-5-1. Leeward slope: suction equal to 40 % of the values in Table RS 9-5-1.

For purposes of design, pressures on vertical, horizontal, and inclined surfaces of the building are to be applied simultaneously.

For the design of wall elements other than glass panels (i.e., mullions, muntins, girts, panels, and other wall elements including their fastenings), the Code design wind pressure, which includes allowances for gust, acting normal to wall surfaces is specified as 30 psf pressure or as 20 psf suction for all heights up to 500 ft. Applicable design pressures for heights over 500 ft are to be determined from a special investigation, but are not allowed to be less than those pressures indicated in Table RS 9-5-1.

Minimum design wind pressures are also given for other building elements; they are to be obtained by multiplying the pressures in Table RS 9-5-1 by the appropriate shape factors in Table RS 9-5-3. The

shape factors vary from 0.7 for upright, circular cylindrical surfaces to 2.0 for signs with less than 70 percent solid surface.

In lieu of using the wind pressures mentioned above, design wind pressures may be established by "suitably conducted model tests," subject to review and approval of the Building Commissioner (Item 6 in Reference Standard RS 9-5). The tests are to be based on a basic (fastest-mile) wind velocity of 80 mph at 30 ft above ground, and are to simulate and include all factors involved in consideration of wind pressure, including pressure and suction effects, shape factors, functional effects, gusts, and internal pressures and suctions.

Design criteria for WTC 1 and WTC 2. Design wind forces on the towers were determined based on a series of wind tunnel tests that were conducted at the Colorado State University (CSU) and the National Physical Laboratory in the United Kingdom. Specific details on these tests can be found in Secs. 2.3.2 and 3.2 of this report.

Design wind pressures were specified in the WTC Design Criteria for external cladding and glazing (WSHJ 1965a). Outward (negative) pressure acting normal to the surface varied from 65 psf below the 7th floor to 125 psf at the 109th floor. Inward (positive) pressures varied from 45 psf below the 7th floor to 55 psf at the 108th floor. These pressures are based on the results of a series of wind tunnel tests that were performed specifically for this purpose (WSHJ 1967a).

Design criteria were also established for the antenna mast located on top of WTC 1 (WSHJ 1973). The antenna and its components were to be designed for the following conditions:

- A mean wind speed of 140 mph in any direction and no ice coating;
- A mean wind speed of 110 mph in any direction with an ice coating of 1/2 in. over all exposed unheated metallic surfaces with a minimum air temperature of 20 °F;
- A mean wind speed of 110 mph in any direction and no ice coating under a range of air temperatures from 10 °F to 90 °F;
- A mean wind speed of 40 mph in any direction and no ice coating under a range of air temperatures from –15 °F to 105 °F; and
- The dynamic effects of wind associated with the mean wind speeds specified above (dynamic effects of wind gusts were obtained by multiplying the mean wind forces by a factor of 5).

The requirement of a 1/2 in. thick coating of ice matches the requirement in C26-905.6 of the Code for the design of open-framed or guyed towers. Also, the Code requires that exterior exposed frames, arches, or shells be designed for the forces and/or movements resulting from an increase or decrease in temperatures of 60 °F for metal construction (C26-905.7). These requirements are less stringent than those contained in the design criteria. It is not evident from the documents how the wind velocities in the specification were established. The design criteria contain a section on how the wind forces were computed based on these velocities.

The effects of wind on the towers were investigated throughout the years as part of the Structural Integrity Inspection program. The results from these investigations are discussed in detail in NIST NCSTAR 1-1C

(This reference is to one of the companion documents from this Investigation. A list of these documents appears in the Preface to this report).

Design criteria for WTC 7. No design criteria or calculations were available for WTC 7 with respect to wind loads. However, a wind tunnel study of WTC 7 was carried out in 1983 by the University of Western Ontario at the request of the structural engineer of record, Irwin G. Cantor, Consulting Engineers (Isyumov 1983). No document is available to show how the wind tunnel test results were used in the design of WTC 7.

Changes in Design Loads

Over the years, the loads imposed on the buildings changed, primarily due to changes in occupancy. Design guidelines were issued by the Port Authority that pertained to tenant modifications, and included allowable design loads that could be applied to the buildings. These guidelines are described in detail in *Maintenance and Modifications to Structural Systems of WTC 1, 2, and 7* (NIST NCSTAR 1-1C). Information on the major structural changes in WTC 1, 2, and 7 can also be found in NIST NCSTAR 1-1C.

2.2.2 Structural Design Requirements of the Code

The following discussion focuses on the design requirements in the Code as they relate to the design and construction of the WTC buildings. Only those requirements that are applicable to the structural design of the members in the WTC buildings are covered. Methods used to proportion structural members and other components of the buildings are contained in Sec. 2.3 of this report.

General Requirements

Code sub-article 1000.0, Scope and General Requirements, contains the minimum requirements for materials, design, and construction of structural elements in buildings. NIST NCSTAR 1-1B describes these minimum requirements. The inspection requirements given in Table 10-1 (Inspection of Materials and Assemblies) and Table 10-2 (Inspection of Methods of Construction) and the material requirements in sub-articles 1003.0 through 1011.0 must be satisfied. Reference Standard RS-10, Structural Work, which contains a list of referenced national standards, is part of the general requirements (C26-1000.2, Standards). The list of national standards that were applicable to the design of the WTC buildings can be found in Annex A1 of NIST NCSTAR 1-1B. For example, reference was made to the 1963 edition of *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings* (AISC 1963b), which was applicable to the design of WTC 1 and WTC 2. The 1978 edition of the specification was applicable to steel design in WTC 7 (AISC 1978).

Design methods and materials other than those prescribed in the Code were allowed to be used, as long as it could be demonstrated to the Building Commissioner that the design would provide a factor of safety against structural failure consistent with the requirements established for the different building materials of construction in sub-articles 1003.0 through 1011.0.

The Code required a signed statement of satisfaction from the architect or engineer when structural elements were detailed on shop or working drawings prepared by someone other than the architect or

engineer. Manufacturers were also required to provide statements or other supporting documentary evidence of accreditation attesting to the accuracy of fire-resistance ratings data, load tables, or similar data supplied in catalogues.

General Structural Design Requirements

The general structural design requirements in sub-article 1001.0 cover, among other things, secondary stresses, combination of loads, and deflection limitations.

- **C26-1001.3, Secondary stresses.** Secondary stresses in trusses must be considered in design.

- **C26-1001.4, Combination of loads.** Dead loads, live loads (including impact), and reduced live loads are defined in this section as basic loads. Loads of infrequent occurrence are wind forces, thermal forces, shrinkage, and unreduced live loads (where live load reduction is permitted by Article 9). Load combinations depend on whether the working stress method or the ultimate strength method is used to proportion the members.

  Where design is based on allowable or working stresses, the loads in Article 9 (discussed above) are to be multiplied by the following factors: (1) for combinations of basic loads only, the factor shall be 1.0; (2) for any combination of one or more basic loads with any one load of infrequent occurrence, the factor shall be 0.75; and (3) for any combination of one or more basic loads with two or more loads of infrequent occurrence, the factor shall be 0.67. The requirements related to the allowable unit stresses for short-time loading design of wood members are given as an exception to these requirements. NIST NCSTAR 1-1B contains the specific load combinations for the building materials used in the WTC towers.

  Where design is based on ultimate strength criteria (including plastic design of steel structures and proportioning of suspended structures), the loads prescribed in Article 9 are to be multiplied by the factors given in C26-1010.5(e) (allowable working loads for suspended structures, if applicable) and the applicable material reference standards. Two exceptions are given: (1) where load factors are given for wind (or earthquake) forces in reference standards, the design must additionally consider combinations of loads that include the other loads of infrequent occurrence substituted for the wind loads and (2) the design shall also consider combinations of loads where the two most critical loads of infrequent occurrence are combined with the basic loads. The load factors in the reference standards and in C26-1010.5(e) for suspended structures may be reduced 15 percent for the combination of basic loads plus one load of infrequent occurrence.

- **C26-1001.5, Deflection limitations.** Vertical deflection limitations for floor and roof assemblies are provided in the referenced material standards for structural steel and concrete (see Sec. 5.10 of NIST NCSTAR 1-1B). In addition to those requirements, the total deflection due to dead load plus live load (including the effects of creep and shrinkage) of members supporting walls, veneered walls, or partitions constructed of or containing panels of masonry, glass, or other frangible materials is limited to the span length divided by 360. No horizontal deflection or drift limitations due to lateral wind forces are prescribed in the Code.

Adequacy of the Structural Design

According to sub-article 1002.0, Adequacy of the Structural Design, the design of structural members is to conform to the applicable material standards mentioned in sub-articles 1003.0 through 1011.0 (C26-1002.1). If such computations as prescribed in these standards cannot be executed due to "practical difficulties," the structural design can be deemed adequate if the member or assembly performs satisfactorily when subjected to load tests in accordance with 1002.4(a). Provisions to determine the adequacy of completed or partially completed structures are also provided. Prequalifying load tests (C26-1002.4(a)) can be used to establish the strength of a member or assembly prior to having such members or assemblies incorporated into a structure. The test specimens are to be a true representation of the actual members or assemblies in all aspects, including the type and grade of material used. Support conditions for the members or assemblies being tested are to simulate the conditions of support in the building, except that conditions of partial fixity might be approximated by conditions of full or zero restraint, whichever produces a more severe stress condition in the member being tested. In regard to strength requirements, the member or assembly must be capable of supporting the following (note: no specific reference to a particular type of building material is given in this section of the Code):

1. Without visible damage (other than hairline cracks) its own weight plus a test load equal to 150 percent of the design live load plus 150 percent of any dead load that will be added at the site, and

2. Without collapse its own weight plus a test load equal to 50 percent of its own weight plus 250 percent of the design live load plus 250 percent of any dead load that will be added at the site.

The latter loading is to remain in place for a minimum period of one week, and all loading conditions in Article 9 of the Code are to be considered. Exceptions to the above load conditions are also given in this section.

The member or assembly is also subject to the following deflection requirements: the recovery of the deflection caused by the superimposed loads listed in item 1 above must be at least 75 percent. Also, the deflection under the design live load is limited to the values prescribed in C26-1001.5.

Requirements are also given for tests on models less than full size. The similitude, scaling, and validity of the analysis are to be attested to by an officer or principal of the firm or corporation making the analysis. The firm or corporation is to be approved by the Building Commissioner.

Concrete Requirements

According to sub-article 1004.0, design of reinforced concrete structural members is to conform to the requirements in that section and Reference Standard RS 10-3, which is the 1963 edition of *Building Code Requirements for Reinforced Concrete* (ACI 1963) with modifications, which is applicable to the design of WTC 1 and WTC 2. One notable modification made to this standard is that all of the requirements under ACI 318 Secs. 902 (Design loads) and 903 (Resistance to wind, earthquake, and other forces) are deleted and replaced with the following: "Building code requirements for loads and infrequent stress conditions shall apply." "Infrequent stress conditions" refer to such conditions as wind and earthquake. In other words, all loads are to be determined in accordance with the 1968 Code. In case of concrete

structures designed by the ultimate strength design method, design (factored) loads are to be determined in accordance with Sec. 1506 of ACI 318-63.

According to the specifications for WTC 7 (WTC 7 Project Specifications 1984), the 1983 edition of ACI 318 was applicable (ACI 1983).

Steel Requirements

Design of steel structural members is to conform to the requirements in sub-article 1005.0 and Reference Standard RS 10-5, which is the 1963 edition of *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings* (AISC 1963b) with modifications, which is applicable to the design of WTC 1 and WTC 2. Similar to the design of reinforced concrete members, the provisions of Sec. 1.3 (Loads and Forces) are deleted and replaced with the following: "The provisions of the building code for loads shall apply." Other notable modifications to the AISC Specification are:

- The following paragraph is added to the definition of composite construction in Sec. 1.11.1: "Concrete materials shall meet the applicable requirements of the building code. Where concrete having a unit weight less than 130 pcf is used, the capacity of the shear connectors to resist applied load under the proposed conditions of use shall be investigated…"

- Sec. 1.25.5 on field connections during erection is deleted and replaced with the following: "…No holes, copes or cuts of any type shall be made to facilitate erection unless specifically shown on the shop drawings or authorized in writing by the party or parties designated for inspection of such work."

Reference Standards RS 10-6 and 10-7 are to be used for light gage cold formed steel and open web steel joists, respectively (see NIST NCSTAR 1-1B).

According to the specifications for WTC 7 (WTC 7 Project Specifications 1984), the 1978 edition of the AISC Specification was applicable (AISC 1978).

2.3 SUMMARY OF METHODS USED TO PROPORTION STRUCTURAL MEMBERS AND COMPONENTS

2.3.1 Overview

This section contains the general methods that were used to proportion the structural members and components in the buildings. Since design calculations were not available for WTC 7, the discussion that follows covers the design methods employed for WTC 1 and WTC 2.

A summary of the design methods is provided for the following structural members in WTC 1 and WTC 2: exterior columns, floor trusses outside of the core area, composite steel beams in the core area, connections, concrete floor slabs, steel deck, and hat trusses.

2.3.2 Exterior Columns

An approximate method was used to estimate the shear forces and bending moments acting on exterior columns (and spandrels) due to the effects of wind (WSHJ 1966a). In general, design shear forces and overturning moments were computed at each floor level from an equivalent design wind velocity at the top of the tower and average pressure coefficients that were derived over the height of the tower from the wind tunnel tests (see Sec. 3.2 in this report for details on the wind tunnel tests). The equivalent design wind velocity was defined as the mean wind velocity averaged over a 20 min period at a height of 1,500 ft above the ground and was based on a 50 year return period (WSHJ 1966c).

A Weibull probability distribution function was used to predict the maximum deflection (static plus dynamic deflections) at the top of a tower as a function of return period (see Sec. 3.2 of this report for more details). From the wind tunnel tests, maximum deflections were recorded at the top of a tower for a number of different wind velocities acting in 24 different directions (i.e., 15 degree intervals) around the towers. The equivalent design wind velocity V_{design} was calculated from the following equation, using a test wind velocity of 100 mph (WSHJ 1966a):

$$V_{design} = 100\sqrt{\frac{A_{50}}{A_{\max}}} \qquad (2\text{–}1)$$

where:

A_{50} = deflection at the top of the tower in the North South or East West direction based on the Weibull probability distribution function using a return period of 50 years

$A_{\max}$ = maximum deflection at the top of the tower in the North South or East West direction obtained from the wind tunnel tests due to a wind velocity equal to 100 mph

Equivalent design wind velocities for both towers in both directions are contained in Table 18 of the wind report, which is reproduced here as Table 2–4. It can be seen from the table that the equivalent 20 min design wind velocity was approximately 98 mph in the N-S and E-W directions for both buildings.

Table 2–4. Equivalent design wind velocity for WTC 1 and WTC 2.[a]

Tower	Direction of Movement	50-year Displacement (ft)	Critical Direction for 100 mph Wind[b]	Maximum Deflection in Critical Direction (ft)	Equivalent Design Wind Velocity (mph)
1	N-S	4.30	70°	4.5	98.0
	E-W	3.54	0°	3.7	98.0
2	N-S	4.64	80°	5.0	96.3
	E-W	3.66	170°	4.1	95.0

a. Based on critical damping ratio = 2.5 %.
b. Measured clockwise from north; zero angle corresponds to wind blowing from north to south.

The shear forces *S* and overturning moments *M* at each floor level due to the equivalent design wind velocity in each of the principal directions were comprised of static and dynamic components:

$$S = \overline{S} \pm S'$$
$$M = \overline{M} \pm M' \quad (2\text{–}2)$$

where the first terms in the summations are the mean or steady-state components and the second terms are dynamic components. Mean shear forces and overturning moments at height *z* above the base, which were derived from the average pressure coefficients measured in the wind tunnel tests at the CSU on the static twin-tower model, were calculated from the following equations in each principal direction (WSHJ 1966a):

$$\overline{S}(z) = \frac{1}{2}\rho \overline{V}_o^2 DHC_S(z)$$
$$\overline{M}(z) = \frac{1}{2}\rho \overline{V}_o^2 DH^2 C_M(z) \quad (2\text{–}3)$$

where:

ρ = design air density = 0.0023 slugs/ft^3

$\overline{V}_o$ = mean design wind velocity = 98 mph

C_S = shear force coefficients from wind tunnel tests (WSHJ 1965b)

C_M = overturning moment coefficients from wind tunnel tests (WSHJ 1965b)

D = plan dimension of building

H = height of building

Dynamic components of the shear forces and overturning moments at any height *z*, which were based on the peak dynamic amplitudes of vibration measured in the wind tunnel tests at CSU on the aeroelastic twin-tower model, were calculated from the following equations in each principal direction (WSHJ 1966a):

$$S'(z) = 4\pi^2 n_o^2 A \int_z^H m(z)\mu(z)dz$$
$$M'(z) = \int_z^H S'(z)dz \quad (2\text{–}4)$$

In the first of these equations, n_o is the natural frequency of oscillation of the building, which is given in the wind report (WSHJ 1966a), and *A* is the amplitude of oscillation at the top of the tower corresponding to a mean design wind velocity of 98 mph. The quantity $m(z)$ is the mass per unit height of the building (see Fig. 121 in WSHJ 1966a) and $\mu(z)$ is the mode amplitude at height *z* for unit amplitude at the top of the building (see Fig. 120 in WSHJ 1966a).

As noted above, 24 wind directions at 15 degree intervals around the towers were considered in the analysis. Since there were four possible combinations of static and dynamic components due to wind (see Eq. 2–2), 96 sets of wind load cases were considered for each tower (WSHJ 1966c). A summary of the total deflections and dynamic amplitudes at the top of the towers and the adjusted pressure coefficients over the height of the towers is contained in WSHJ (1966c). Figure 2–15 shows the total (static plus dynamic) deflections at the top of WTC 1 (A) and WTC 2 (B) in both the north-south and east-west directions due to wind velocities of 100 mph and 98 mph (design wind speed; see Table 2–4). Through interpretation of information contained in documents provided by Leslie E. Robertson Associates (LERA) in July 2004, it is possible to determine the design wind pressures from the wind tunnel tests.

WORTHINGTON, SKILLING, HELLE & JACKSON — Civil & Structural Engineers
THE WORLD TRADE CENTER — THE PORT OF NEW YORK AUTHORITY
MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT
EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT
DATE 3-15-66 — PREPARED BY PC — APPROVED — Sheet No.

TOTAL DEFLECTION @ TOP (STATIC + DYNAMIC)
Damping = 2.5%
$I = 10.4 \times 10^{12}$ Slug-Ft^2

Azimuth Angle α	$\bar{V}$ = 100 mph				$\bar{V}$ = 98 mph			
	$A_{N\text{-}S}$	$A_{E\text{-}W}$	$B_{N\text{-}S}$	$B_{E\text{-}W}$	$A_{N\text{-}S}$	$A_{E\text{-}W}$	$B_{N\text{-}S}$	$B_{E\text{-}W}$
0°	4.3	3.7	3.17	3.1	4.12	3.55	3.04	2.98
15	4.2	2.35	3.3	1.5	4.03	2.26	2.88	1.44
30	3.7	1.5	2.45	0.46	3.55	2.21	2.40	1.52
45	3.1	2.6	3.1	2.35	3.00	2.50	2.85	2.40
60	4.05	3.0	3.9	3.6	3.89	2.88	3.74	3.45
75	4.4	3.3	4.9	3.9	4.22	3.17	4.70	3.74
90	4.05	3.4	4.85	3.95	3.89	3.26	4.65	3.79
105	2.6	3.1	4.3	3.2	2.50	2.98	4.12	3.07
120	2.0	3.5	4.3	3.7	1.92	3.36	4.12	3.55
135	1.75	1.45	3.7	3.2	1.68	1.39	3.55	3.07
150	2.05	1.8	2.55	2.75	1.97	1.73	2.45	2.64
165	1.5	2.3	3.1	3.3	1.44	2.21	2.98	3.17
180	3.2	2.7	4.15	3.55	3.07	2.59	3.98	3.41
195	3.13	1.25	3.6	2.9	3.00	1.20	3.46	2.78
210	2.97	1.2	3.3	3.1	2.85	1.15	3.17	2.98
225	2.86	1.7	3.0	3.35	2.74	1.63	2.88	3.22
240	2.6	2.3	2.1	3.55	2.50	2.21	2.02	3.41
255	2.45	3.05	1.8	3.35	2.35	2.93	1.73	3.22
270	2.2	3.3	2.05	3.2	2.11	3.17	1.97	3.07
285	2.2	3.0	1.56	3.0	2.11	2.88	1.50	2.88
300	2.7	2.6	1.5	2.75	2.59	2.50	1.44	2.64
315	2.25	2.25	1.5	2.0	2.16	2.16	1.44	1.92
330	2.64	1.8	1.55	1.45	2.54	1.73	1.49	1.39
345	2.8	2.04	1.32	2.05	2.69	1.96	1.27	1.97

Source: WSHJ 1966c. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 2–15. Total deflections (ft) at top of WTC 1 and WTC 2 due to wind.

Once the total shear forces were computed at each floor level, concentrated forces due to wind were determined and applied at each floor level. Member forces were computed based on these applied forces.

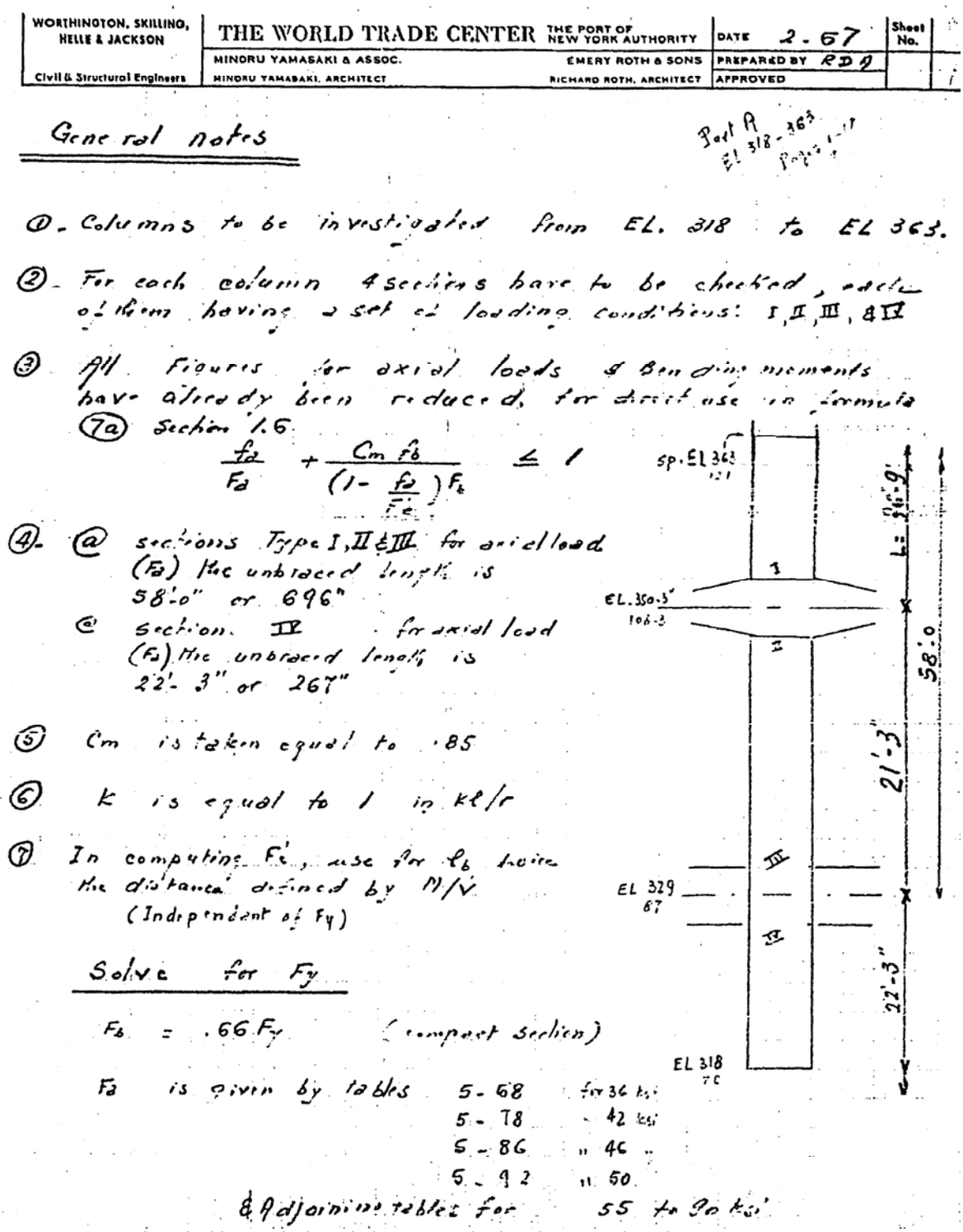
Typical hand calculations for an exterior column are given in WSHJ (1967b). These calculations are representative of the allowable stress methods used to proportion exterior columns throughout the towers. The first two pages of the calculations are contained in Fig. 2–16. As can be seen from the figure, Formula (7a) from Sec. 1.6.1 (Combined Stresses, Axial Compression and Bending) of the AISC Specification (AISC 1963b) was used to proportion the members for the design loads contained in the tables on the second page of the calculations. For given section properties of the columns, the required yield strength of the steel was determined from Formula (7a).

2.3.3 Floor Trusses

Design data for the composite floor trusses that were used outside of the core area are given in Laclede Steel Company (1967). Four pages from this document, which are contained in Fig. 2–17, summarize the loads, materials, design equations, shear connectors, and deflection criteria used in design. As shown on the third page in the figure, truss members with lengths less than or equal to 24 in. were designed for allowable tension and compression stresses per AISC Specification Secs. 1.5.1.1 (Tension) and 1.5.1.3 (Compression), respectively (AISC 1963b). Top chord members with lengths greater than 24 in. were designed for combined axial and bending stresses per Sec. 1.6.1 (Combined Axial Compression and Bending).

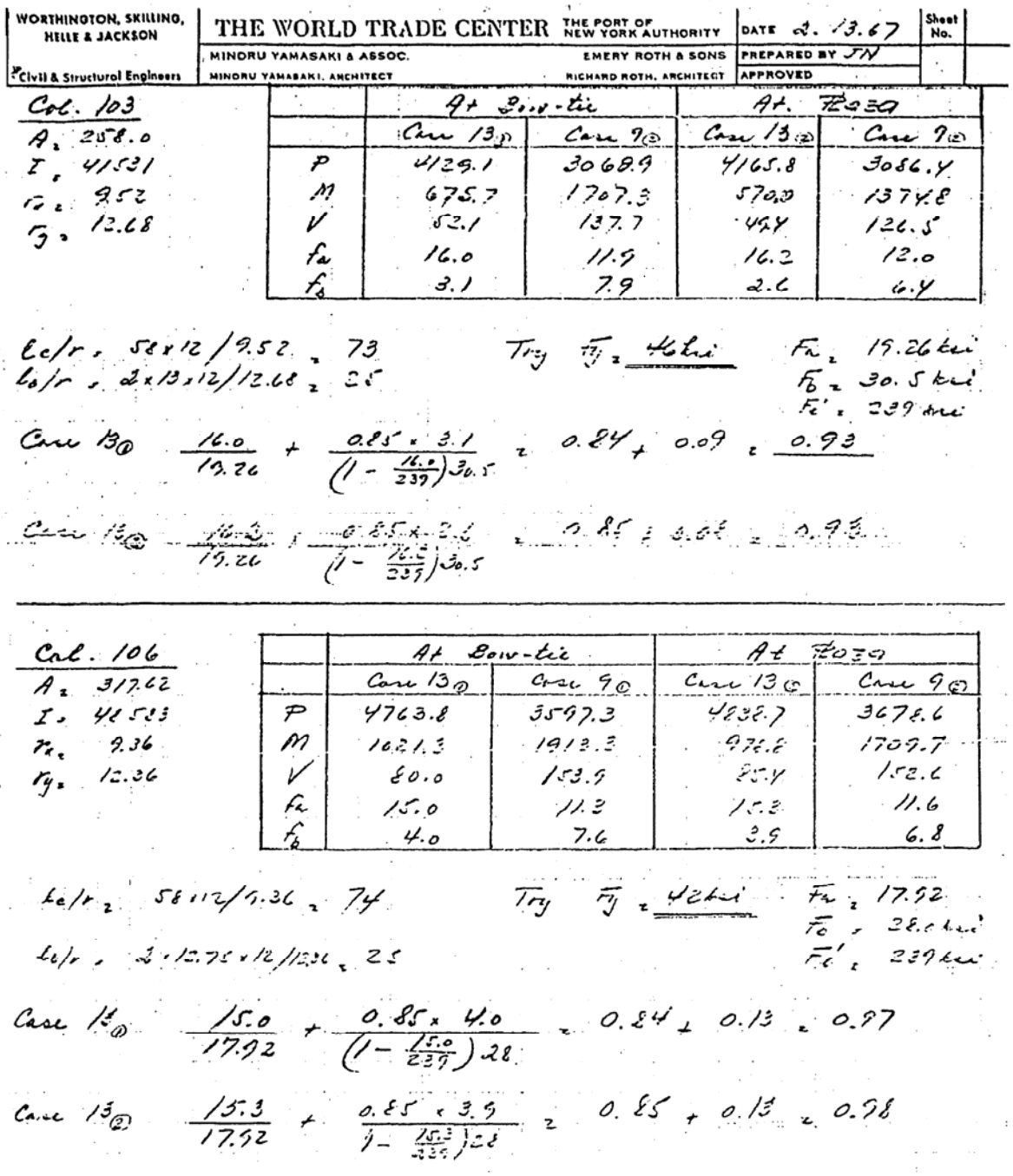
Floor truss panel points were connected by electronically controlled resistance welds providing at least two times the strength of the connected members at full design load (Laclede Steel Company 1967).

As shown in Fig. 2–18, truss seat connection capacities were tabulated for connections at the core and at the exterior columns (SHCR 1971). The governing capacity, which was to be determined in accordance with the AISC Specification (AISC 1963b) per the Design Criteria (WSHJ 1965a), was taken as the smallest of the capacities of the members and connectors that made up a particular connection.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 2–16. Design method for exterior columns in WTC 1 and WTC 2.



WORTHINGTON, SKILLING, HELLE & JACKSON — Civil & Structural Engineers
THE WORLD TRADE CENTER — THE PORT OF NEW YORK AUTHORITY
MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT
EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT
DATE 2. 13.67 — PREPARED BY JN — APPROVED — Sheet No.

Col. 103

A_s = 258.0
I = 41531
r_x = 9.52
r_y = 12.68

	At Belt		At Floor	
	Case 13①	Case 9②	Case 13②	Case 9②
P	4129.1	3068.9	4165.8	3086.4
M	675.7	1707.3	570.0	1374.8
V	82.1	137.7	49.4	126.5
f_a	16.0	11.9	16.2	12.0
f_b	3.1	7.9	2.6	6.4

l_c/r = 58×12/9.52 = 73 — Try F_y = 46 ksi — F_a = 19.26 ksi
l_b/r = 2×13×12/12.68 = 25 — F_b = 30.5 ksi
F_e' = 239 ksi

Case 13① $\frac{16.0}{19.26} + \frac{0.85 \times 3.1}{\left(1 - \frac{16.0}{239}\right)30.5} = 0.84 + 0.09 = 0.93$

Case 13② $\frac{16.2}{19.26} + \frac{0.85 \times 2.6}{\left(1 - \frac{16.2}{239}\right)30.5} = 0.85 + 0.08 = 0.93$

Col. 106

A_s = 317.62
I = 41503
r_x = 9.36
r_y = 12.36

	At Belt		At Floor	
	Case 13①	Case 9②	Case 13②	Case 9②
P	4763.8	3597.3	4838.7	3678.6
M	1021.3	1913.3	976.6	1709.7
V	80.0	153.9	85.4	152.6
f_a	15.0	11.3	15.3	11.6
f_b	4.0	7.6	3.9	6.8

l_e/r = 58×12/9.36 = 74 — Try F_y = 42 ksi — F_a = 17.92
l_b/r = 2×12.75×12/12.36 = 25 — F_b = 28.6 ksi
F_e' = 239 ksi

Case 13① $\frac{15.0}{17.92} + \frac{0.85 \times 4.0}{\left(1 - \frac{15.0}{239}\right)28} = 0.84 + 0.13 = 0.97$

Case 13② $\frac{15.3}{17.92} + \frac{0.85 \times 3.9}{\left(1 - \frac{15.3}{239}\right)28} = 0.85 + 0.13 = 0.98$

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Figure 2–16. Design method for exterior columns in WTC 1 and WTC 2 (continued).

ACLEDE STEEL COMPANY

D100-1
Date February 6, 1967

WORLD TRADE CENTER
FLOOR GRID TRUSSES
BASIC DESIGN DATA

Based on double truss units. Mark 2CT__ or 2ST__.
Single truss components. Mark CT__ or ST__.

DIMENSIONS:

Unless specifically noted otherwise, see "ST" Details.

Truss clearspan in feet = L. Overall length of truss minus end bearings in feet (2 x 5" = 10"). Example: 59'9" overall length. Clearspan L = 59'9" minus 10" or 58'11" or 58.92'.

Length of member, clear of attachments = "ℓ"

Depth of Truss

Composite type "C" (Measured top of shear member to bottom of lower chord.)

Standard type "S" (Measured out to out of chord members.)

Total depth of composite section = "D_t"

TOLERANCES:

Overall length 1/4"+ or 1/4"-.

Depth 1/8"+ or 1/8"-.

LOADS:

Total load = Live load + Dead load

Applicable for composite design.

Applicable for combined slab and top chord design and bottom chord design.

Construction load = Applicable Dead load

Applicable for top and bottom chord steel design.

Dead load = Actual weight of structural system in pounds per square foot.

Live load = Assigned live load for panel area in pounds per square foot.

Design load in pounds per square foot = "w"

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Figure 2–17. Design method for floor trusses in WTC 1 and WTC 2.

ACLEDE STEEL COMPANY

D100-2

Date February 6, 1967

Applicable design load in pounds per foot equals design load in pounds per square foot times spacing of trusses in feet = ... "W"

TOTAL MOMENT:

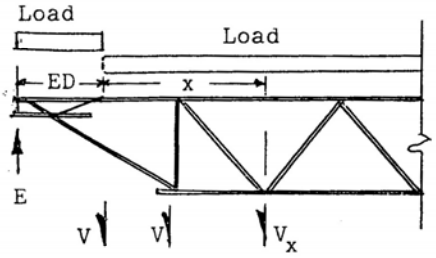
"M" (In inch pounds) = WL^2 x 1.5.

END REACTION:

"R" (In pounds) = "W" x .5 (overall length of truss in feet).

SHEAR:

At first top chord panel in pounds = V = R- (W x ED)

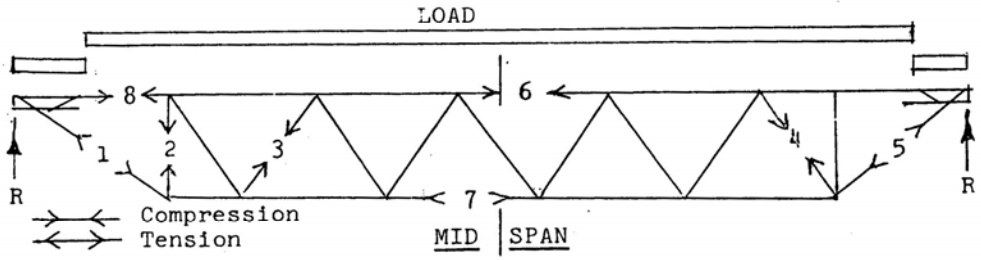


ED = Distance first top chord panel point to truss end.

Shear at other points in pounds = V_x = (R- ED x W)-W (distance to first top chord panel point in feet).

(In no case less than 50% of end reaction "R".)

DESIGNATION OF MEMBERS:



1. End diagonal (long end) tension member
2. First panel vertical (long end) compression
3. Second panel compression diagonal
4. First panel member (short end) compression
5. End diagonal (short end) tension
6. Top chord critical compression member at mid span
7. Bottom chord critical tension member at mid span
8. End top chord compression member (long end)

MATERIALS:

A-36 steel . . . . . 36 ksi minimum yield strength

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Figure 2–17. Design method for floor trusses in WTC 1 and WTC 2 (continued).

ACLEDE STEEL COMPANY

D100-3

Date February 6, 1967

A-441 modified for weldability. . . . . 50 ksi minimum yield strength low alloy "H" Series.

See sheets D101 through D103 for Properties of Sections.

APPLICABLE FORMULAE: Stress Determination (Web or Chord Members)

A-36 steel

(36 ksi minimum yield)

f_y = Minimum Yield Strength 36,000 psi

f_s = Tension 22,000 psi

f_{sc} = Compression for $\ell/r < 127$ $18{,}540 - .574\,(\ell/r)^2$ psi

for $\ell/r > 127$ $\dfrac{149{,}000{,}000}{(\ell/r)^2}$ psi

ℓ = clear distance between attachments

r = least radius of gyration

A-441 steel

(50 ksi minimum yield)

f_y = Minimum Yield Strength 50,000 ksi

f_s = Tension 30,000 psi

f_{sc} = Compression for $\ell/r < 108$ $25{,}750 - 1.108\,(\ell/r)^2$ psi

for $\ell/r > 108 < 200$ $\dfrac{149{,}000{,}000}{(\ell/r)^2}$ psi

Continuous members shall be designed for only axial compressive stress when the panel length clear of attachments does not exceed 24". When the panel length clear of attachments exceeds 24", the top chord shall be designed as a continuous member subject to combined axial and bending stress and shall be of proportion that the quantity -

$$\frac{f_a}{30{,}000} + \frac{f_b}{F_b}$$

does not exceed unity at the panel point, or that the quantity -

$$\frac{f_a}{F_a} + \frac{f_b C_m}{F_b\left(1 - \dfrac{f_a}{F'_e}\right)}$$

does not exceed unity at the mid panel.

Permissible axial unit compressive stress = "F_a"

Permissible bending unit stress = "F_b"

Permissible compressive stress factor (column equation $\dfrac{149{,}000{,}000}{(\ell/r)^2}$ psi) = "F'_e"

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Figure 2–17. Design method for floor trusses in WTC 1 and WTC 2 (continued).

ACLEDE STEEL COMPANY

D100-4
Date February 6, 1967

Actual axial unit compressive stress = ... f_a

Actual bending unit stress = ... f_b

MAXIMUM SLENDERNESS RATIOS:

Top chord panels (interior) = 85
Top chord end panels = 120
Compression members other than top chord = 200
Tension members = 240

FILLERS OR TIES:

Members in compression composed of two components shall have fillers or ties spaced so that the ratio of ℓ/r of each component shall not exceed the ratio of ℓ/r of the whole member. The minimum "r" shall be used in calculating the critical ratio ℓ/r of any component.

SHEAR CONNECTORS:

Shall be considered to provide a minimum 15 ksi horizontal shear per web end connector imbedded in the concrete. This is for 3,000 psi concrete. (f_c)

DEFLECTION:

Applicable deflection formula for uniform load.

Maximum deflection $\Delta = \frac{25.88\ (WL^4)}{29{,}000{,}000I}$

COMPOSITE SLAB AND JOIST DESIGN:

[illegible] . . . . . y_1

Distance from top of concrete flange to neutral axis of top chord angles = ... y_2

Distance from top of concrete flange to neutral axis of bottom chord angles = ... y_3

Distance from top of concrete flange to neutral axis of composite section = ... $\bar{y}$

Distance from neutral axis of composite section to neutral axis of concrete flange = ... d_1

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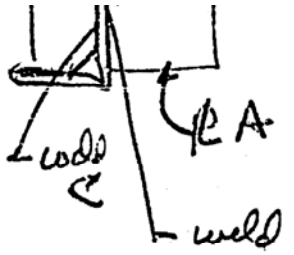
Figure 2–17. Design method for floor trusses in WTC 1 and WTC 2 (continued).

SKILLING HELLE CHRISTIANSEN ROBERTSON | PROJECT The WTC | DATE 5/ '71 | Sheet No.

KD-4 HUNG D.13

ITEM / DETAIL NO.	PL.(A)	WELD(A)	PL.(B)	PL.(C)	WELD(C)	
10	75	56	75	100	47 *	
11	75	56	75	100	47 *	
12	75	56	75	216	43 *	
13	92	84	92	288	61 *	
14	180	142	180	206	134 *	
15	84	82 *	84	126	156	.82
16	124	124	124	600	65 *	
17	84	82	84	140	54 *	
18	166	128	166	296	100 *	
19	110	96	110	242	52 *	
20	85	64 *	85	146	64 *	
21	72	52 *	72	220	52 *	
22	64	50 *	64	140	57	50
23	64	50	64	130	35 *	
24	107	92 *	107	360	93	92
25	92	92	92	175	61 *	
26	87	80	87	288	71 *	
27	102	84 *	102	230	93	84
28	87	80 *	87	246	94	80
29	110	112	110	258	106 *	
30	98	108	98	467	88 *	
31	75	70	75	467	59 *	
32	75	70	75	267	59 *	
(I)-226A	180	140 *	180	200	156	← ?



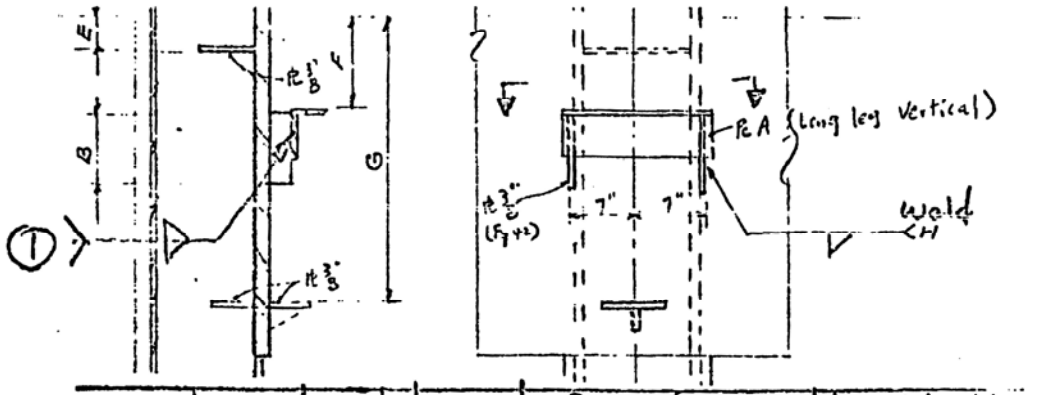
Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 2–18. Tabulation of component capacities of floor truss connections in WTC 1 and WTC 2.

CHRISTIANSEN ROBERTSON
Structural & Civil Engineers

EXT. TRUSS SEATS

PREPARED BY
APPROVED



Rev. Load	Design Load	Col. No.	Detail No.	Pc A Angle SIZE	CAP	Weld to Size	Length (B)	CAP	Weld @ 5K. CAP

2.3.4 Composite Steel Beams

"Design standards" for the composite floor systems in the core area are given in the Design Criteria (WSHJ 1965a), and are summarized in Fig. 2–19. As seen on the first page in the figure, the provisions for effective flange width of the concrete slab were modified from those given in Sec. 906(d) (Requirements for T-beams) of the 1963 edition of ACI 318 (ACI 1963) to accommodate the case that is depicted in the figure. Design of the composite members followed Sec. 1.11 (Composite Construction) in the AISC Specification (AISC 1963b).

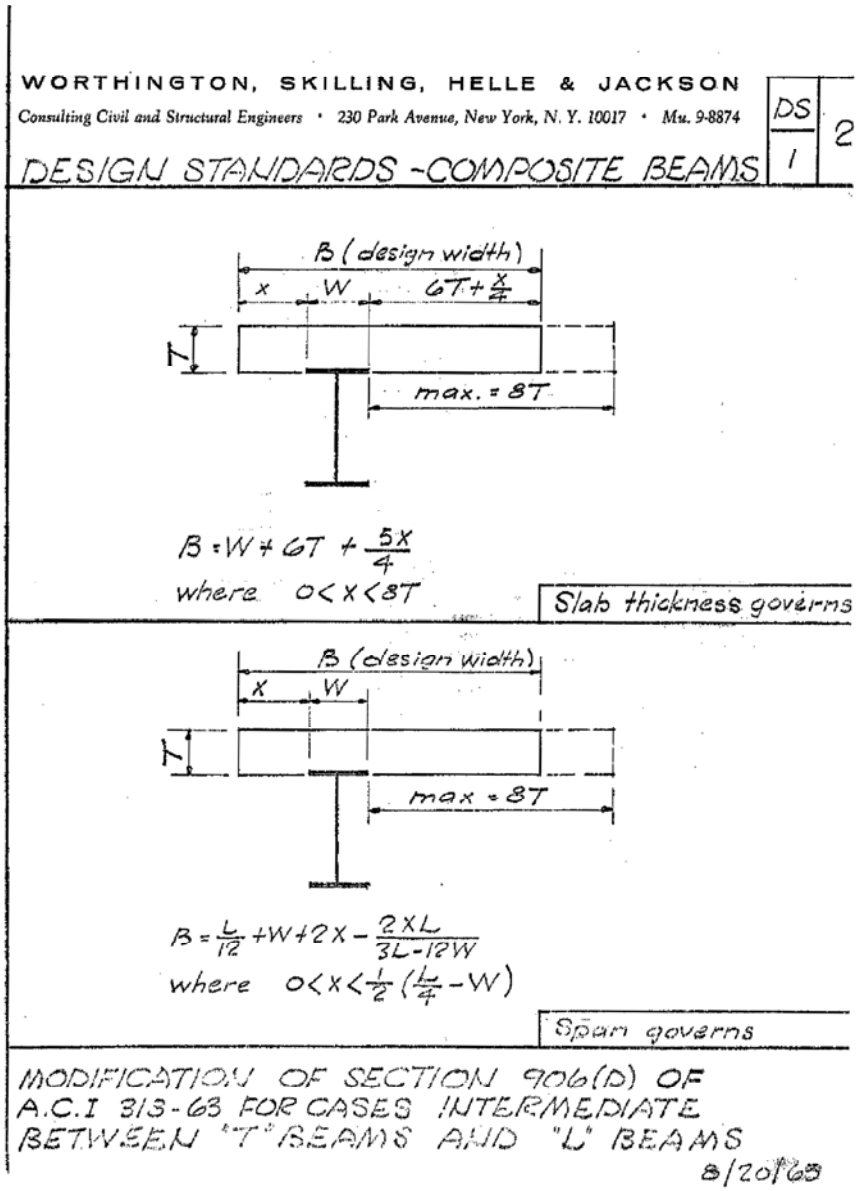


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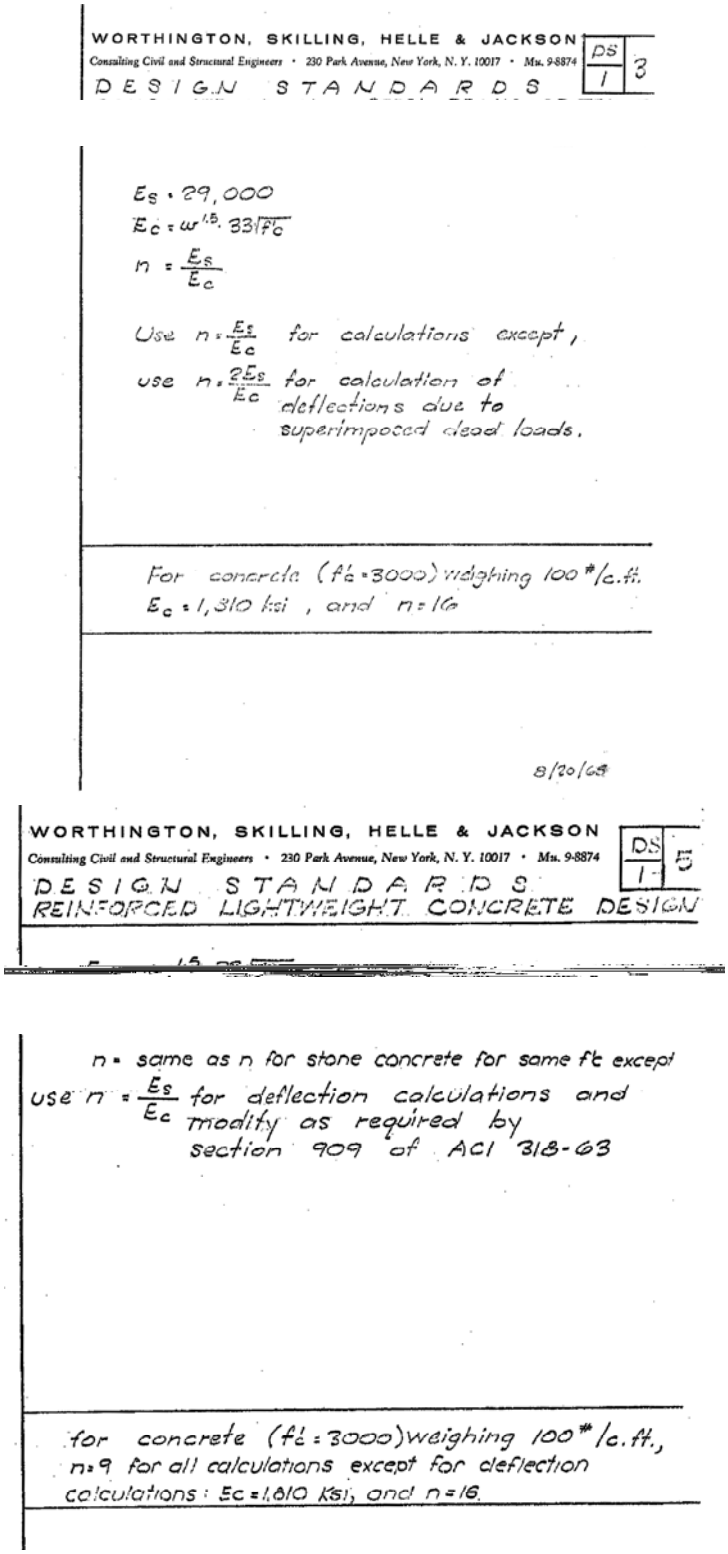
Figure 2–19. Design standard for composite sections in WTC 1 and WTC 2.



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DESIGN STANDARDS
DS / 1 / 3

$E_s = 29{,}000$
$E_c = w^{1.5} \cdot 33\sqrt{f'_c}$
$n = \frac{E_s}{E_c}$

Use $n = \frac{E_s}{E_c}$ for calculations except,
use $n = \frac{2E_s}{E_c}$ for calculation of deflections due to superimposed dead loads.

For concrete (f'_c = 3000) weighing 100 #/c.ft.
E_c = 1,310 ksi, and n = 16

8/20/68

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DESIGN STANDARDS
REINFORCED LIGHTWEIGHT CONCRETE DESIGN
DS / 1 / 5

n = same as n for stone concrete for same ft except
use $n = \frac{E_s}{E_c}$ for deflection calculations and modify as required by section 909 of ACI 318-63

for concrete (f'_c = 3000) weighing 100 #/c.ft.,
n = 9 for all calculations except for deflection calculations: Ec = 1,810 ksi, and n = 16.

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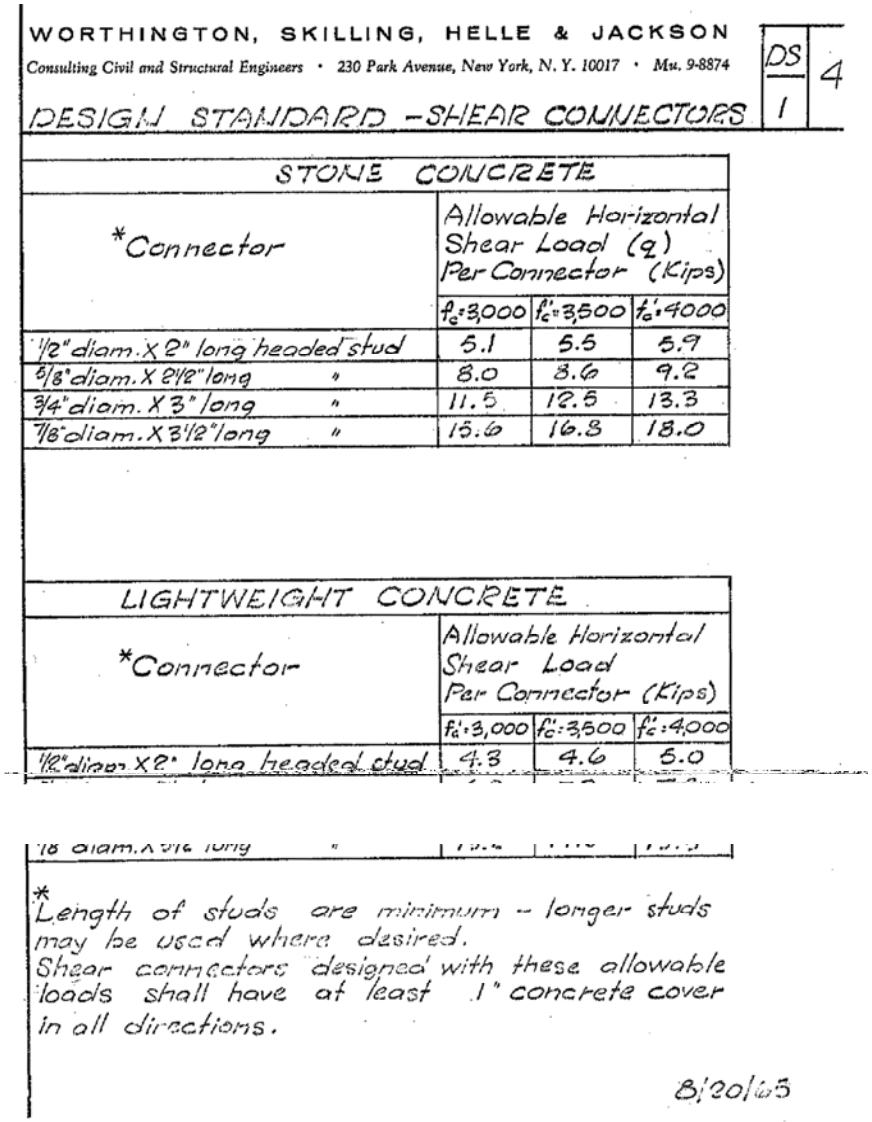
Figure 2–19. Design standard for composite sections in WTC 1 and WTC 2 (continued).



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DS 4 / 1

DESIGN STANDARD – SHEAR CONNECTORS

STONE CONCRETE

*Connector	Allowable Horizontal Shear Load (q) Per Connector (Kips)		
	f'_c=3,000	f'_c=3,500	f'_c=4000
1/2" diam. X 2" long headed stud	5.1	5.5	5.9
5/8" diam. X 2 1/2" long "	8.0	8.6	9.2
3/4" diam. X 3" long "	11.5	12.5	13.3
7/8" diam. X 3 1/2" long "	15.6	16.8	18.0

LIGHTWEIGHT CONCRETE

*Connector	Allowable Horizontal Shear Load Per Connector (Kips)		
	f'_c=3,000	f'_c=3,500	f'_c=4,000
1/2" diam. X 2" long headed stud	4.3	4.6	5.0

* Length of studs are minimum – longer studs may be used where desired.
Shear connectors designed with these allowable loads shall have at least 1" concrete cover in all directions.

8/20/63

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Figure 2–19. "Design standard" for composite sections in WTC 1 and WTC 2 (continued).

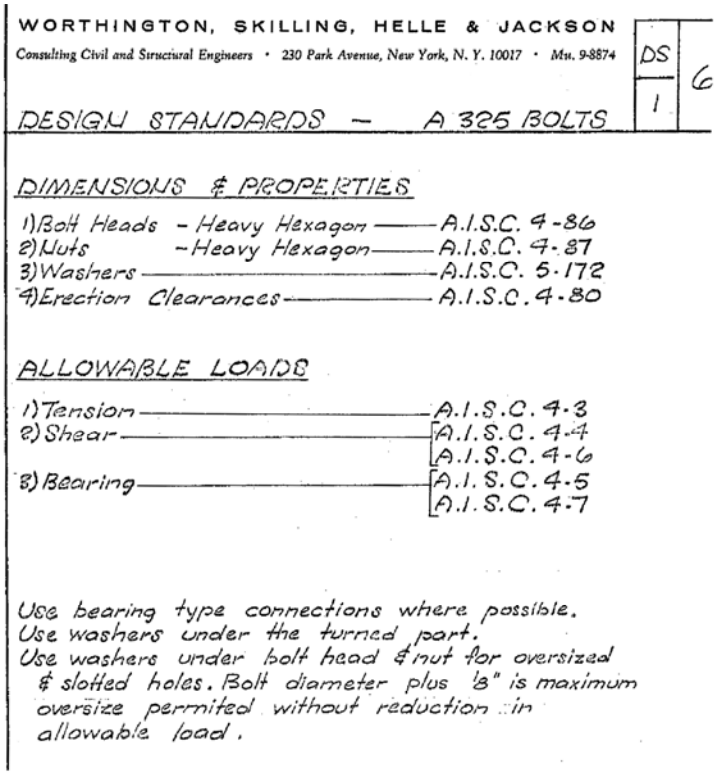
Allowable horizontal shear loads for the connectors in "stone concrete," which are shown on sheet number 4 in the figure, are taken directly from Table 1.11.4 in the AISC Specification (AISC 1963b). According to Commentary Sec. 1.11.4 (Shear Connectors), the allowable shear loads for connectors in concrete with aggregates not conforming to ASTM C 33[6] must be established by a suitable testing program. Note that the allowable shear loads for the connectors in "lightweight concrete" used in design are 85 percent of the values listed for "stone concrete" (see Fig. 2–19). The Port Authority requested tests to be performed (based on a test program established by Skilling, Helle, Christiansen, & Robertson) at the Fritz Engineering Laboratory at Lehigh University to determine the shear capacity of 3/4 in. diameter by 4 1/2 in. long studs welded through the troughs of Roll Form Type "B" steel deck in lightweight

[6] This specification defines the requirements for grading and quality of fine and coarse aggregate (other than lightweight or heavyweight aggregate) for use in concrete.

aggregate concrete with a compressive strength of 3,000 psi (see Sec. 3.5 of this report). Results from this testing program could not be located, and no evidence was found that this system was utilized in WTC 1 and WTC 2. The floor trusses outside of the core area did not use shear studs to make them composite with concrete slab. Instead, truss diagonals were extended above the top chord; this "knuckle" acted like a shear stud (see Sec. 5.4 of this report).

2.3.5 Connections

General design standards for the A325 bolts used in the connections are given in the Design Criteria (WSHJ 1965a) and are shown in Fig. 2–20. Page numbers from the *Manual of Steel Construction* (AISC 1963a) (which also contains the AISC Specification) are given in the figure for bolt dimensions and properties and for allowable loads.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DS 6
1

DESIGN STANDARDS — A 325 BOLTS

DIMENSIONS & PROPERTIES

1) Bolt Heads - Heavy Hexagon — A.I.S.C. 4-86
2) Nuts - Heavy Hexagon — A.I.S.C. 4-87
3) Washers — A.I.S.C. 5-172
4) Erection Clearances — A.I.S.C. 4-80

ALLOWABLE LOADS

1) Tension — A.I.S.C. 4-3
2) Shear — A.I.S.C. 4-4, A.I.S.C. 4-6
3) Bearing — A.I.S.C. 4-5, A.I.S.C. 4-7

Use bearing type connections where possible.
Use washers under the turned part.
Use washers under bolt head & nut for oversized & slotted holes. Bolt diameter plus ⅛" is maximum oversize permited without reduction in allowable load.

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Figure 2–20. Design standard for bolted connections in WTC 1 and WTC 2.

Specifications for welded connections depended on the structural members that were being connected. In particular, the specifications in the contracts with the suppliers of the floor trusses, box core columns and built-up beams, exterior wall, and rolled columns and beams each contained requirements that the welding conform as a minimum to the provisions in the then current edition of *Code for Welding in Building Construction*, D1.0, American Welding Society (see Chapters 5 and 6 of this report for more information on the requirements in these contracts). For the exterior columns, the welding electrodes that were to be used depended on the lower yield strength of the plates that were joined (see Sheet 2-AB2-3 in WSHJ 1967c, which is reproduced here in Fig. 2–21).

A connection manual was assembled by WSHJ that contained tables and charts with allowable loads for the typical connections used in the project (WSHJ 1967d).

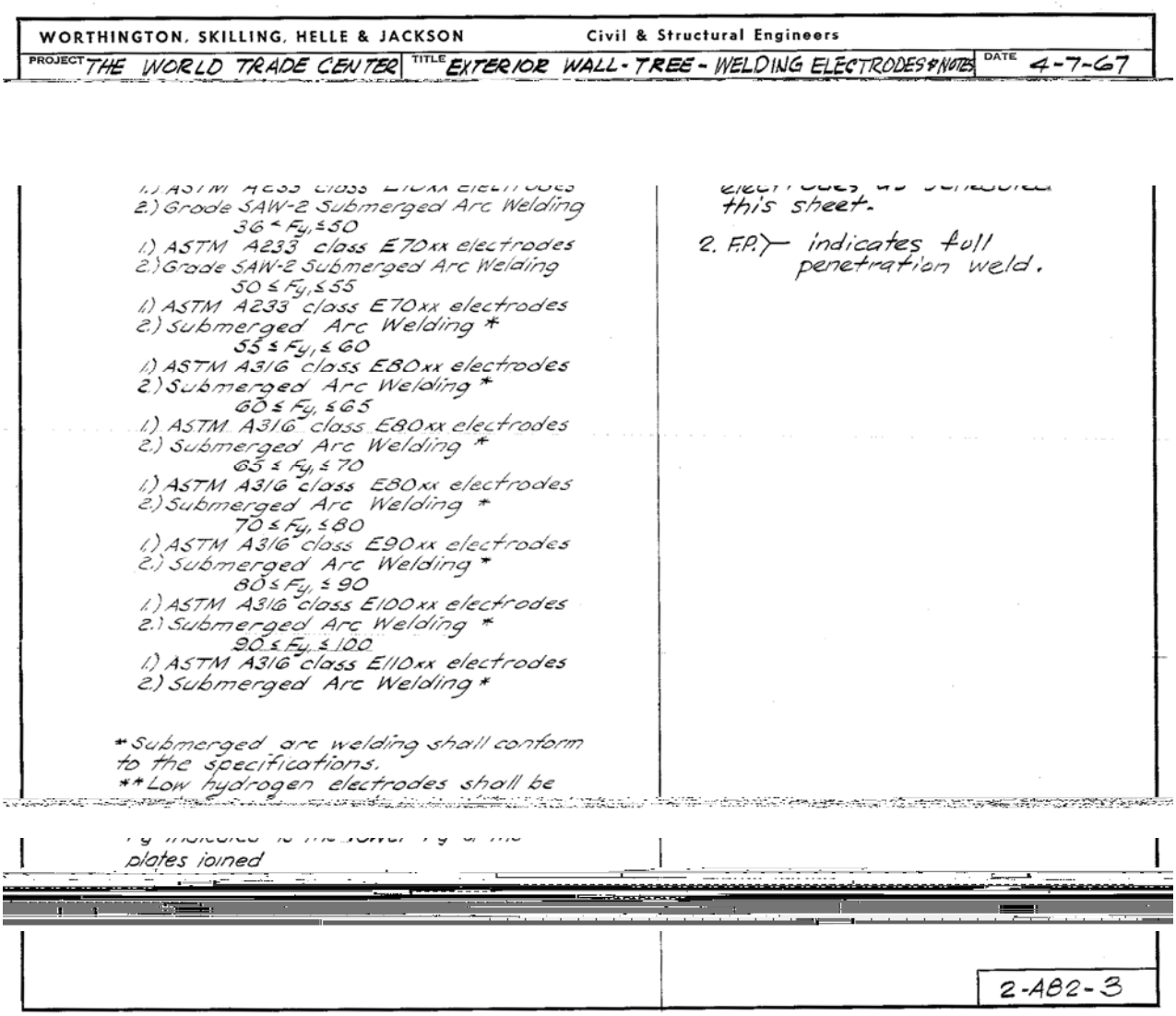

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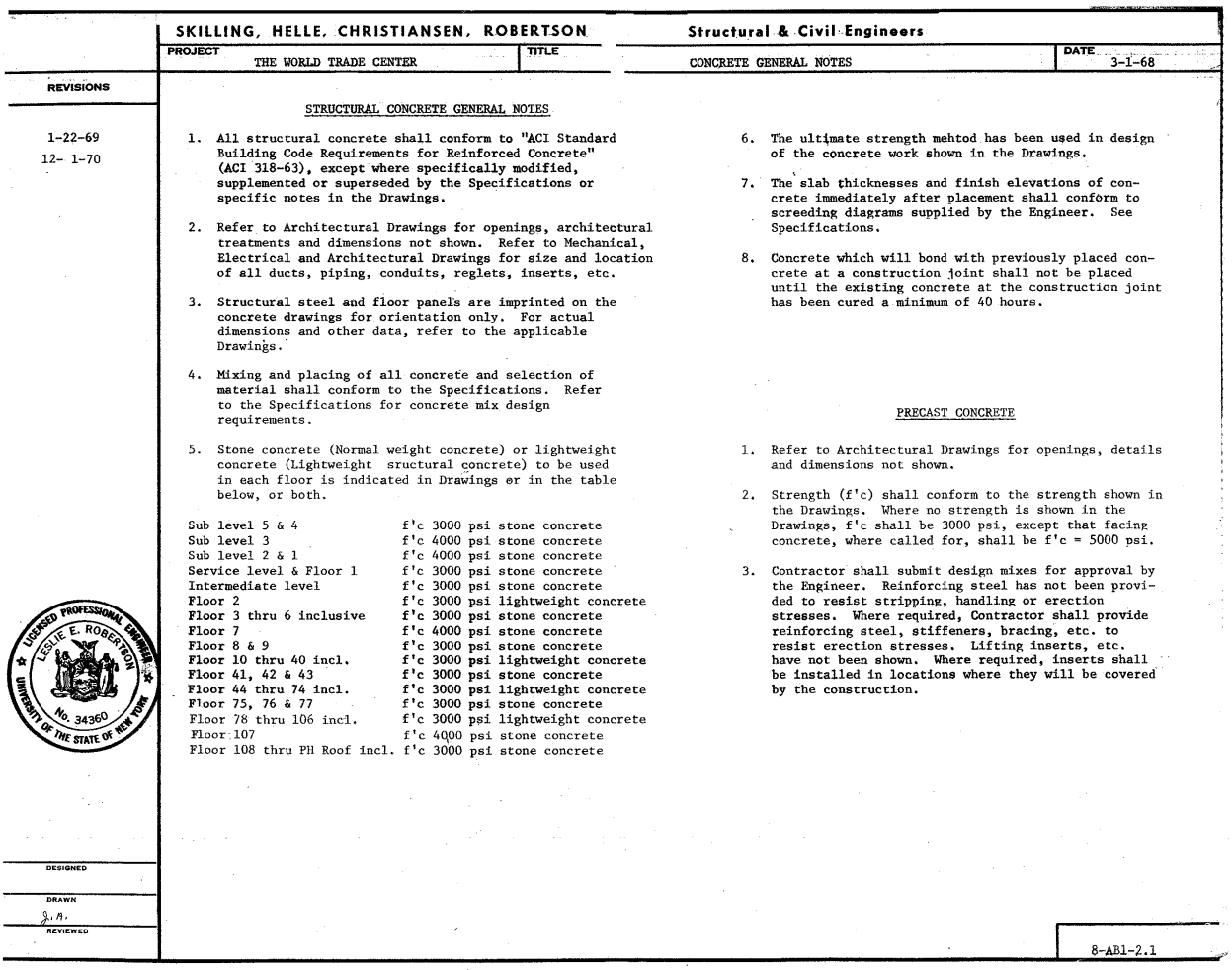
Figure 2–21. Schedule of welding electrodes for connections in exterior columns in WTC 1 and WTC 2.

A note on structural drawing sheet S-24 of WTC 7 references the "AISC Beam Tables" for connection design of composite and non-composite beams (The Office of Irwin G. Cantor 1983). As noted in Sec. 2.1.2 of this report, the project specifications for WTC 7 (WTC 7 Project Specifications 1984) required that the structural steel be designed in accordance with the then current New York City Building Code and the latest edition of the AISC *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings* (AISC 1963a).

2.3.6 Concrete Floor Slabs

According to the first general note for structural concrete contained in Book 8 of the structural drawings for WTC 1 and WTC 2 (WSHJ 1967c), all structural concrete was to conform to the 1963 edition of ACI 318 (ACI 1963), except where specifically modified, supplemented, or superseded by the Specifications or specific notes in the drawings (see Fig. 2–22).



SKILLING, HELLE, CHRISTIANSEN, ROBERTSON — Structural & Civil Engineers

PROJECT: THE WORLD TRADE CENTER | TITLE: CONCRETE GENERAL NOTES | DATE: 3-1-68

REVISIONS

1-22-69
12- 1-70

STRUCTURAL CONCRETE GENERAL NOTES

1. All structural concrete shall conform to "ACI Standard Building Code Requirements for Reinforced Concrete" (ACI 318-63), except where specifically modified, supplemented or superseded by the Specifications or specific notes in the Drawings.
2. Refer to Architectural Drawings for openings, architectural treatments and dimensions not shown. Refer to Mechanical, Electrical and Architectural Drawings for size and location of all ducts, piping, conduits, reglets, inserts, etc.
3. Structural steel and floor panels are imprinted on the concrete drawings for orientation only. For actual dimensions and other data, refer to the applicable Drawings.
4. Mixing and placing of all concrete and selection of material shall conform to the Specifications. Refer to the Specifications for concrete mix design requirements.
5. Stone concrete (Normal weight concrete) or lightweight concrete (Lightweight sructural concrete) to be used in each floor is indicated in Drawings or in the table below, or both.

Sub level 5 & 4	f'c 3000 psi stone concrete
Sub level 3	f'c 4000 psi stone concrete
Sub level 2 & 1	f'c 4000 psi stone concrete
Service level & Floor 1	f'c 3000 psi stone concrete
Intermediate level	f'c 3000 psi stone concrete
Floor 2	f'c 3000 psi lightweight concrete
Floor 3 thru 6 inclusive	f'c 3000 psi stone concrete
Floor 7	f'c 4000 psi stone concrete
Floor 8 & 9	f'c 3000 psi stone concrete
Floor 10 thru 40 incl.	f'c 3000 psi lightweight concrete
Floor 41, 42 & 43	f'c 3000 psi stone concrete
Floor 44 thru 74 incl.	f'c 3000 psi lightweight concrete
Floor 75, 76 & 77	f'c 3000 psi stone concrete
Floor 78 thru 106 incl.	f'c 3000 psi lightweight concrete
Floor 107	f'c 4000 psi stone concrete
Floor 108 thru PH Roof incl.	f'c 3000 psi stone concrete

6. The ultimate strength mehtod has been used in design of the concrete work shown in the Drawings.
7. The slab thicknesses and finish elevations of concrete immediately after placement shall conform to screeding diagrams supplied by the Engineer. See Specifications.
8. Concrete which will bond with previously placed concrete at a construction joint shall not be placed until the existing concrete at the construction joint has been cured a minimum of 40 hours.

PRECAST CONCRETE

1. Refer to Architectural Drawings for openings, details and dimensions not shown.
2. Strength (f'c) shall conform to the strength shown in the Drawings. Where no strength is shown in the Drawings, f'c shall be 3000 psi, except that facing concrete, where called for, shall be f'c = 5000 psi.
3. Contractor shall submit design mixes for approval by the Engineer. Reinforcing steel has not been provided to resist stripping, handling or erection stresses. Where required, Contractor shall provide reinforcing steel, stiffeners, bracing, etc. to resist erection stresses. Lifting inserts, etc. have not been shown. Where required, inserts shall be installed in locations where they will be covered by the construction.

LICENSED PROFESSIONAL ENGINEER — LESLIE E. ROBERTSON — No. 34360 — UNIVERSITY OF THE STATE OF NEW YORK

DESIGNED
DRAWN
REVIEWED

8-AB1-2.1

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Figure 2–22. General notes for structural concrete in WTC 1 and WTC 2.

The ultimate strength method was used in concrete design (see general note 6 in Fig. 2–22). The basic requirement for strength design may be expressed as follows:

$$\text{Required Strength} \leq \text{Design Strength, or} \qquad U \leq \phi\,(\text{Nominal Strength}) \tag{2–5}$$

where the required strength (U) is determined from the load combinations given in Sec. 1506, the nominal strength is determined in accordance with the provisions in Chapters 15 through 19, and the capacity

reduction factors (ϕ) are obtained from Sec. 1504, where all section and chapter numbers are from ACI 318 (ACI 1963). The load combinations in Sec. 1506 of ACI 318-63 are summarized as follows:

- $U = 1.5D + 1.8L$
- $U = 1.25(D + L + W)$
- $U = 0.9D + 1.1W$

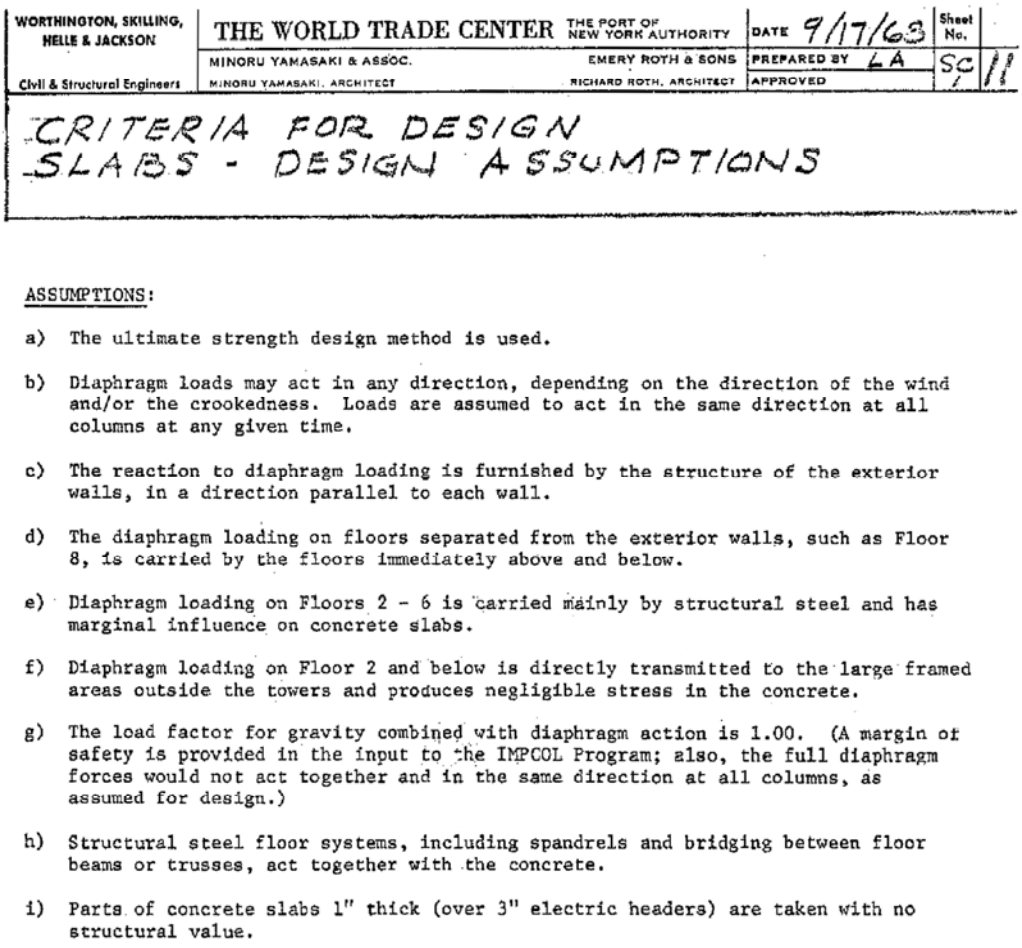
where

D = effects of the dead loads

L = effects of the live loads

W = effects of the wind forces

Additional assumptions used in the design of the floor slabs are contained in the Design Criteria (WSHJ 1965a), as shown in Fig. 2–23.



WORTHINGTON, SKILLING, HELLE & JACKSON
Civil & Structural Engineers

THE WORLD TRADE CENTER — THE PORT OF NEW YORK AUTHORITY

MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT

EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT

DATE 9/17/63 | PREPARED BY LA | APPROVED | Sheet No. SC 11

CRITERIA FOR DESIGN
SLABS - DESIGN ASSUMPTIONS

ASSUMPTIONS:

a) The ultimate strength design method is used.

b) Diaphragm loads may act in any direction, depending on the direction of the wind and/or the crookedness. Loads are assumed to act in the same direction at all columns at any given time.

c) The reaction to diaphragm loading is furnished by the structure of the exterior walls, in a direction parallel to each wall.

d) The diaphragm loading on floors separated from the exterior walls, such as Floor 8, is carried by the floors immediately above and below.

e) Diaphragm loading on Floors 2 - 6 is carried mainly by structural steel and has marginal influence on concrete slabs.

f) Diaphragm loading on Floor 2 and below is directly transmitted to the large framed areas outside the towers and produces negligible stress in the concrete.

g) The load factor for gravity combined with diaphragm action is 1.00. (A margin of safety is provided in the input to the IMPCOL Program; also, the full diaphragm forces would not act together and in the same direction at all columns, as assumed for design.)

h) Structural steel floor systems, including spandrels and bridging between floor beams or trusses, act together with the concrete.

i) Parts of concrete slabs 1" thick (over 3" electric headers) are taken with no structural value.

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Figure 2–23. Design assumptions for concrete floor slabs in WTC 1 and WTC 2.

Calculations for the slab design on floors 10 through 87 (WSHJ 1967e) as well as concrete design tables (WSHJ 1967f) confirm the use of the ultimate strength design method. Figure 2–24 shows sample calculations for the one-way slab design based on this design method.

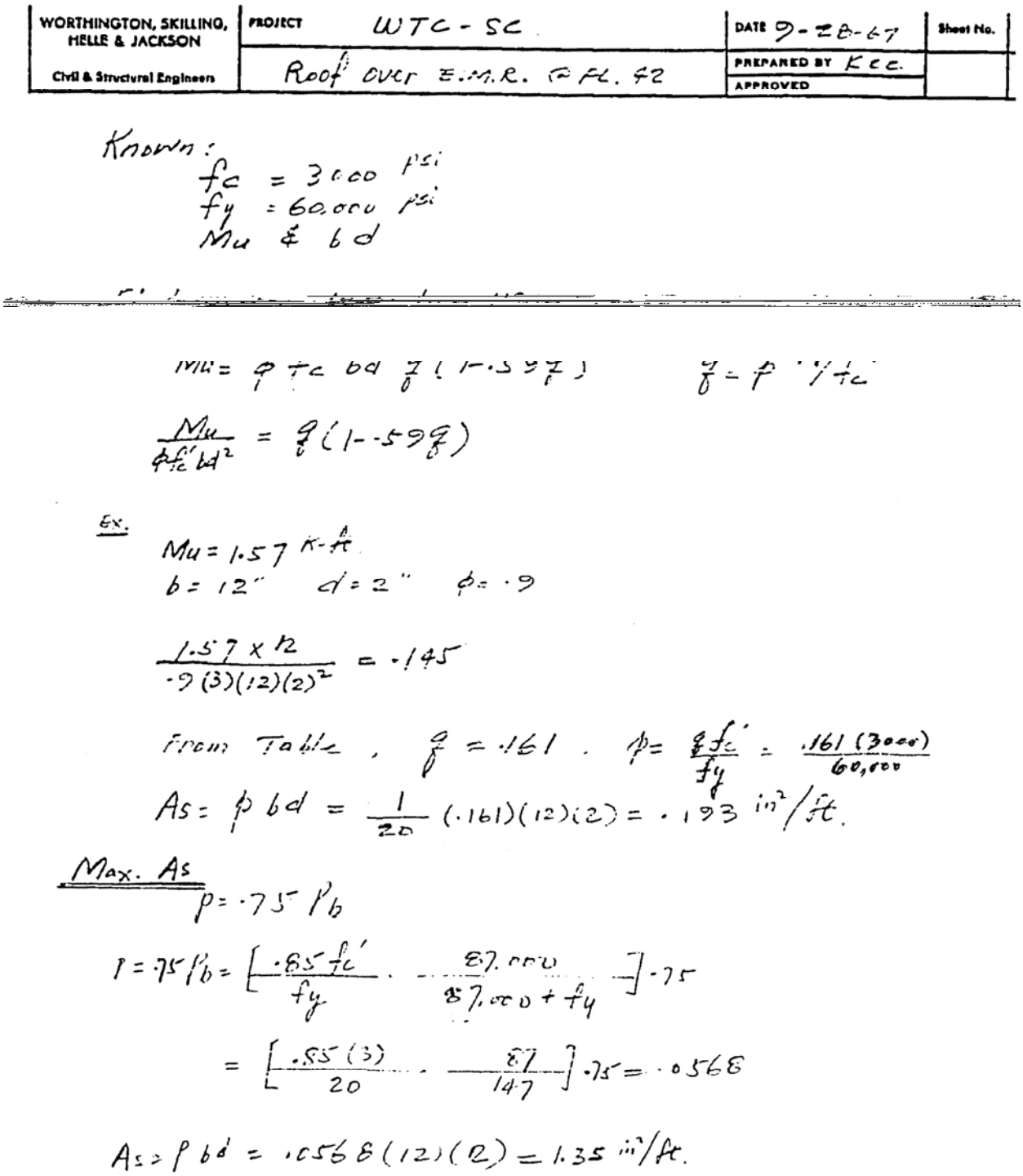

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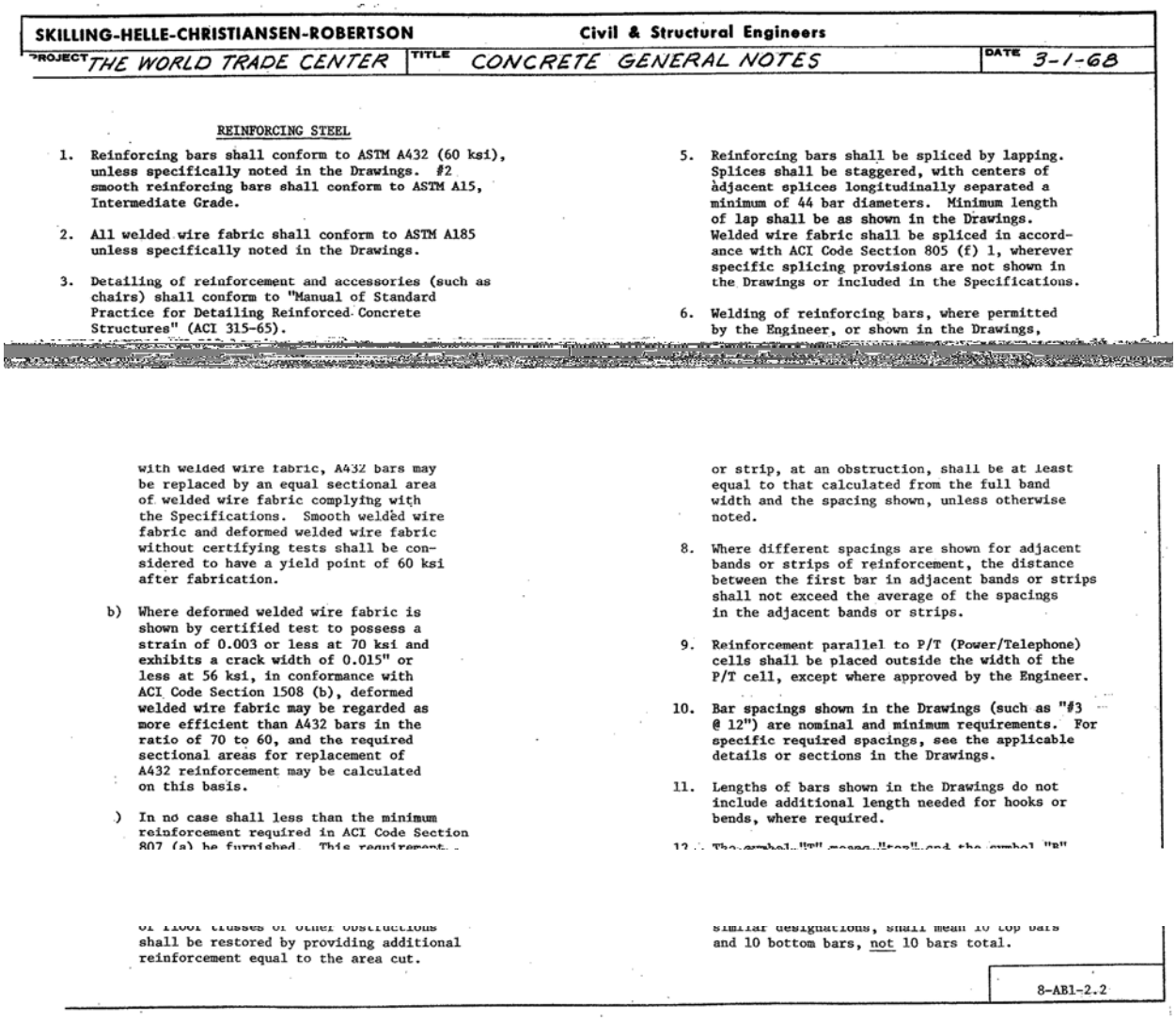
Figure 2–24. Reinforced concrete one-way slab design in WTC 1 and WTC 2.

Specifications for the reinforcing steel used in the concrete members are given on structural drawing 8-AB1-2.2 (WSHJ 1967c), and are reproduced here in Fig. 2–25.



SKILLING-HELLE-CHRISTIANSEN-ROBERTSON — Civil & Structural Engineers

PROJECT THE WORLD TRADE CENTER | TITLE CONCRETE GENERAL NOTES | DATE 3-1-68

REINFORCING STEEL

1. Reinforcing bars shall conform to ASTM A432 (60 ksi), unless specifically noted in the Drawings. #2 smooth reinforcing bars shall conform to ASTM A15, Intermediate Grade.

2. All welded wire fabric shall conform to ASTM A185 unless specifically noted in the Drawings.

3. Detailing of reinforcement and accessories (such as chairs) shall conform to "Manual of Standard Practice for Detailing Reinforced Concrete Structures" (ACI 315-65).

5. Reinforcing bars shall be spliced by lapping. Splices shall be staggered, with centers of adjacent splices longitudinally separated a minimum of 44 bar diameters. Minimum length of lap shall be as shown in the Drawings. Welded wire fabric shall be spliced in accordance with ACI Code Section 805 (f) 1, wherever specific splicing provisions are not shown in the Drawings or included in the Specifications.

6. Welding of reinforcing bars, where permitted by the Engineer, or shown in the Drawings,

with welded wire fabric, A432 bars may be replaced by an equal sectional area of welded wire fabric complying with the Specifications. Smooth welded wire fabric and deformed welded wire fabric without certifying tests shall be considered to have a yield point of 60 ksi after fabrication.

b) Where deformed welded wire fabric is shown by certified test to possess a strain of 0.003 or less at 70 ksi and exhibits a crack width of 0.015" or less at 56 ksi, in conformance with ACI Code Section 1508 (b), deformed welded wire fabric may be regarded as more efficient than A432 bars in the ratio of 70 to 60, and the required sectional areas for replacement of A432 reinforcement may be calculated on this basis.

) In no case shall less than the minimum reinforcement required in ACI Code Section 807 (a) be furnished. This requirement

or strip, at an obstruction, shall be at least equal to that calculated from the full band width and the spacing shown, unless otherwise noted.

8. Where different spacings are shown for adjacent bands or strips of reinforcement, the distance between the first bar in adjacent bands or strips shall not exceed the average of the spacings in the adjacent bands or strips.

9. Reinforcement parallel to P/T (Power/Telephone) cells shall be placed outside the width of the P/T cell, except where approved by the Engineer.

10. Bar spacings shown in the Drawings (such as "#3 @ 12") are nominal and minimum requirements. For specific required spacings, see the applicable details or sections in the Drawings.

11. Lengths of bars shown in the Drawings do not include additional length needed for hooks or bends, where required.

12. The symbol "T" means "top" and the symbol "B"

of floor trusses or other obstructions shall be restored by providing additional reinforcement equal to the area cut.

similar designations, shall mean 10 top bars and 10 bottom bars, not 10 bars total.

8-AB1-2.2

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Figure 2–25. Specification for reinforcing steel used in WTC 1 and WTC 2.

2.3.7 Steel Deck

The design criteria for the steel deck used in the composite floor system are in the Design Criteria (WSHJ 1965a) and are shown in Fig. 2–26.

2.3.8 Hat Trusses

A series of diagonal members together with the building columns and floor members formed hat trusses between the 107th floor and the roof in WTC 1 and WTC 2. Six trusses ran parallel to the long direction, and eight trusses ran parallel to the short direction of the core.

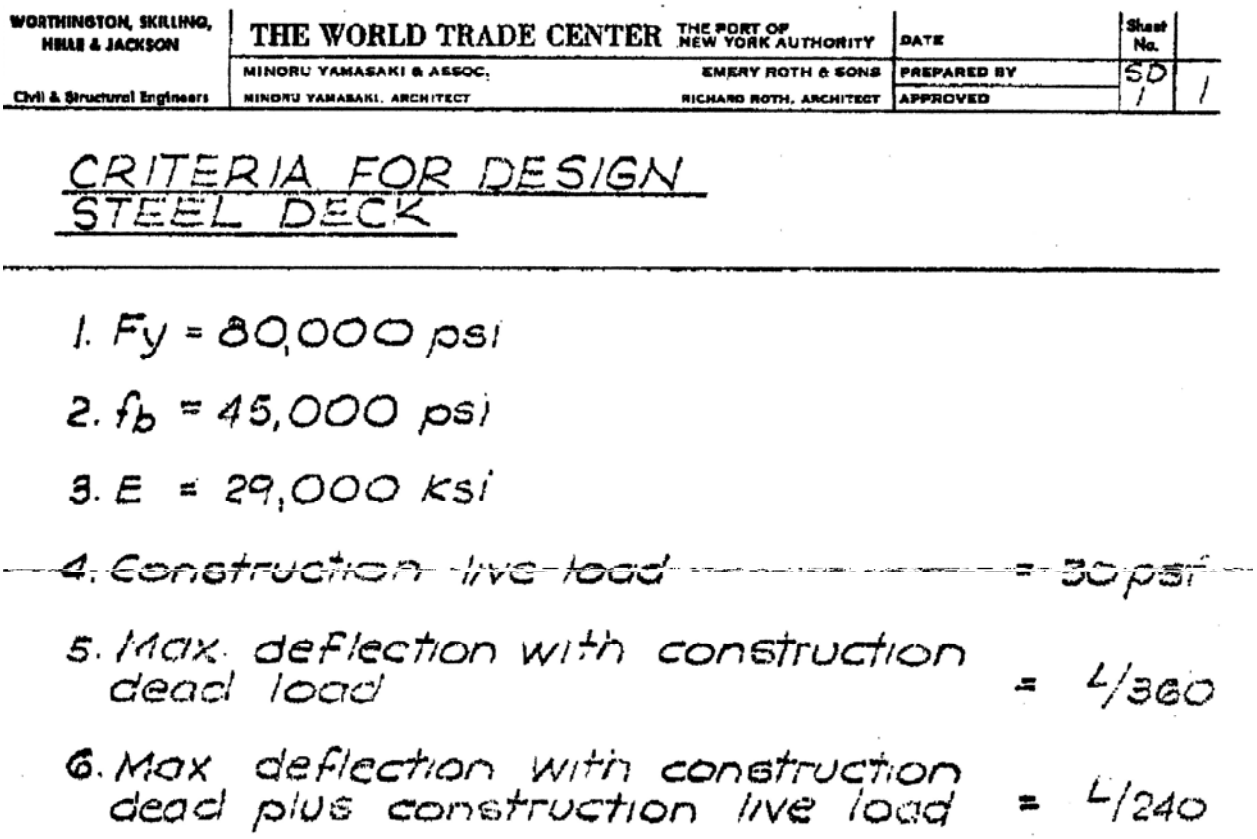

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Figure 2–26. Design criteria for steel deck in WTC 1 and WTC 2.

According to the 1995 Structural Integrity Inspection report that was written by LERA, "the hat trusses…control individual column expansion and contraction due to uneven column temperatures" (LERA 1995). Additionally, the hat trusses in WTC 1 provided stability for the 362 ft tall TV mast that was centered on the top of that tower. The hat trusses in both buildings were designed to support one large mast or four smaller towers near the perimeter of the core region. The 1995 report also noted that the horizontal members of the hat trusses were composite with the concrete floor slabs, which made the concrete floor slabs a vital component of the hat trusses.

Design calculations for the different types of trusses that were used are contained in SHCR (1969). Members in the trusses were designed for axial forces or axial forces plus bending moments due to the combined effects of gravity loads (including the weight of the TV mast) and wind loads. Typical calculations for a truss running in the north-south direction in WTC 1 are shown in Fig. 2–27. These calculations are representative of the allowable stress methods used to proportion the members in the trusses. As can be seen from the figure, the AISC Specification (AISC 1963b) was used to proportion the members for the design loads contained on the first page of the calculations. No calculations were found that showed how the trusses controlled column expansion and contraction due to uneven temperatures, as discussed in the 1995 report by LERA.

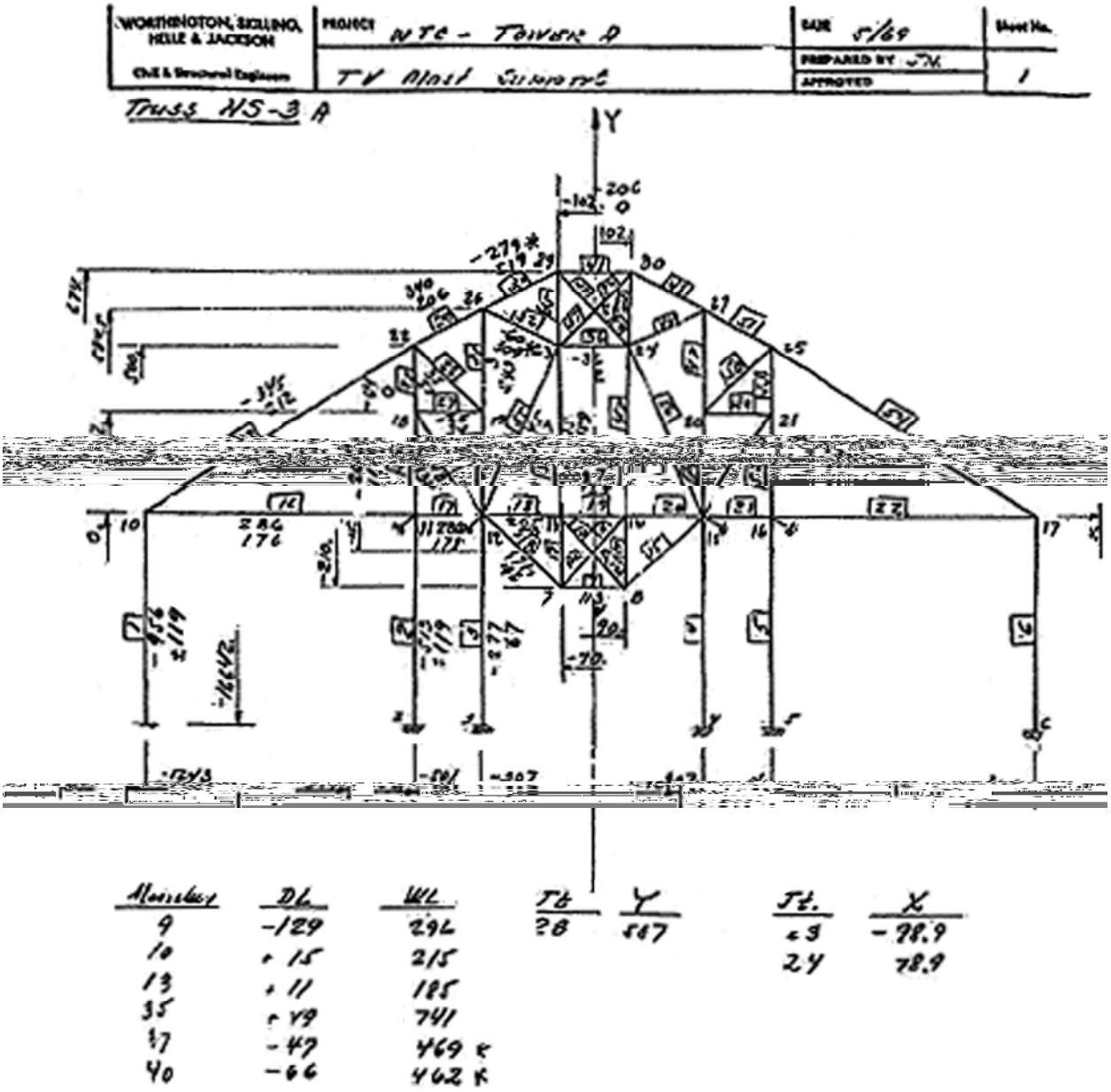

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Figure 2–27. Design method for hat trusses in WTC 1 and WTC 2.

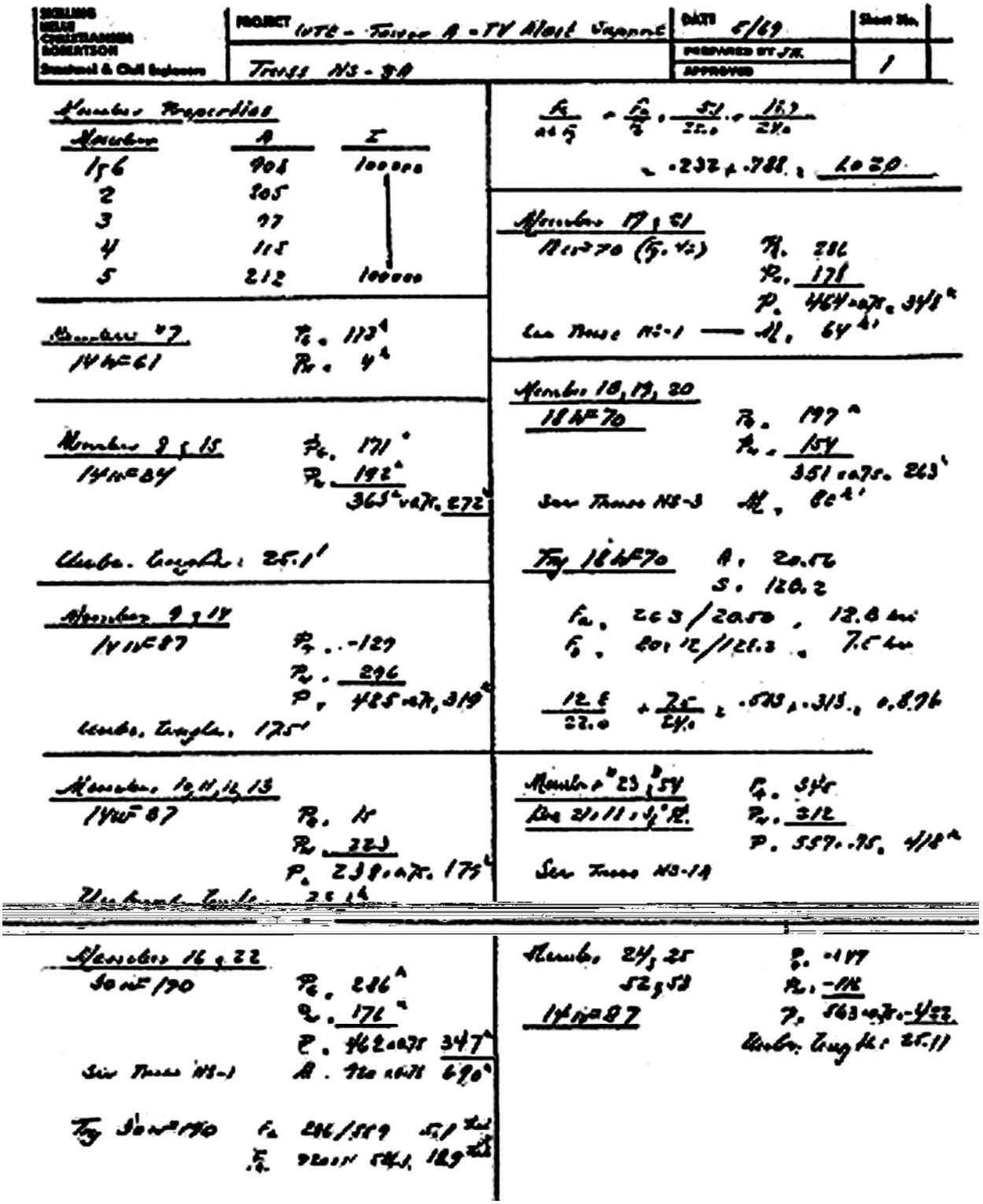

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Figure 2–27. Design method for hat trusses in WTC 1 and WTC 2 (continued).

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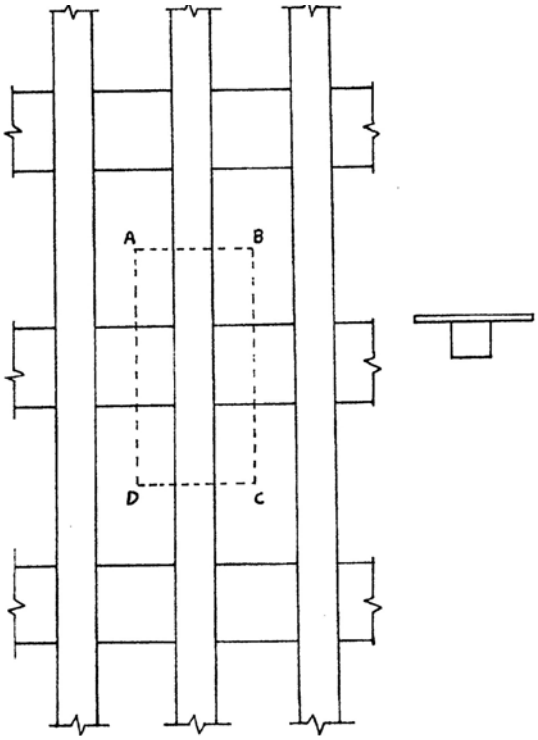
Chapter 3
TESTS PERFORMED TO SUPPORT DESIGN INNOVATIONS

3.1 EXTERIOR WALL PANEL TESTS

Scaled model tests were performed at the University of Western Ontario to determine load-deflection characteristics of typical exterior wall panel units along the height of the building (Gardner 1966). One of the main goals of these tests was to determine how the overall stiffness of the wall panels changed as changes were made in the sizes of the members that made up the wall panels (i.e., columns, spandrels, and stiffeners). According to the report, it was anticipated that the results from these tests would help in determining the "most effective construction" for the wall panels.

In lieu of testing a typical wall panel, which was comprised of three columns and three spandrels, subassembly ABCD depicted in Fig. 3–1 was tested. According to the report, this subassembly was chosen for its simplicity, flexibility, and low cost. Models were built to a scale of one-quarter of full size and were fabricated from sheets of thermoplastic. The following advantages of using thermoplastic sheet were listed in the report: (1) it has a low modulus of elasticity, which produced large deflections for comparatively small loads, (2) it possesses linear stress-strain characteristics, similar to structural steel, and (3) it is easily machined and can be easily joined.



Source: Gardner 1966. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–1. Subassembly used for testing external wall panel in WTC 1 and WTC 2.

Models of structural units were fabricated that replicated the external wall panels at floor levels 20, 47, and 74. In some cases, stiffeners of varying thicknesses were added to the test model as described below.

The forces that were applied to the test models to simulate the forces acting on a unit of the actual wall section are shown in Fig. 3–2. The models were tested in the test rig depicted in Fig. 3–3. The load in the "*y*" direction was applied to the models via chains with attachments that were adjustable so that the line of action of the load passed through the shear center of the model. Axial load was applied to the model by a threaded bar. Also shown in this figure are the stiffeners that were added to some of the specimens in order to measure their effect on the overall behavior.

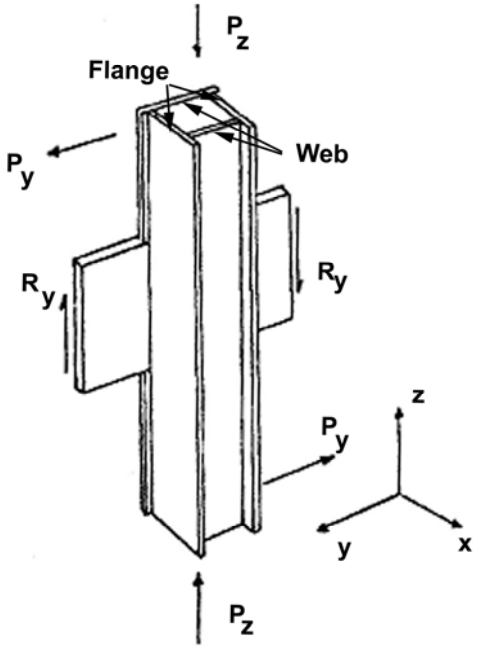


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Figure 3–2. Loads applied to model of exterior wall panel.

Fifteen different tests were run—four for the case of the model replicating the 20th floor exterior wall, nine for the 47th floor, and two for the 74th floor. In some cases, diaphragms were present and in other cases, they were not. The effects of stiffener thickness, spandrel thickness, spandrel flanges (see Fig. 3–4), depth between webs, and removal of outer webs were also studied.

The deflections and rotations that were measured during the testing are depicted in Fig. 3–5. Variation of story deflection (Δ_1) was plotted as a function of load (P_y) for the cases described above. In all cases, a linear relationship was found between applied load and story deflection. The shear stiffness of a unit was determined by dividing the load (P_y) by the deflection (Δ_1).

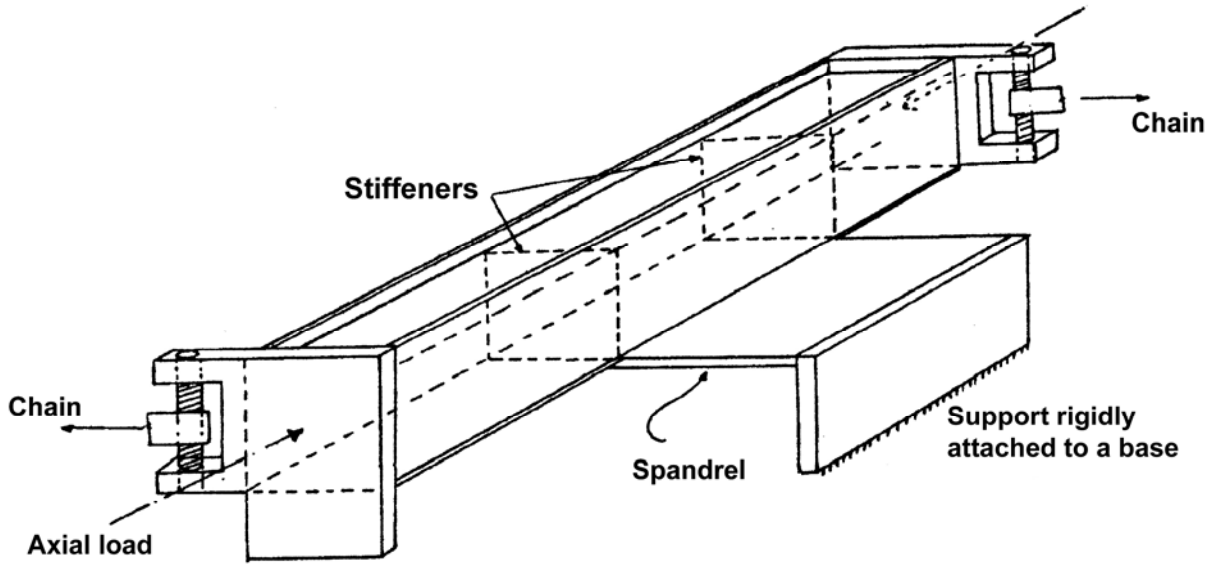

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Figure 3–3. Test rig used for testing model of external wall panels in WTC 1 and WTC 2.

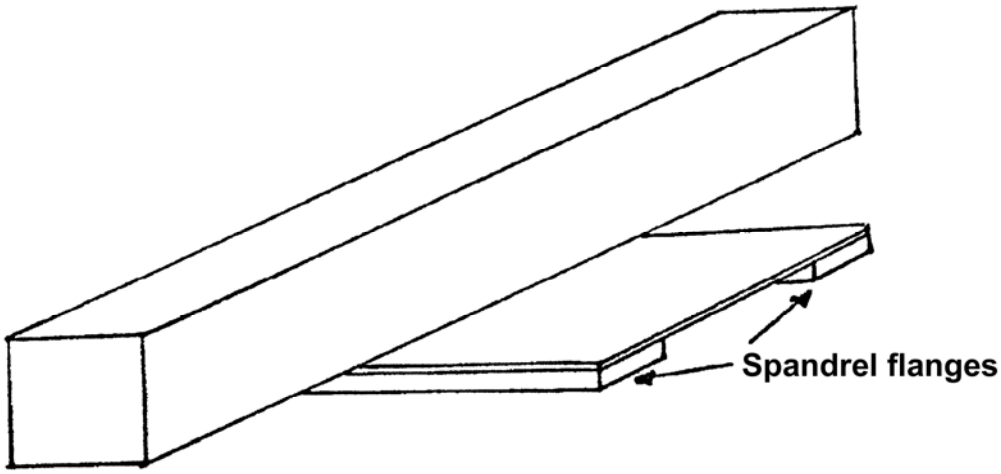

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Figure 3–4. Spandrel flanges used in some test models of exterior wall panels.

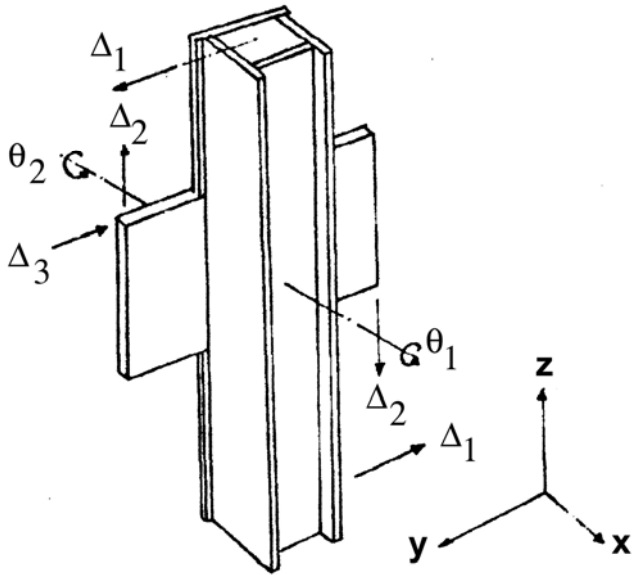

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Figure 3–5. Displacements and rotations measured during model test program of exterior wall panels.

The following conclusions from these tests were reported:

- Stiffeners are necessary for enhanced performance, but the thickness of the stiffeners is not critical.
- Axial loads do not appear to affect the shear stiffness of the model.
- Spandrel flanges do not contribute to the shear stiffness of the model.
- The distance between the webs of the column should be the longest possible.
- The thickness of the spandrel increases the shear stiffness of the unit.
- The depth of the spandrel increases the shear stiffness of the unit.
- Increasing the thicknesses of either the column webs and/or the column flanges increases the torsional stiffness of the model.
- Distortion due to twisting can be reduced by using thicker stiffeners.

3.2 WIND TUNNEL TESTS

Wind tunnel tests were part of a four-pronged wind program that was developed by Worthington, Skilling, Helle & Jackson (WSHJ) for the design of the World Trade Center (WTC) (WSHJ 1964). The elements of this program were:

- **Meteorological Program.** The purpose of this program was to determine mean wind speeds, return periods, the magnitude of wind shear and gradient, the directional characteristics of the wind, and the energy spectra of wind gusts that were expected at the site of the WTC.

- **Wind Tunnel Program.** The goals of this program were to (a) develop a physical model of lower Manhattan and subject the model to wind velocities obtained from the meteorological program, (b) obtain static and dynamic responses of the WTC towers, (c) study construction problems (no additional information on this could be found in the documentation), and (d) study the effect of the structural parameters on the integrity of the towers.

- **Structure Damping Program.** The main objectives of this program were to determine the critical damping ratio of the structural system and to determine ways of increasing this ratio.

- **Physiological Program.** The objective of this program was to determine acceptable levels of response to wind-induced excitations as measured by perception levels of a cross-section of the population.

The meteorological and wind tunnel programs are discussed in an 8-volume set of reports written by the structural engineer, WSHJ. These reports are referenced in the following sections of this report. No documentation was found on the structure damping program or the physiological program.

3.2.1 Meteorological Program

One of the basic requirements of the meteorological program was the acquisition of data from sources that measured wind velocity (WSHJ 1965a). According to the WSHJ report, both the mean wind speed and turbulence characteristics were key items that needed to be determined. Air density corresponding to the extreme wind, a statistical distribution of wind speeds, and changes of wind velocity with respect to direction were other parameters that were needed as well.

The report points out that earlier studies of extreme wind speeds, including those carried out for the American Society of Civil Engineers (ASCE 1961), were not adequate for the design of the WTC towers for the following reasons (WSHJ 1965a):

- They were general studies that did not address the specific environment at the site of the WTC.

- They did not consider surface roughness to have an influence on wind speeds.

- They did not relate specifically to building heights comparable to the WTC.

- They used wind speed parameters, such as the fastest-mile wind, that were not completely appropriate for the WTC.
- They did not consider variations of extreme wind speed with respect to direction.

In order to help in determining the extreme average wind speed that was expected at the top of the towers, data from the following sources were examined:

- Annual maximum hourly average wind speed (1912–1958), annual maximum 5 min average wind speed (1912–1958), and fastest-mile wind speed (1912–1959) from the U.S. Weather Bureau Station at the Whitehall Building in lower Manhattan, which was less than a half mile from the WTC site.
- Annual maximum hourly average wind speed from the Brookhaven National Laboratory (1954–1964). Included were data relating to wind profile and hurricanes.
- Annual maximum hourly average wind speeds from weather stations on the Atlantic seaboard in the Maritime Provinces of Canada for all years of record.
- Annual fastest-mile wind speed for all U.S. Weather Bureau Stations on the eastern seaboard from Atlantic City, New Jersey, to Eastport, Maine, for all years since 1912.
- Records of surface winds from balloons launched at John F. Kennedy (JFK) Airport (1956–1964). Balloons were released and observed every 6 h.

A statistical model for estimating the extreme wind velocity was developed based on a Fisher-Tippet Type I theoretical distribution. It was reported that the agreement between the observed distributions based on the data from the above locations and the theoretical distribution was satisfactory.

A study was also performed to determine a suitable mean wind velocity profile as a function of surface roughness. The following relationship was reported to adequately represent the distribution of wind speed with respect to height and exposure based on the data from the Brookhaven National Laboratory, the balloon study at JFK Airport, and the results from the wind tunnel tests:

$$\frac{V_z}{V_G} = \left(\frac{z}{z_G} \right)^{\alpha} \tag{3–1}$$

where:

V_z = wind velocity at height z

V_G = gradient wind velocity at height z_G

The constants z_G and α that were used in the study, which depend on the exposure, are given in Table 3–1.

Table 3–1. Constants used in wind study of WTC 1 and WTC 2.

Exposure	α	z_G (ft)
Southeast direction (over Brooklyn)	0.30	1,250
Southwest direction (over open water)	0.17	1,100

One other conclusion that was reported was that the wind speed at the top of the WTC towers was expected to be approximately 1.65 times greater than the wind speed at 355 ft above ground measured at the Brookhaven National Laboratory, based on Eq. 3–1.

A suitable averaging period for the design wind speed was also studied. In lieu of using averaging periods that were used in routine meteorological observations (5 min average, hourly average, fastest-mile), the report concluded that an averaging period should be selected considering the aerodynamic behavior of the towers and the wind tunnel tests. A 20 min averaging period was selected based on the following considerations:

- Based on wind tunnel observations, a 20 min averaging time allowed steady-state response of the towers to develop.
- The sampling period used in the Colorado State University (CSU) wind tunnel tests generally corresponded to approximately 20 min.

An empirical relationship was developed for maximum wind speeds averaged over different periods. It was shown that the 20 min average wind speed was expected to be approximately 10 percent greater than the hourly average wind speed.

Based on a comparison of estimates of actual wind speeds obtained from the five sources noted above (i.e., Whitehall Building, Brookhaven National Laboratory, Canadian weather stations, U.S. weather stations, and JFK Airport), the following equation is given for the design 20 min mean wind speed V_r in miles per hour at the top of the towers for any return period r in years (WSHJ 1965a):

$$V_r = 90 - 11\log_e\left[-\log_e\left(1-\frac{1}{r}\right)\right] \qquad (3–2)$$

A study on air density was performed at the Whitehall Building. This study suggested that an appropriate design value was 0.0024 slugs/ft^3 at the bottom of the towers and 0.0023 slugs/ft^3 at the top of the towers. These values were used to correct the wind tunnel results that were carried out at CSU.

The directionality of wind speeds was estimated from the balloon data at JFK Airport. It was found that winds were stronger from westerly and northerly quadrants, and that those from the southeast were the weakest. It was also observed that the direction of the strongest winds changed with height. On average, the wind direction changed approximately 15 degrees between the surface and the top of the towers for the westerly wind quadrants and about 25 degrees for the easterly quadrants. According to the report, these results were significant in the estimation of wind pressures on the towers.

Part III of the Final Chapter of the WSHJ Wind Report (WSHJ 1966a) re-examined the design wind velocity equation presented in Supplement #3 of the Wind Program Interim Report (see Eq. 3–2 above), since it was evident from the wind tunnel tests, which are discussed in the next section of this report, that the response of the towers was highly sensitive to wind direction. It was reported that wind velocities based on a Weibull probability distribution $P(V)$ closely fit the observations recorded at John F. Kennedy Airport for wind velocities V greater than 16 m/s (36 mph):

$$P(V) = 1 - e^{-\left(\frac{V}{10.5}\right)^{1.7}} \tag{3–3}$$

where the velocity V in Eq. 3–3 is in meters per second.

Wind velocities less than 16 m/s (36 mph) were reported to have had only a small influence on the structural performance of the towers. According to the report, the Weibull distribution produced slightly conservative values for wind velocities at the top of the towers assuming that these velocities were equally likely from all directions, even though from the observed data, there appeared to be a higher probability of stronger winds from the northwest and a relatively lower probability of the same from the southeast. Wind velocities based on a Weibull distribution were also reported to adequately predict the maximum static plus dynamic deflections at the tops of the towers in both principal directions, which were obtained from the CSU wind tunnel tests. As discussed in Sec. 2.3.2 above, these deflections were used to determine the forces in the exterior columns and spandrels.

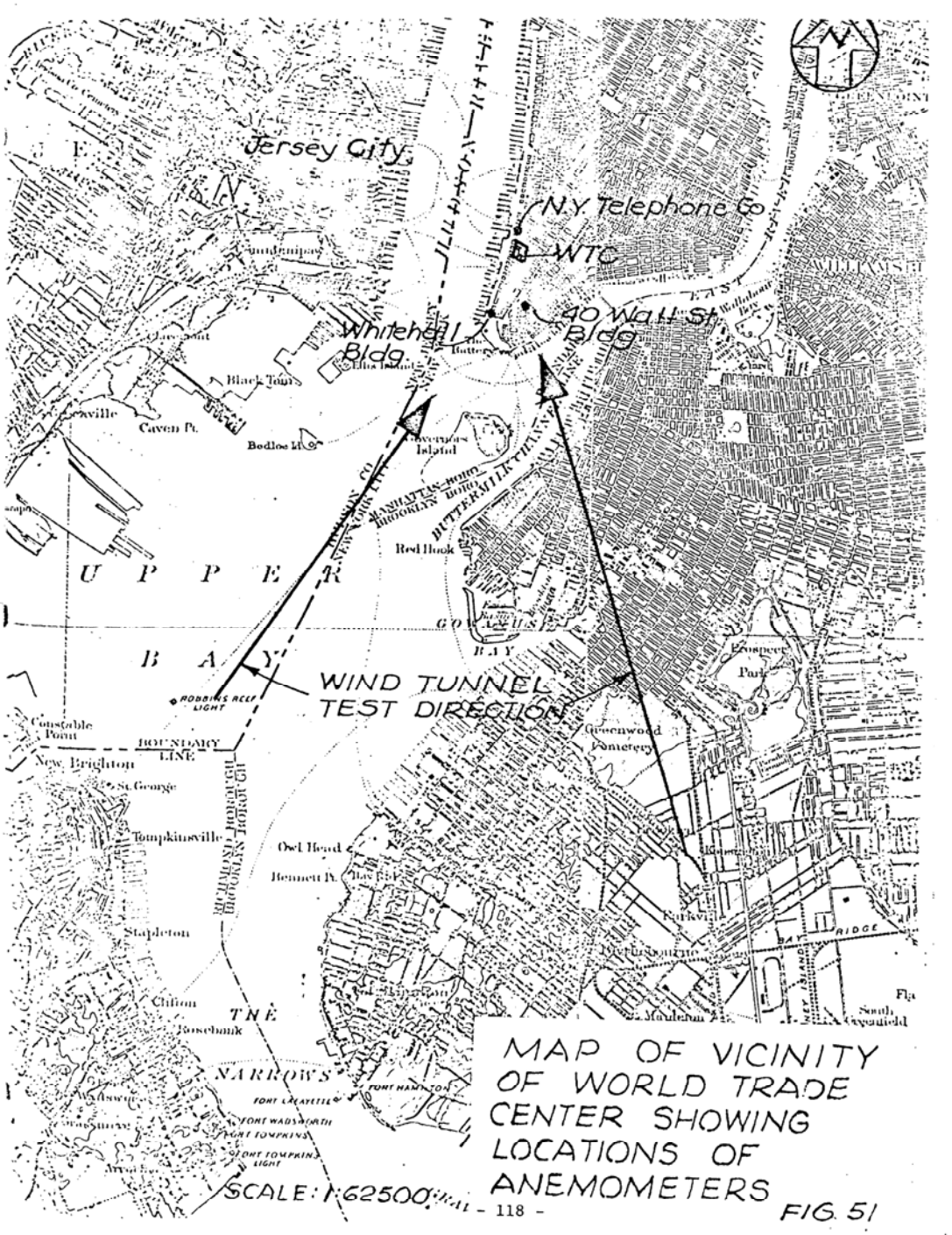
In order to obtain representative measurements of wind in the neighborhood of the WTC, anemometers were mounted on the New York Telephone Building and the 40 Wall Street Building, which were both in close proximity to the WTC site in lower Manhattan. These sites, as well as the wind directions used in the wind tunnel tests, are depicted in Fig. 3–6 (WSHJ 1966b). The information from these measurements was used to adjust the characteristics of air flow in the wind tunnel tests, especially with respect to turbulence. Wind tunnel tests indicated that the velocity of the wind at the New York Telephone Building was similar to that at the same elevation at the WTC site. More details on the results of this study are contained in WSHJ (1966b).

3.2.2 Wind Tunnel Program

Wind tunnel tests were conducted at CSU and the National Physical Laboratory (NPL), located in Teddington, Middlesex, United Kingdom. Tests were conducted on single-tower and twin-tower configurations subject to uniform and turbulent flow conditions. A description of the tests conducted at both locations follows.

Tests Conducted at CSU

Over 2,000 tests were conducted at the CSU Microclimatological Wind Tunnel to study the behavior of static and aeroelastic models (WSHJ 1964). All work took place in the long test section, which made it possible to develop a boundary layer in the tunnel (WSHJ 1965b). The directions chosen for the wind tunnel testing of the models of lower Manhattan corresponded to the most turbulent (southeast direction over Brooklyn) and the least turbulent (southwest over open water) directions.



Source: WSHJ 1966b. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–6. Location of anemometers in wind study for WTC 1 and WTC 2.

According to WSHJ (1965b), one of the most important requirements in the modeling process was to achieve correct simulation of the wind velocity profile (considering both surface roughness and its influence on wind velocity with respect to height) as it approached the model of lower Manhattan. From the southeast direction, wind traveled across Brooklyn to the site of the WTC, which was a relatively

rough urban area. From the southwest, wind traveled mainly across open water. To simulate these conditions in the tunnel at CSU, the Brooklyn fetch was represented by a bed of 1/4 in. to 1/2 in. gravel, while the open water fetch was simulated by coarse emery cloth. Also, as discussed in Sec. 3.2.1, the mean wind velocity profile defined by Eq. 3–1 above was used.

Aside from wind velocity, the principal variables in the wind tunnel tests were the following (WSHJ 1964):

- Spacing of towers
- Number of towers
- Damping
- Wind direction
- Boundary layer characteristics
- Relative stiffnesses of the models

It was found that the models oscillated in the wind due to vortex shedding, gust buffeting, and wake buffeting under certain combinations of the above variables.

Two hundred tests were run at CSU to study the effect of tower spacing on the response of the buildings. It was concluded that the "as planned" spacing was satisfactory.

Aeroelastic tests and measurements of steady pressure for single-tower and twin-tower configurations in uniform flow (i.e., insignificant level of turbulence) constituted a major portion of the tests that were run at CSU (WSHJ 1965c). Part of the purpose of these tests was to provide a comparison between the performance of the models at CSU and at the NPL (Whitbread and Scruton 1965). The report concluded that the aeroelastic tests at the two locations were in good qualitative and quantitative agreement.

The aeroelastic tests were designed to determine the predominant sway motion (i.e., deflections or amplitudes) of the towers and to provide a check of the steady-state component of the overturning moment at the base. To determine the pressure distribution on the towers, tests were conducted using models with pressure points along a regular grid. From these tests, shear forces and overturning moments were obtained along the height of the towers.

Three aeroelastic models of the towers were constructed at CSU using a scale of 1/500, which was dictated by the size of the wind tunnel. The basic components of the models included: (1) a rigid exterior shell fabricated from Sitka spruce (a wood having high stiffness to weight properties), (2) spring elements at the base that provided stiffness ratios about the two horizontal axes that corresponded to the full-scale structures, and (3) a damping unit that provided levels of structural damping between about 0.8 and 100 percent of critical damping (WSHJ 1965c). The model was based on preliminary studies that indicated that the largest amplitudes of the buildings would be associated with the fundamental mode of oscillation and that the shape of the fundamental mode corresponded approximately to a straight line. Deformations were measured by strain gauges mounted on the model. Wind velocities were gradually increased during the tests. Readings were taken for wind velocities up to 200 mph in the case of the low-

frequency models and up to 140 mph in the case of the high-frequency models at 15 degree azimuth intervals, except when large amplitudes were encountered; in those situations, readings were taken at 5 degree intervals. A discussion on the low- and high-frequency models used in the study is given later in this section of the report.

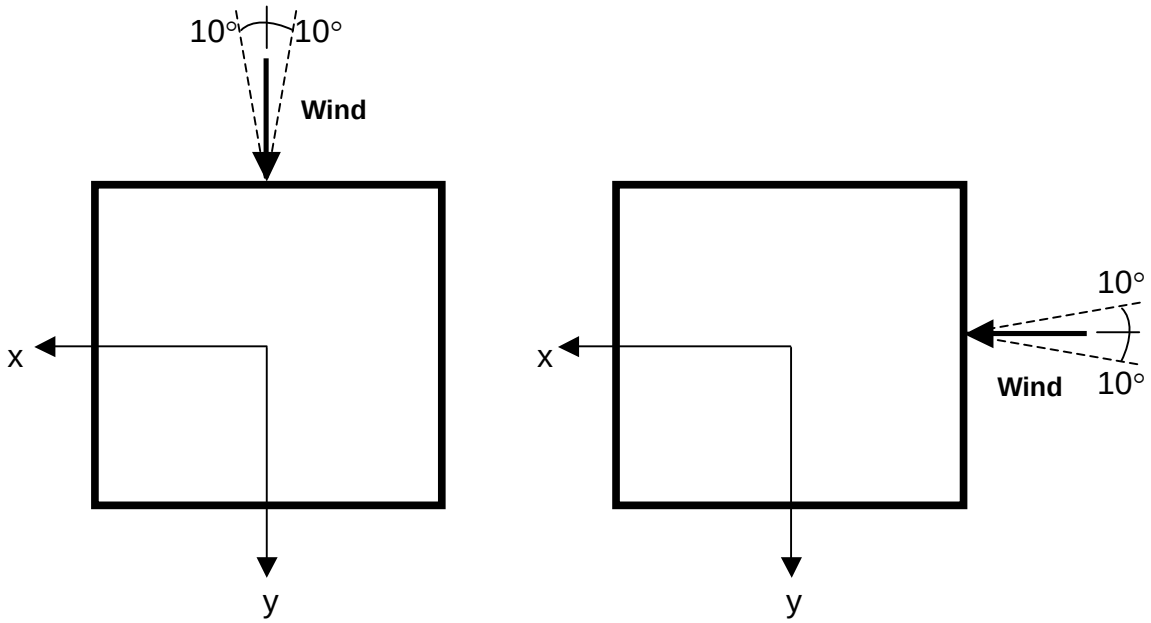
Models used for the pressure tests at the CSU were constructed of clear acrylic plastic at a scale of 1/500, the same scale used in the aeroelastic tests (WSHJ 1965d). Approximately 75 pressure taps were mounted on the pressure models, and test results were obtained for the single tower (0 degrees to 45 degrees) and the twin towers (0 degrees to 180 degrees).

During the tests, pressure differences were determined between pressures measured at points on the model and the datum ambient pressure in the tunnel. Local pressure coefficients C_p were defined by the following equation:

$$C_p = \frac{P - P_{REF}}{\frac{1}{2}\rho V_{REF}^2} \tag{3–4}$$

where P and P_{REF} are the absolute pressures on the model and at the reference point, respectively, $\rho V_{REF}^2 / 2$ is the reference velocity pressure, and V_{REF} is the wind velocity in miles per hour applied on the model. An averaging process was used to determine average pressure coefficients on the tower in the two principal directions (see Figs. 17a through 17e in WSHJ [1965c]). From these average pressure coefficients, shear force and overturning moment coefficients were obtained with respect to height. A comparison of aerodynamic coefficients of overturning moments derived from steady pressure tests and from aeroelastic model tests is given in Fig. 18 of WSHJ (1965c). It was reported that the results from these tests were in good agreement. The results from the CSU tests were also compared to those obtained at the NPL, and as noted above, the report states that results from these two sets of tests were in good qualitative and quantitative agreement.

The tests also indicated that large lateral deflections at the top of the building occurred for wind velocities in the range of 125 mph to 130 mph for angles of incidence within approximately 10 degrees of normal (see Fig. 3–7). The results are plotted in Figs. 19 and 20 in WSHJ (1965c). The deflections showed a consistent dependence on the degree of damping and were shown to be inversely proportional to the damping ratio.



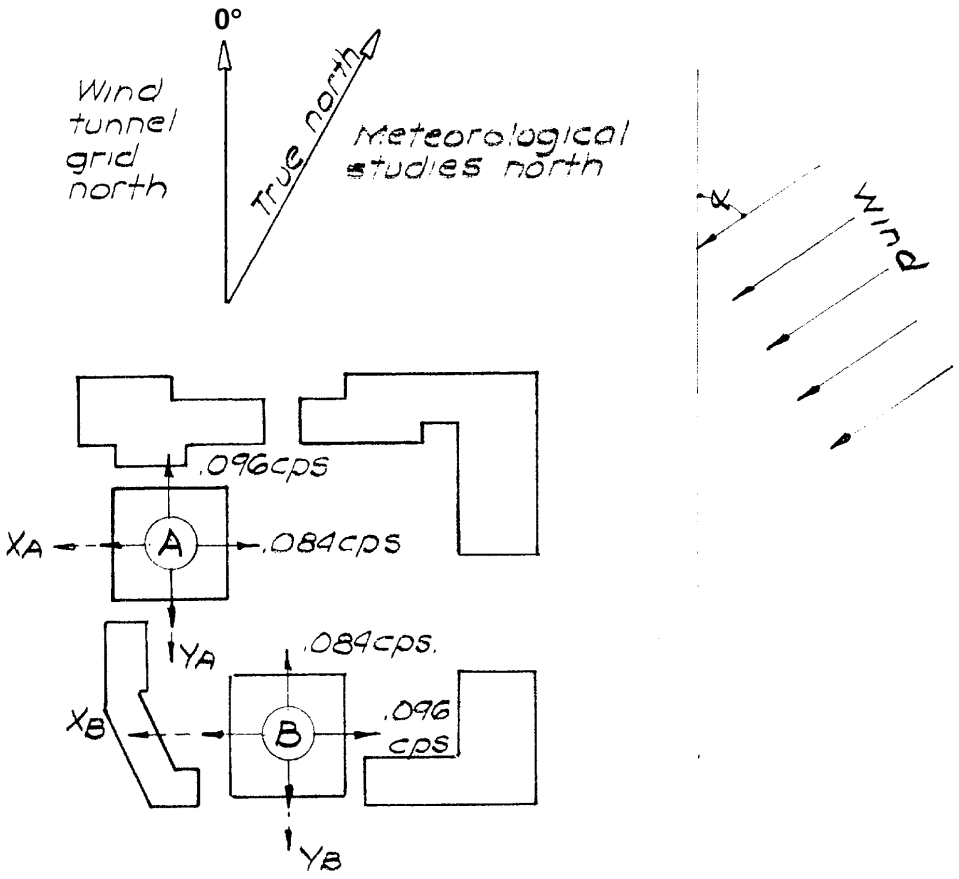
Source: WSHJ 1965c. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–7. Wind directions that produced the greatest displacements at the top of the tower during the wind tunnel tests.

Tests were also conducted at CSU using the southeast and southwest models of lower Manhattan subjected to turbulent flow conditions (WSHJ 1966c)[1]. Both single-tower and twin-tower configurations were considered. Definition of the grid system and tower configurations used in the tests is illustrated in Fig. 5 of WSHJ (1966c), which is reproduced here as Fig. 3–8. Also shown in the figure are the fundamental frequencies of the towers in the two principal directions in cycles per second (cps). Included in these tests were measurements of the maximum deflections at the tops of the towers (aeroelastic tests; wood models) and pressures along the height of the towers (thermoplastic models).

Similar to the other tests described above, test results for the single-tower model indicated that the most severe oscillations were transverse to the wind and occurred with the wind blowing within a small range of angles on either side of the normal to a face (see Figs. 9 through 13 in WSHJ [1966c]). The results also showed that an increase in turbulence, which was characteristic of the southeast model of lower Manhattan, appeared to suppress vortex shedding but gave rise to turbulence excitation with increased wind speed. Finally, it was observed that greater levels of damping reduced the dynamic response of the single tower in all cases, more so in uniform flow conditions than in turbulent conditions.

[1] As noted in Sec. 3.2.1 of this report, it was found that winds were stronger from westerly and northerly quadrants. Wind from the southeast direction was chosen in the wind tunnel program not because the velocity from this direction was the greatest, but because winds from this direction were the most turbulent (wind in this direction traveled over Brooklyn, which is a relatively rough urban area). Turbulence plays an important part in the dynamic excitation of structures, especially tall, slender structures. A fundamental discussion on turbulence and resulting aeroelastic phenomena can be found in Simiu and Scanlon (1996).



Source: WSHJ 1966c. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–8. Definition of grid system and tower configurations for wind tunnel tests at CSU.

Test results for the twin-tower model are plotted in Figs. 14 through 29 in WSHJ (1966c). These graphs, which also include results from the wind tunnel tests conducted at the NPL (Whitbread 1967), give peak amplitudes of oscillation (deflections) at the tops of the towers for a range of wind velocities, wind directions, and degrees of damping for both the southeast and southwest models of lower Manhattan. In order to determine whether different time scales had an influence on the response of the towers due to wind velocity, two different time scales were considered in these tests. The first time scale was set equal to the model scale raised to the two-thirds power, i.e., $(1/500)^{2/3} = 1/60$. This time scale was used in what was referred to as the low-frequency model tests. The second time scale, which was used in the high-frequency tests, was set equal to 1/200. According to the report, with this time scale, the maximum wind velocity of the tunnel would coincide with the maximum wind velocity that could reasonably be expected. It was reported that since the natural frequency of vibration of the full-scale tower in the fundamental mode was close to 0.1 cps, the required frequency of vibration of the model corresponding to a time scale of 1/60 (i.e., low-frequency model) was 0.1/(1/60) = 6 cps. Similarly, the required frequency of vibration of the high-frequency model was 20 cps. These model frequencies were obtained by using different stiffnesses of the springs attached to the base of the models, as described previously.

The following conclusions were made in the report on the test results for the twin-tower model (WSHJ 1966c):

- In all tests, deflections (peak amplitudes) at the tops of the towers increased monotonically with increasing wind velocity without any apparent peaks.
- At wind velocities below 150 mph, deflections at the tops of the towers from the southeast model of lower Manhattan tested at CSU and NPL were qualitatively similar and had about the same magnitude. At wind velocities greater than 150 mph, the largest deflections came from the NPL tests. At a wind velocity of approximately 175 mph, the NPL deflections were significantly larger. Deflections from the southwest model of lower Manhattan were less than those obtained from the southeast model of lower Manhattan tested at CSU and NPL, but were qualitatively similar.
- Comparison of the high-frequency and low-frequency tests conducted at CSU indicated that larger displacements occurred in the southwest model of lower Manhattan with the high-frequency models. Results from the southeast model of lower Manhattan indicated the opposite effect.
- The largest displacements in all tests were found to be with wind from the directions noted in Table 3–2 below.

Table 3–2. Wind directions that produced the largest displacements at the tops of the towers from the twin-tower wind tunnel tests.

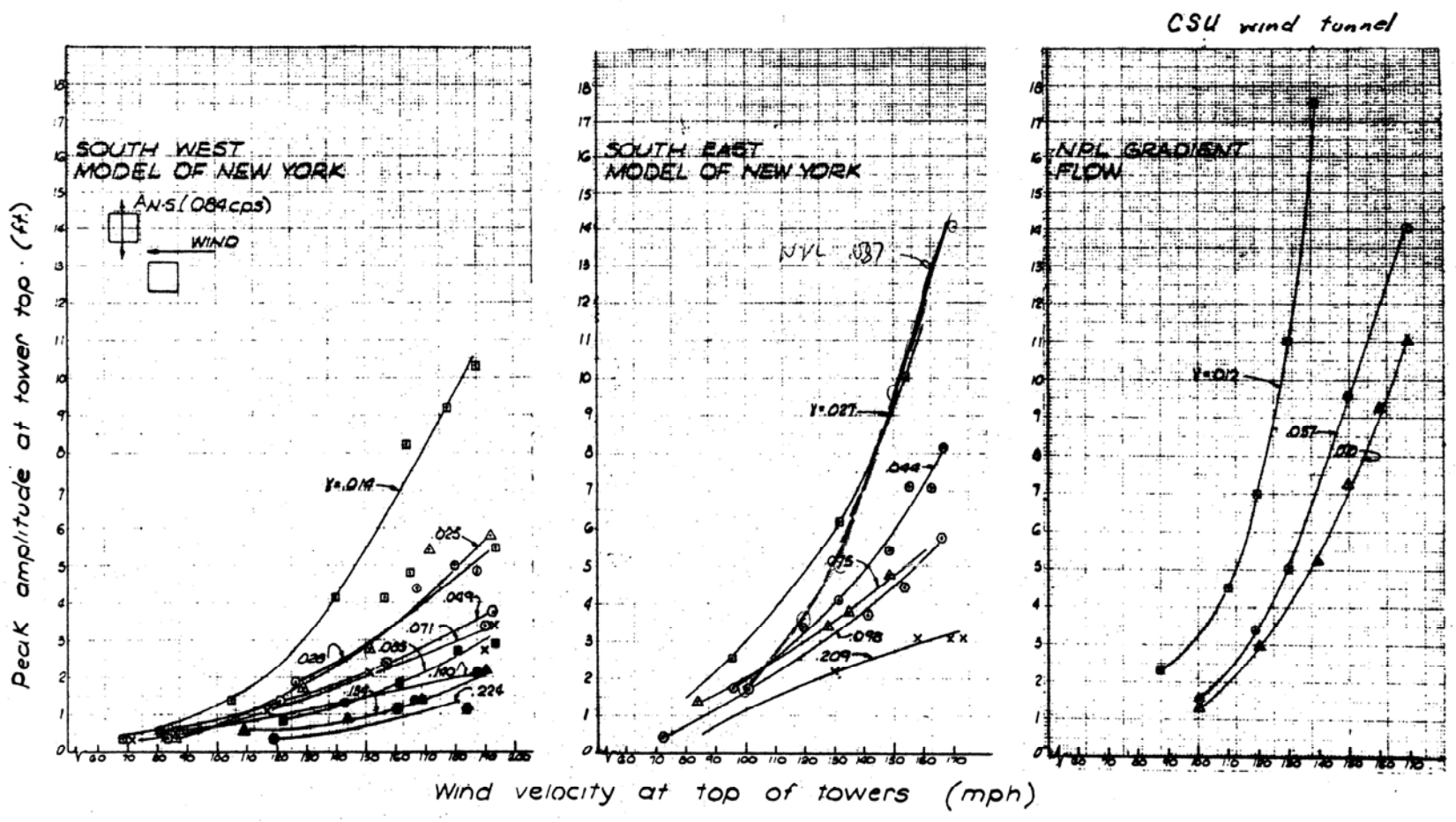
	WTC 1		WTC 2	
Building axis	E-W	N-S	E-W	N-S
Wind direction[a]	0°, 150°, 180°	90°	0°, 180°, 330°	270°

a. See Figs. 3–7 and 3–8 for definition of wind direction angle, α.
Source: WSHJ 1966c.

A comparison of the test results for the displacements at the top of WTC 1 in the north-south direction for wind blowing in the east-west direction ($\alpha = 90°$, most severe case) is given in Fig. 30 of WSHJ (1966c) and is reproduced here in Fig. 3–9. Results were plotted for the southeast and southwest models of lower Manhattan obtained from tests at CSU as well as for those obtained from tests at NPL.

Based on the results obtained from the twin-tower wind tunnel tests, it was concluded in WSHJ (1966c) that the response of the WTC towers was governed by three aerodynamic factors: (1) Magnitude of the effective turbulence forces induced by the wind flow, (2) Magnitude of the effective forces induced by vortex shedding and turbulence in the structure's own wake, and (3) Effective aerodynamic damping and coupling forces generated by the motion of the tower through the airflow. It was also noted that the effective mass, effective stiffness, the mode of vibration, and the mechanical damping of the towers influenced these factors.

A theoretical method was derived and was used to predict the dynamic behavior of the towers (WSHJ 1966c). Results from the theoretical models were compared to the results from the wind tunnel tests. A comprehensive discussion on this comparison can be found in WSHJ (1966c).



Source: WSHJ 1966c. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–9. Comparison of the variation of the N-S deflection (amplitude) of WTC 1 subjected to E-W wind for different degrees of damping (γ) and flow conditions.

The results from the wind tunnel tests were used in the design of the exterior columns and spandrels, which is discussed in Sec. 2.3.2 of this report.

The extensive wind tunnel testing that was performed to establish the lateral wind loads used in the design of WTC 1 and WTC 2 was state-of-the-art at that time.

Tests Conducted at NPL

Tests were performed on single-tower and twin-tower models at NPL to measure deflections at the tops of the towers in both smooth (uniform) flow and turbulent flow conditions (Whitbread and Scruton 1965). The models were constructed of light timber framework supported on diaphragms at 6 in. intervals from a central 2 in. diameter aluminum tube. The models had an external covering of plywood.

Principal differences between the CSU and NPL models were (WSHJ 1965c): (1) the model scale was 1/400 at the NPL compared to 1/500 at the CSU, (2) displacements were determined from output of accelerometers mounted near the tops of the models at NPL compared with strain gauges at CSU, and (3) displacements were recorded on a resetting digital voltmeter at the NPL compared with chart records at CSU. In the NPL tests, a grid of tubes in a plane normal to the wind stream was used to provide the required velocity profile over the height of the model. According to Whitbread and Scruton (1965), the velocity profile achieved in this manner was similar to that observed in the tests carried out at CSU on the model of lower Manhattan.

As noted previously, it was reported that the overall results obtained from the tests conducted at NPL were in good qualitative and quantitative agreement with those obtained from the tests performed at CSU.

3.3 DAMPING UNIT TESTS

Two testing programs were carried out to test certain important properties of the damping units. These programs were designed to help confirm the effectiveness and efficiency of the damping units in controlling building motion due to wind.

The Minnesota Mining and Manufacturing Company (3M) conducted the first set of tests in May 1967.[2] Twenty-two full-size dampers were assembled and tested in accordance with the procedure outlined in Sec. III, paragraph b of the test report. The specimens, which were tested in a servo-controlled testing machine, were subjected to cyclic axial deformation in the form of a sine wave at 0.1 Hz frequency with a constant amplitude of 0.020 in. for 100 cycles. The specimens were also stretched or compressed monotonically at a steady rate of 0.5 in. per minute until they were “physically broken.” Although the number of tests that were run was insufficient for a rigorous statistical analysis, it was reported that the results confirmed that the damper mechanical properties would meet or exceed the minimum requirements prescribed in the specifications. The specifications for the damping units are given in Sec. 5.3.2 of this report.

[2] Letter dated June 22, 1967 and enclosure from Don Caldwell of 3M to Peter Chen of SHCR (WTCI-501-L; reproduced in Appendix B without appendices that are contained in WTCI-501-L).

Dr. S. H. Crandall of the Massachusetts Institute of Technology conducted the second test program during 1968 and 1969.[3] Thirty-nine prototypes, which consisted of the exterior column, the damping units, and the floor truss system, were tested in a manner that simulated the in-place conditions of the damping units.[4] Twenty units were tested according to the test procedures previously established for the first series of test that were performed by 3M, which, as noted above, consisted of cycling tests and monotonic ultimate shear strength tests. Nineteen additional tests were performed to investigate the endurance capabilities of the specimens under conditions that were different from the aforementioned tests. In particular, these tests included variations in (1) amplitude and frequency of the applied cyclic axial deformation, (2) ambient temperature, and (3) a static preload superimposed on the simple harmonic loading. In all cases, the tests were performed in a specially built test frame, which was supposed to simulate the structural environment in which the damping units were to be placed (as noted above, the specimens were tested by 3M in a servo-controlled testing machine). In general, it was found that "…the energy absorbing capabilities of the elements are generally adequate to provide the expected damping under design conditions and that the elements do perform satisfactorily under limited variations of loading conditions, speed of oscillation, duration of oscillation, and ambient temperature." It was reported, however, that specimens that were tested for ultimate shear strength would not meet the appropriate acceptance requirements of the design specifications (see Sec. 5.3.2 of this report), due to a large standard deviation.

A letter from Leslie Robertson of Skilling, Helle, Christiansen, & Robertson (SHCR) to Malcolm Levy of the Port of New York Authority (Port Authority or PONYA) discussed deficiencies in the test equipment used by Crandall, which may have had an effect on the test results.[5] The possible influence of additional bolt holes, which were made in the specimens in order for them to fit the test jig, on the ultimate strength results obtained from this test program was noted in the SHCR review of the Crandall report (Crandall and Wittig 1969).[6] A response from Crandall to this review provided a more comprehensive description of the testing machine that was used to determine the ultimate shear strength, since the report contained a "somewhat abbreviated explanation."[7] Additional testing of the damping units was also proposed by Crandall after the dampers had been installed in the towers in order to compare those results to those that were performed previously in the laboratory. No evidence has been found that indicates whether these tests were actually performed or not.

A report was produced by SHCR that compared the two testing programs.[8] Table 1 in the report contains a summary of the methods employed in the two test programs, and Table 2 compares the results of the mechanical properties (dynamic stiffness, loss tangent, and ultimate strength) of the damping units. Major differences in test results occurred with respect to ultimate strength: the tests performed by 3M indicated that the ultimate strength of the units was satisfactory with respect to the design parameters (note: some of

[3] "Test Program for World Trade Center Viscoelastic Damping Units," by Stephen H. Crandall of MIT, May 20, 1968 (WTCI-501-L; see Appendix B).

[4] "Test of Viscoelastic Damping Units for World Trade Center Tower Buildings," S.H. Crandall and L.E. Wittig, April 23, 1969 (Box 9, 233 Park Ave.; see Appendix B).

[5] Letter dated August 29, 1968 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-501-L; see Appendix B).

[6] Letter dated May 22, 1969 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-501-L; see Appendix B).

[7] Letter dated June 2, 1969 from Stephan H. Crandall of MIT to John M. Kyle of PONYA (WTCI-501-L; see Appendix B).

[8] "World Trade Center Report No. DU-3, Viscoelastic Damping Units," by SHCR, June 2, 1969 (WTCI-501-L; reproduced in Appendix B without appendices that are contained in WTCI-501-L).

the information in the SHCR report, including design parameters, have been redacted), whereas, the tests performed by Crandall showed that about 20 percent of the damping units would be near or over the ultimate shear strength, which implies that they would fail in shear. According to the SHCR report, the reason for this discrepancy is not clear; however, the report goes on to state that perhaps this discrepancy is due to differences in the test set up used in the two programs.

During construction of WTC 1, a number of damper units were installed in November of 1970 and remained in place for almost a year, part of that time in unheated space. A request to test 12 of these damper units for loss factor and stiffness, fatigue, and ultimate strength was made by Malcolm Levy of the Port Authority to Don Caldwell of 3M.[9] These tests were to help ascertain if cold temperatures during the winter had any affect on the mechanical properties of the damper units. No results from these tests have been found in any of the documentation.

The damper units were periodically tested as part of the Structural Integrity Inspection program. Results from that program are summarized in NIST NCSTAR 1-1C.

3.4 FLOOR TRUSS TESTS

3.4.1 Full-Scale Flexural Tests

According to Sec. 105.102 of the specification for the floor trusses, which was part of the contract between the Port Authority and Laclede Steel Company (PONYA 1967), full-scale load tests were to be performed on completely fabricated floor truss components. A minimum of one load test was required for each of the 23 different types of floor trusses designated in the design drawings. During testing, two equal concentrated test loads would be applied to the trusses in a test frame. Each load was to be applied at a panel point of the truss. For example, Fig. 3–10 shows the location of the concentrated loads that were applied during testing of 32 in. deep short-span, long-span, and two-way floor trusses.[10] In WTC 1 or WTC 2, a floor truss would be subjected primarily to a uniformly distributed load on its top chord. Thus, since the tests were conducted using concentrated loads instead of uniformly distributed loads, the uniformly distributed loads had to be converted into equivalent concentrated loads (see footnote 10 for the reference that shows the details on this conversion). Included in Fig. 3–10 is the conversion factor (labeled "ECF" in the figure, which stands for "Elastic Conversion Factor") that was used to convert the bending moments obtained from the tests (based on concentrated loads) to bending moments based on uniformly distributed loads.

The floor trusses were to be cambered for a design load equal to the total dead load, which was specified in the Design Criteria (see, for example, Fig. 2–4 in Sec. 2.2.1 of this report). Midspan deflections were measured for various target loads, including the design load, and were compared to the cambers that were specified in structural drawing number 7-AB1-54. Results were found for the flexural tests for Shipment No. 2 in May of 1969.[11] Tabulated results (deflection vs. total applied load) from these tests are shown in Fig. 3–11, including the results for Test No. 27, which is depicted in Fig. 3–10. Also shown in Fig. 3–11

[9] Letter dated November 5, 1971 from Malcolm P. Levy of PONYA to Don Caldwell of 3M (WTCI-513-L; see Appendix B).

[10] Letter dated April 3, 1969 from David B. Neptune of the Laclede Steel Company to W.C. Borland of PONYA (WTCI-503-L; see Appendix B).

[11] Internal Laclede Steel Company memo dated May 15, 1969 from David B. Neptune to R.D. Bay (part of WTCI-82-I; see Appendix B).

are the design displacements (column 3), which are the cambers given in structural drawing number 7-AB1-54 for the various floor trusses. As noted above, the design loads (column 4) are the total dead loads specified in the Design Criteria. The design load of 58 psf for the long-span trusses can be found in Fig. 2–4 of this report. Maximum deflections at midspan as a function of total applied load were reported for the 32 in. deep trusses in Shipment No. 2 and are shown in Fig. 3–12.

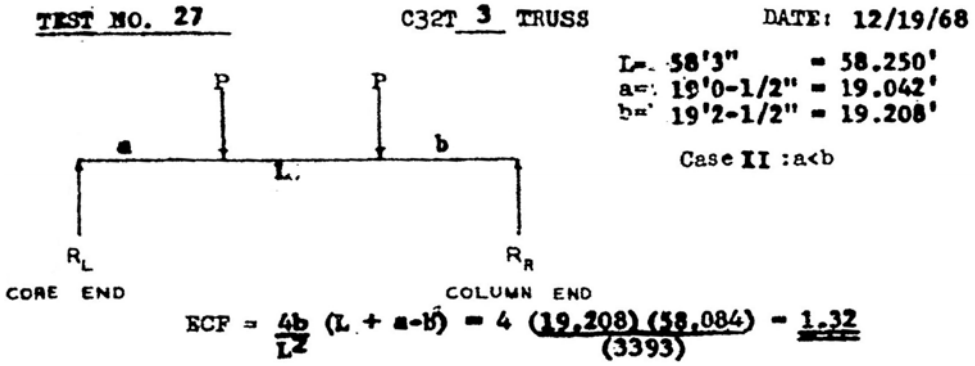


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Figure 3–10. Location of concentrated loads in the full-scale testing of the floor trusses in WTC 1 and WTC 2.

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FLEXURAL TESTS
NOS. 23 THRU 40

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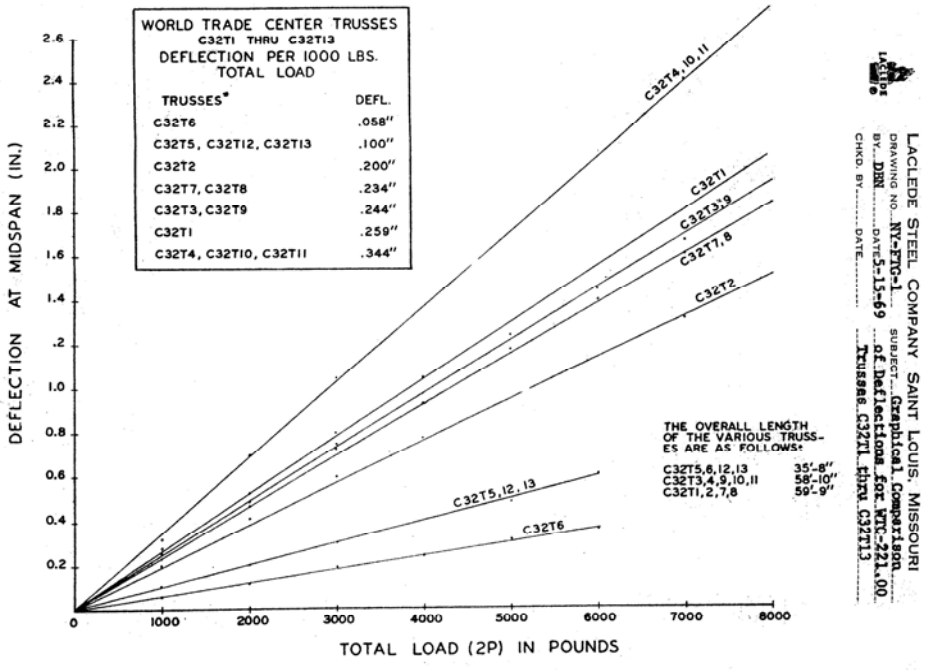
Comparative Deflections+ in Inches for Incremental Target Loads of 500 Pounds

(1)	(2)	(3)	(4)										
TRUSS MARK NO.	TEST NO.	DESIGN DEFL In.	DESIGN LOAD Psf	TARGET LOAD IN POUNDS (5)									
				500	1000	1500	2000	2500	3000	3500	4000	4500	5000
C32T1A	24	2.000	58	.246	.551	.802	1.060	1.335	1.605	1.910	2.170	2.447	2.751
C32T2A	23	2.063	62	.207	.408	.595	.775	.997	1.165	1.335	1.535	1.752	1.962
C32T3	27	2.063	62	.262	.490	.715	.995	1.178	1.414	1.646	1.888	2.120	2.367
C32T4	29	0.750	62	.370	.708	1.029	1.357	1.683	2.033	2.372	2.743	-	-
C32T5	33	0.375	54	.104	.201	.299	.395	.500	.602	-	-	-	-
C32T6	35	0.938	62	.064	.118	.171	.226	.279	.334	.390	.446	-	-
C32T7A	25	2.063	62	.281	.510	.747	.977	1.227	1.440	1.675	1.920	2.174	2.437
C32T8A	26	2.000	62	.286	.541	.807	1.083	1.321	1.575	1.839	2.122	2.400	2.700
C32T9	28	1.938	62	.261	.501	.742	.983	1.233	1.462	1.700	1.943	2.208	2.445
C32T10	30	1.688	62	.360	.711	1.042	1.371	1.699	2.023	2.377	2.729	-	-
C32T11	31	1.313	62	.400	.742	1.070	1.414	1.756	2.095	2.437	2.793	-	-
C32T12	32	0.250	62	.113	.204	.293	.385	.478	.570	-	-	-	-
C32T13	34	0.438	62	.109	.199	.289	.378	.467	.554	-	-	-	-
C32T14AL	38	2.000	58	.281	.565	.841	1.103	1.377	1.649	1.921	2.226	2.490	2.812
C32T16AL	39	2.063	62	.273	.511	.738	.977	1.214	1.465	1.716	1.987	2.241	2.519
C32T21L	40	1.375	62	.416	.765	1.117	1.464	1.825	2.165	2.575	2.917	-	-
C32T23L	36	0.375	54	.116	.224	.326	.430	.533	.638	-	-	-	-
C32T26L	37	0.875	62	.072	.134	.195	.258	.322	.387	.449	.513	-	-

Source: Laclede Steel Company 1969.

Figure 3–11. Results from full-scale flexural tests of 32 in. deep floor trusses.



Source: Laclede Steel Company 1969.

Figure 3–12. Maximum midspan deflections from full-scale flexural tests of 32 in. deep floor trusses.

3.4.2 Shear Knuckle Tests

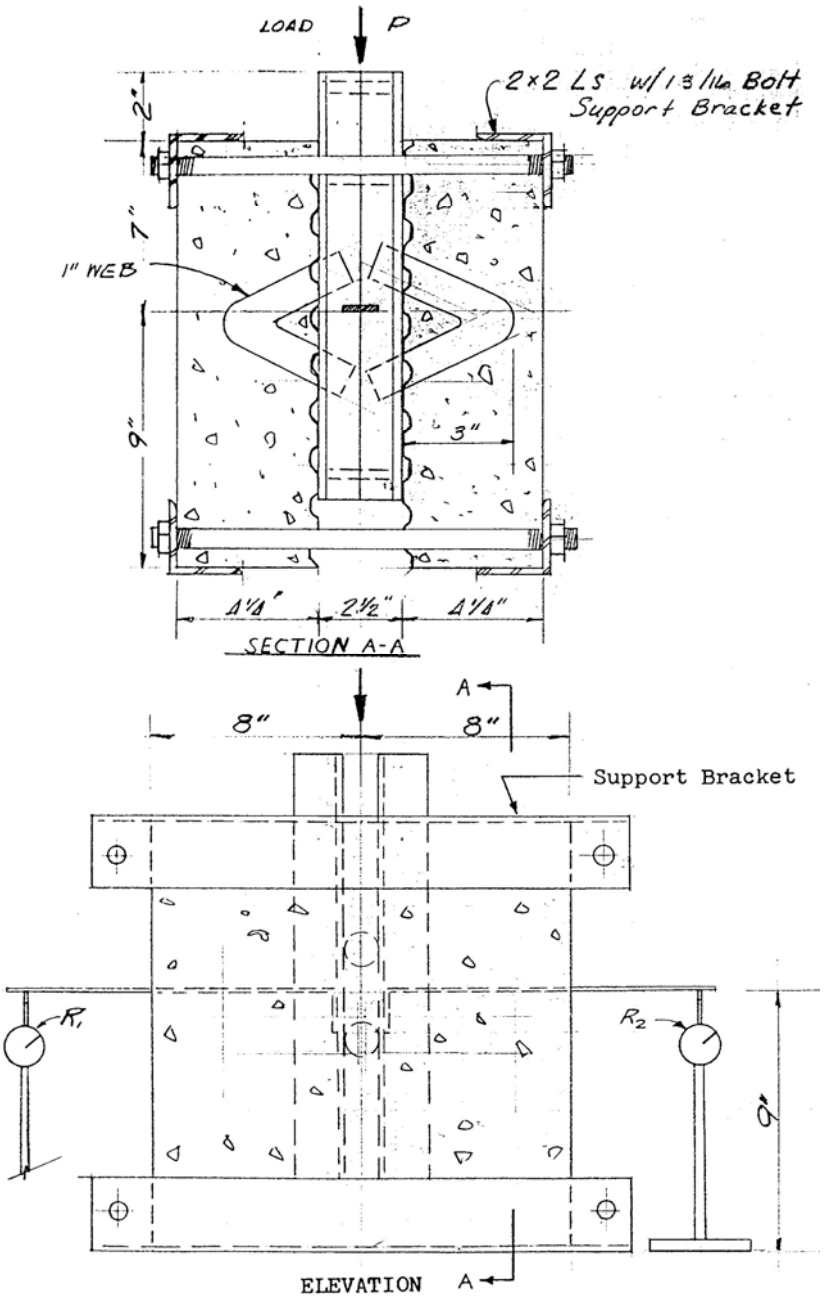
Composite action was achieved between the floor trusses and the concrete slab by extending diagonals above the top chord (see Sec. 5.4.1 of this report). The "knuckle" acted like a shear connector, which made the floor trusses and concrete slab act in a composite manner.

A test program was undertaken at Laclede's Madison plant to determine the failure loads of the shear knuckles. Failure loads were determined for specimens subjected to transverse and longitudinal loads. In the transverse tests, shear knuckles were embedded in lightweight concrete (110 pcf) similar to the type that was used in the WTC, while in the longitudinal tests, the shear knuckles were embedded in normal weight concrete (152 pcf). It is not evident from the documentation why normal weight concrete was used in the longitudinal tests.

Results were found for transverse and longitudinal shear knuckle tests conducted in September 1967 (see Fig. 3–13 for the longitudinal test setup).[12] Tabulated results from the longitudinal tests are given in Fig. 3–14. A summary of the shear knuckle tests that were completed to that date was reported to SHCR.[13] According to the letter, shear strength of the knuckles determined from both transverse and longitudinal testing were found to be well over the allowable values assumed in design.

[12] Internal Laclede Steel Company memo dated September 7, 1967 from J.R. Paul to A.C. Weber (WTCI-85-I; see Appendix B).

[13] Letter dated August 10, 1967 from A. Carl Weber of the Laclede Steel Company to Wayne Brewer of SHCR (WTCI-235-L; see Appendix B).



Source: Laclede Steel Company 1967.

Figure 3–13. Test setup for longitudinal shear knuckle tests.

Spec.	Cyl.	Date Poured	Date Tested	Curing Time Days	Total Load #	Strength PSI	Comments
	A	5-4-67	6-1-67*	28		3891	
	B	5-4-67	6-1-67*n	28		4687	
	C	5-4-67	8-8-67	96	80700	2850	
1		5-4-67	6-3-67	30	59850		At 45,000# faint popping noises heard
2		5-4-67	6-3-67	30	65660		At 60,000# faint popping noises heard
3		5-4-67	6-3-67	30	44520		At 40,980# weld broke

Shear Test					
Specimen 4 * *			Specimen 5 * *		
	Deflection			Deflection	
Load #	R1 in.	R2 in.	Load #	R1 in.	R2 in.
500	0	0	500	0	0
4,000	.003	.011	4,000	.001	.007
8,000	.017	.018	8,000	.003	.020
10,000	.018	.024	10,000	.005	.024
15,000	.022	.029	15,000	.006	.027
20,000	.028	.033	20,000	.007	.027
25,000	.026	.033	25,000	.0075	.027
30,000	Filler Weld Broke		60,550	Weld Broke	
45,570	Main Weld Broke				

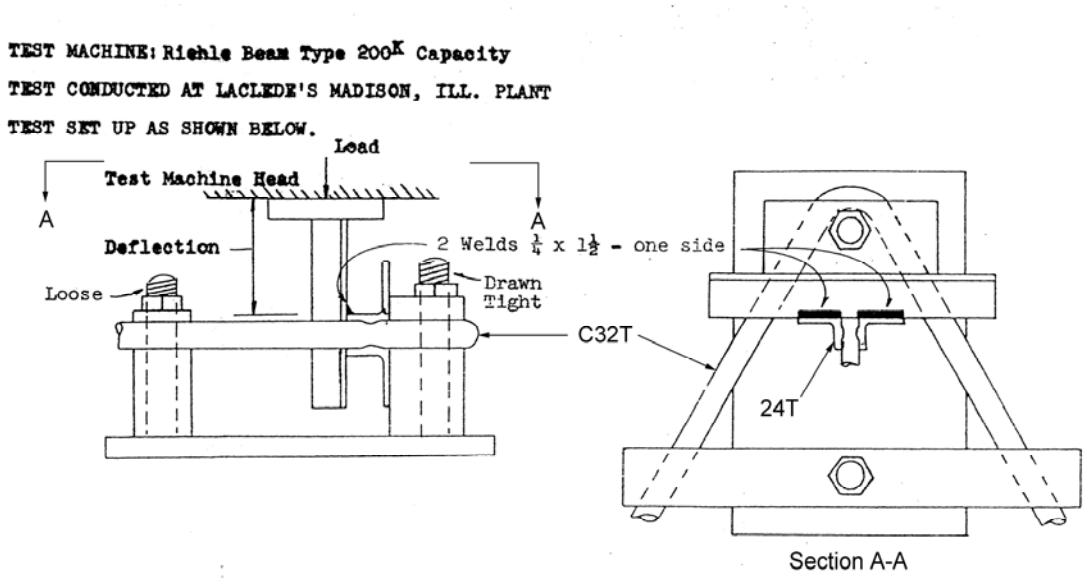
NOTES:
Concrete supplied by:
Lyberger Supply, Granite City, Ill.
Max. Aggregate = 1"
Approximate Slump = 5"
Ave. Cylinder Wt. = 29.90#
Wt. Per Cu. Ft. = 152#
Typical specimen as shown on Left.
Cylinders used were standard 6" diameter testing cylinders.
*Tested by Pittsburgh Testing Laboratory.
**Poured from same batch and same day as other specimens.

Source: Laclede Steel Company 1967.

Figure 3–14. Results from longitudinal shear knuckle tests.

3.4.3 Interior Panel Connection Tests

A test program was established to verify the horizontal and vertical design loads for two connections between the 32 in. deep floor trusses and the 24 in. deep bridging trusses (Laclede Steel Company 1968). Tests for 4C connections (5 kip connections of 24T bridging trusses to C32 trusses at center panel) were run in the testing laboratory at the Madison Plant of Laclede Steel Company. The test setup at the Madison Plant for the case of horizontal loads applied to the welds connecting the bridging trusses to the main floor trusses is depicted in Fig. 3–15. Load was applied monotonically until failure, and the horizontal and vertical deflections of the transverse bridging truss with respect to the connection to the 32 in. floor truss were recorded. Results from one of these tests are shown in Fig. 3–16.



Source: Laclede Steel Company 1968.

Figure 3–15. Test setup for interior panel connection test – horizontal load on welds.

The test setup for vertical loads applied to the welds is depicted in Fig. 3–17. This test setup was approved by SHCR, subject to the following additional requirements:[14]

- The top chords of the C32T floor trusses were to be approximately 7 in. apart.
- The tests were to be conducted with the following weld sizes: 1/4 in. by 3 in., 5/16 in. by 3 in., and 3/8 in. by 3 in.

Two sets of tests were to be conducted: one set with the knuckle restrained and one set with the knuckle unrestrained. According to the letter, the latter set of tests would allow evaluation of the joint strength under construction loading conditions.

Similar horizontal and vertical tests for 5C connections (over 5 kip through 15 kip connections of 24T bridging trusses to C32 trusses at center panel) were run at the Urbauer Laboratory at Washington University, St. Louis, Missouri.

Average recorded failure loads for both 4C and 5C types of connections were equal to at least twice the design values (Laclede Steel Company 1968).

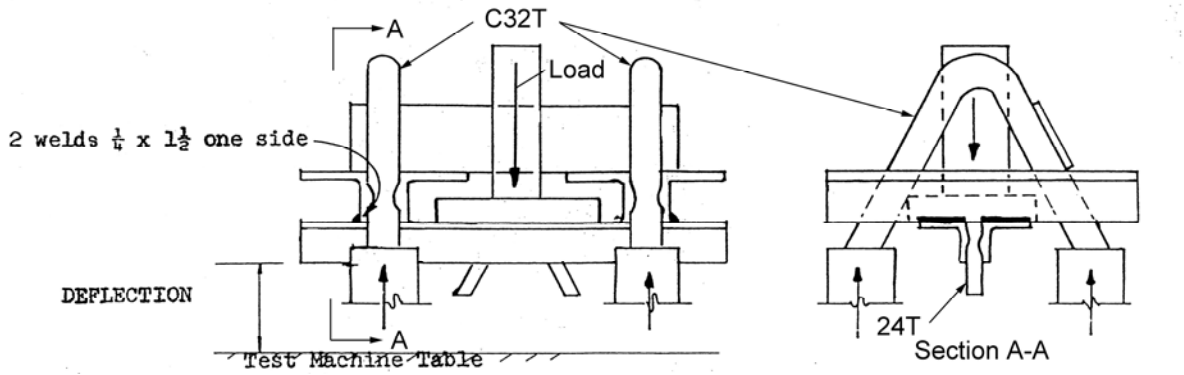
[14] Letter dated April 19, 1968 from Wayne A. Brewer of SHCR to R.M. Monti of PONYA (WTCI-87-I; see Appendix B).

DRAWING NO. _____ SUBJECT _____
BY TMC DATE 14 MAY 68 WELD CAPACITY TESTS FOR INTERIOR,
CHKD. BY _____ DATE _____ PANEL CONNECTIONS UNDER HORIZONTAL LOAD
MODEL BH - 1

TOTAL LOAD	Gage Reading	Deflection
Kips	Inches	Inches
10	3 27/32	0
10.5	3 13/16	.0112
11.0	3 25/32	.0625
11.5	3 2/3	.0687
12.0	3 23/32	.1250
*11.5	3 9/16	.2807
12.0	3 17/32	.3125
12.77	3 7/32	.6250
32" TOP CHORD DEFORMED LATERALLY		

Source: Laclede Steel Company 1968.

Figure 3–16. Results from interior panel connection tests – horizontal load on welds.

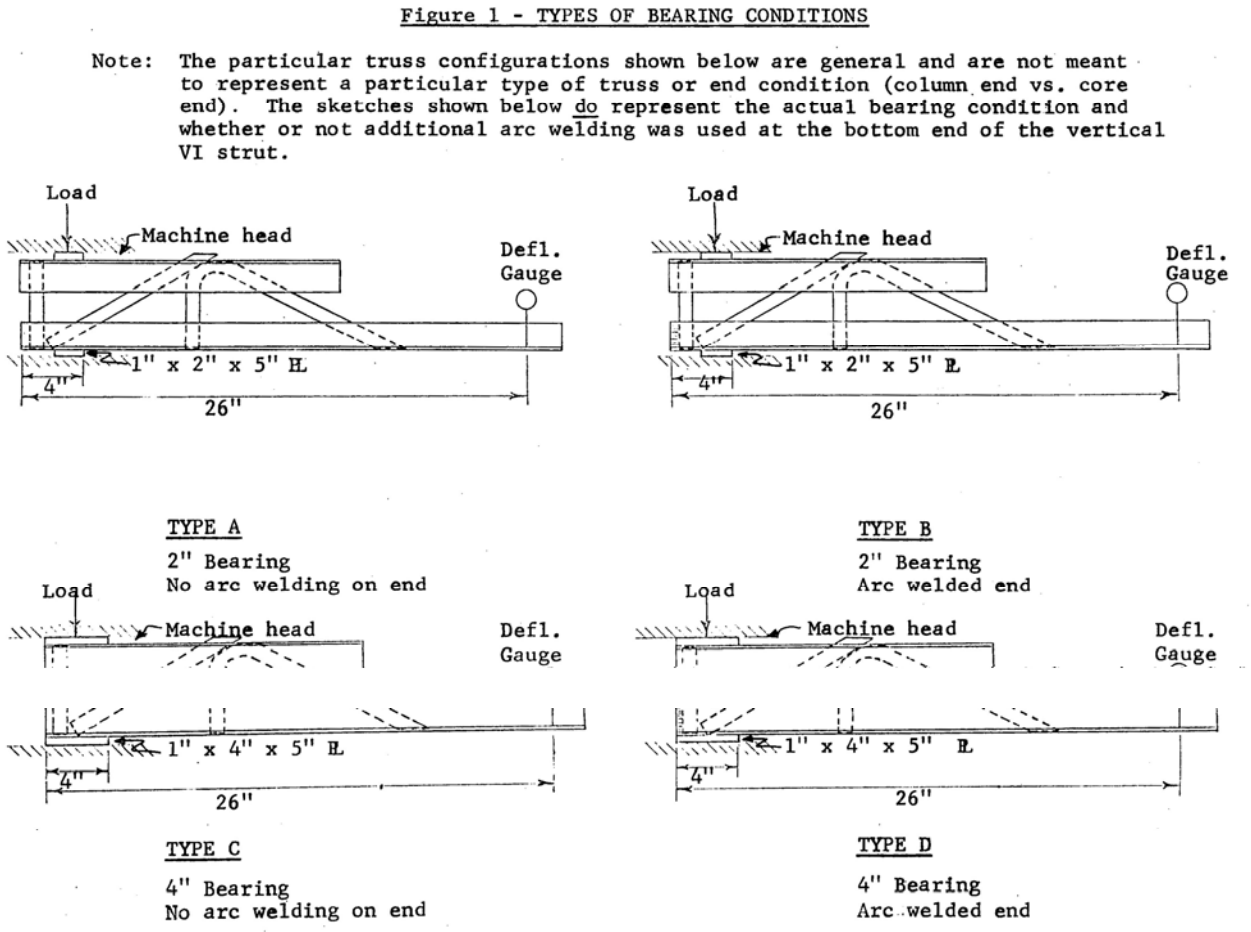


Source: Laclede Steel Company 1968.

Figure 3–17. Test setup for interior panel connection test – vertical load on welds.

3.4.4 Bearing Capacity Tests

Two types of tests were performed to determine the bearing capacity at the ends of the floor trusses.[15] The first set of tests was designed to determine the bearing strength of the as-designed floor trusses. The test setup for these tests is depicted in Fig. 3–18 and the test results are shown in Fig. 3–19 (see reference given in footnote number 15).



Source: Laclede Steel Company 1969.

Figure 3–18. Test setup for first set of bearing capacity tests on floor trusses.

[15] Internal Laclede Steel Company memo dated March 18, 1969 from David B. Neptune to R.D. Bay (part of WTCI-82-I; see Appendix B).

GROI NO. 1

BEARING CAPACITY OF TRUSS ENDS

Test No.	Test Specimen (1)	Load at .06" Deflection (2) KIPS	Ultimate Load KIPS	Observations
1	C32T6 - Type B, Column end	30	48	Angles bent - weld failure
2	C32T6 - Type A, Core end	50	50	Test stopped - no failure
3	C32T1 - Type B, Column end	32	50	Angles bent - no weld failure
4	C32T1 - Type B, Column end	30	50	Angles bent - no weld failure
5	C32T1 - Type C, Column end	60	60	Angles bent - no weld failure
6	C32T1 - Type B, Core end	52	52	Angles bent - no weld failure
7	24T14 - Type A, Column end	38	50	Angles bent - no weld failure

Notes:

(1) For specimen type identification see drawing (Figure 1) on page 3.

(2) Load at .06" deflection as measured 22" from end of bearing is equivalent to a total deflection at midspan for a 60 foot span of .98" and to a total deflection at midspan for a 35 foot span of .60".

Source: Laclede Steel Company 1969.

Figure 3–19. Results from the first set of bearing capacity tests on floor trusses.

The following is a summary of the test results:

- Only one test resulted in a broken weld and this was at a load greater than the load that caused the initial bending of the angles.
- Using a 2 in. bearing length (Types A and B in Fig. 3–18) resulted in a “more critical loading condition” than using a 4 in. bearing length (Types C and D in Fig. 3–18). Deformation of the angles with a 2 in. bearing length occurred sooner than with a 4 in. bearing length.
- The weld failure load at the core end connection was found to be greater than that at the column end.
- Arc welding the bottom of the vertical strut decreases the possibility of a weld failure.

In all of the cases tested in the first set of tests, the ultimate load of the bearing capacity of the floor truss ends was shown to be greater than the design loads.

The purpose of the second set of tests was to determine the strength of repaired bearing ends that would be welded onto floor trusses at the jobsite. According to the report on these tests (Laclede Steel Company 1969), it was sometimes necessary to perform such modifications after the resistance welding was completed. Two types of tests were performed. The first type of test, which is depicted in “Figure 2-A” in Fig. 3–20, tested the capacity of the end as a unit (see reference given in footnote 15). In the second type of test, the strength of each joint in the bearing end was tested (see “Figure 2-B” in Fig. 3–20). The load capacities of the arc welded bearing ends obtained from these tests are shown in Fig. 3–21. The report concluded that the floor truss bearing ends, repaired in accordance with the procedure outlined in that report, were capable of carrying a load “substantially higher” than the design end reaction (Laclede Steel Company 1969).

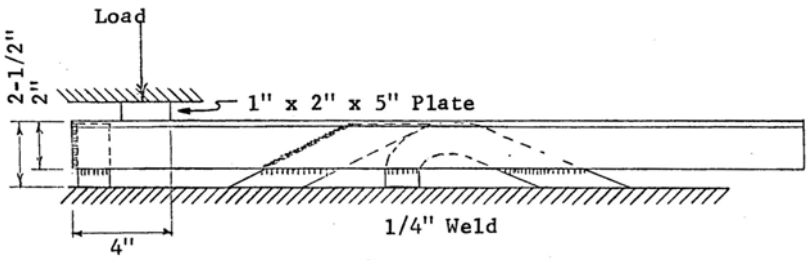


Figure 2-A-BEARING TEST

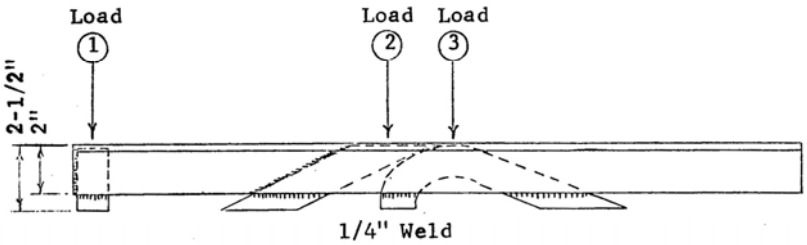


Figure 2-B-WELD SHEAR TEST

Source: Laclede Steel Company 1969.

Figure 3–20. Test setup for second set of bearing capacity tests on floor trusses.

GROUP NO. 2

LOAD CAPACITY OF ARC WELDED BEARING ENDS

Bearing Test (Figure 2-A):

Test No.	Angle Size	Web Size	Failure Load	Type of Failure	Other Comments
1	2" x 1½" x .37"	1.14"	27K	Angle bend	55K - No weld failure
2	2" x 1½" x .37"	1.14"	25K	Angle bend	59K - No weld failure

Weld Shear Test (Figure 2-B):

Test No.	Angle Size	Web Size	Load at Weld Failure (lbs.) Point 1	Point 2	Point 3
3	2" x 1½" x .37"	1.14"	44830	56100	33250
4	2" x 1½" x .37"	1.14"	44180	61000	29250

Source: Laclede Steel Company 1969.

Figure 3–21. Results from the second set of bearing capacity tests on floor trusses.

3.5 STUD SHEAR CONNECTOR TESTS

A testing program was established to determine the horizontal shear capacity of 3/4 in. diameter by 4 1/2 in. long stud shear connectors welded through the troughs of Roll Form Type "B" steel deck and embedded in a lightweight concrete slab. These tests were needed, since, as noted in Sec. 2.3.4 of this report, the allowable shear load for such connectors in concrete with aggregates not conforming to ASTM International C 33 (i.e., the specification for normal weight aggregate) was to be established by a suitable testing program (AISC 1963). Requirements for the test program were outlined in a letter from SHCR to Bethlehem Fabricators.[16] A work order was sent from the Port Authority to the Fritz Engineering Laboratory at Lehigh University to perform the tests on the specimens.[17]

It has not been possible to locate any results from this testing program.

3.6 REFERENCES

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Simiu, E., and Scanlon, R.H. 1996. *Wind Effects on Structures – Fundamentals and Application to Design*. Third Edition. John Wiley & Sons, Inc., New York, NY.

[16] Letter dated November 3, 1969 from James White of SHCR to Lester S. Feld of PONYA (part of WTCI-253-L; see Appendix B).

[17] Contract dated January 6, 1970 from Guy F. Tozzoli of PONYA to Roger G. Slutter of the Fritz Engineering Laboratory, Lehigh University (part of WTCI-253-L; see Appendix B).

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Whitbread, R.E., and Scruton, C. 1965. *An Investigation of the Aerodynamic Stability of a Model of the Proposed Tower Blocks for the World Trade Center, New York, Part I – An investigation of the amplitudes of oscillation in the fundamental mode for a range of wind conditions.* National Physical Laboratory. (part of WTCI-271-L).

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WSHJ (Worthington, Skilling, Helle, & Jackson). 1965c. *The World Trade Center – Wind Program Interim Report, Supplement #2*. 1965. (part of WTCI-68-L).

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Chapter 4
PORT AUTHORITY POLICIES AND AGREEMENTS WITH NEW YORK CITY DEPARTMENT OF BUILDINGS

A memorandum of understanding between the Port Authority of New York and New Jersey (Port Authority or PANYNJ) and the New York City Department of Buildings was established in 1993.[1] Even though it was a "long-standing policy" of the Port Authority that its facilities meet or exceed New York City Building Code requirements, the purpose of this document was to formally restate that policy. Specific commitments were made by the Port Authority to the Buildings Department that would ensure that any building construction project undertaken by the Port Authority or by any of its tenants at the buildings owned and operated by the Port Authority that were located within the Department of Buildings' jurisdiction would conform to the New York City Building Code.

A summary of this agreement follows:

- The Port Authority was to thoroughly review and examine all plans for conformance with the requirements of the then current New York City Building Code. Such reviews were to be conducted by New York State licensed professional engineers or architects retained or employed by the Port Authority. Plans for projects undertaken by Port Authority tenants were to be prepared and sealed by a New York State licensed professional engineer or architect retained or employed by the tenant. Similarly, for projects undertaken by the Port Authority, plans were to be prepared and sealed by a New York State licensed professional engineer or architect retained or employed by the Port Authority.

- The Port Authority was to maintain a file containing the most recent drawings, plans, and other documents required in connection with the review of the project for code conformance.

- The Port Authority was required to obtain the certification of a New York State licensed professional engineer or architect that any tenant project undertaken at any of its facilities was constructed in accordance with the approved plans and specifications for the project. Such certification was to be kept in the project file described above.

- The Port Authority was required to provide copies of any project files to the Department of Buildings at any time.

- The Port Authority was to promptly advise the Department of Buildings of any variances from code requirements that were proposed on a project. In cases where the Department of Buildings believed that such variances were unacceptable, further review by the Port Authority Board of Commissioners was required.

[1] Memorandum of Understanding Between the New York City Department of Buildings and the PANYNJ, 1993 (WTCI-160-P; see Appendix C).

- The Port Authority was required to perform building inspections and structural integrity inspections on a cyclical basis for all of its structures located in New York City.
- The Port Authority was responsible for life safety in buildings at its facilities. The Department of Buildings was not responsible for any type of inspection or review.
- Personnel from the Port Authority and the Department of Buildings were not to be held personally responsible under any provision of this agreement.

A supplement to this agreement was executed in 1995.[2] The supplement added that the design professional responsible for performing the review and certification of plans for World Trade Center tenants must not be the same design professional providing certification that the project had been constructed in accordance with the plans and specifications.

[2] Supplement to Memorandum of Understanding Between the New York City Department of Buildings and the PANYNJ, 1995 (WTCI-113-P; see Appendix C).

Chapter 5
INNOVATIVE SYSTEMS, TECHNOLOGIES AND MATERIALS, AND ACCEPTANCE PROCEDURES USED BY THE PORT AUTHORITY

5.1 INNOVATIVE FEATURES OF THE STRUCTURAL SYSTEM

The structural system, comprising the lateral-force-resisting as well as the gravity-load-carrying systems, of World Trade Center (WTC) 1 and WTC 2 towers incorporated several innovative features including the following:

1. The towers represented one of the earliest applications of the framed-tube lateral-force-resisting system to super high-rise buildings (see Sec. 5.2).

2. Uniform perimeter column geometry (14 in. by 14 in. cross-section) was maintained over most of the height of the 110-story buildings.

3. Fourteen different specified grades of steel were used to allow the perimeter column geometry to remain uniform throughout the heights of the buildings.

4. Deep spandrel plates were used as beam elements connecting perimeter columns, enabling framed tube action by strapping around the structure.

5. Prefabrication of steel construction was extensively used, through using 3-column-wide by 3-stories-high panels, bolted butt-plate column splices, and high-strength bolted shear connections of the spandrel plates.

6. Specially designed corner panels with chamfered edges were used to facilitate force transfer around the corners of the framed-tubes.

7. Long-span floor trusses were used for the floor systems. Composite action was achieved between the floor trusses and the concrete floor slab by extending the truss diagonals above the top chord into the slab. The concrete floor slab acted as a rigid diaphragm, which distributed the lateral forces to the elements of the tube according to their stiffnesses.

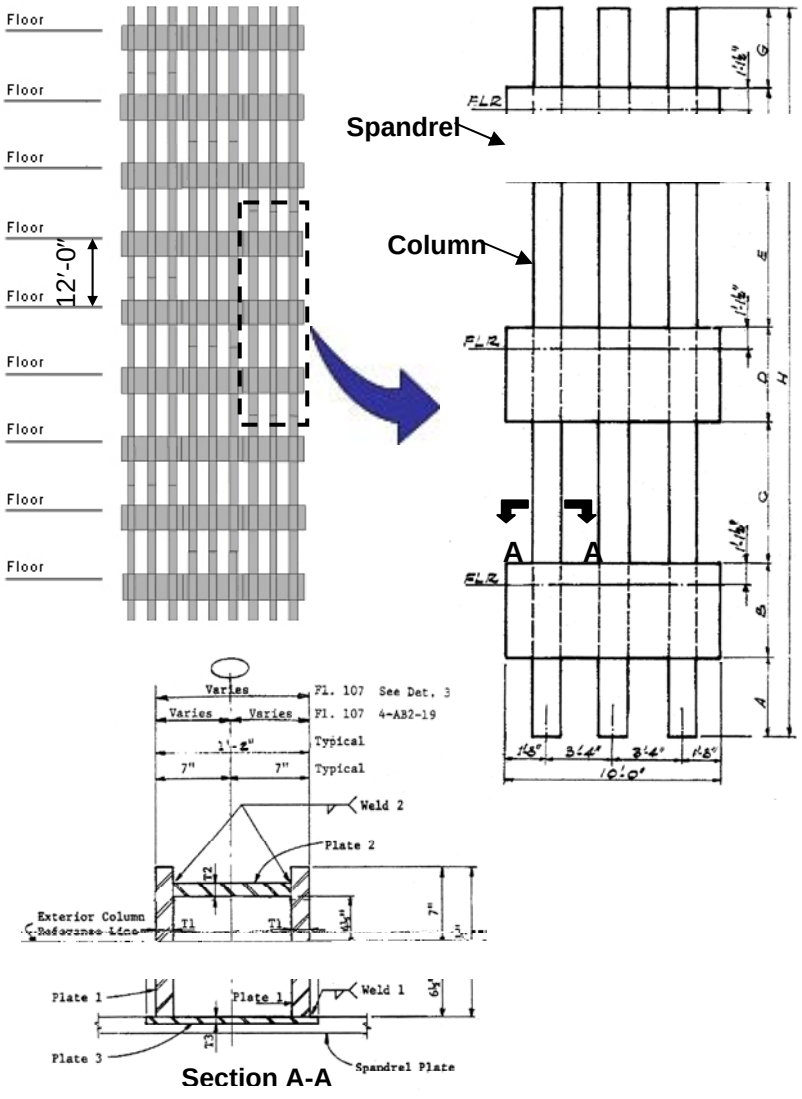
8. Viscoelastic dampers connecting the floor trusses to the perimeter framed tube system were used in each tower to control dynamic response, as discussed in Sec. 5.4.

9. Extensive wind tunnel testing was performed to establish the lateral wind loads used in the design of the towers.

It is important to note that except for Items 7 and 8 above, the innovative features were not appraised by acceptance procedures. Such procedures for Items 7 and 8 are discussed in Secs. 5.3 and 5.4, respectively. Tests to support the design innovations were done for Items 5, 7, 8, and 9.

5.2 LATERAL-FORCE-RESISTING SYSTEM OF WTC 1 AND WTC 2

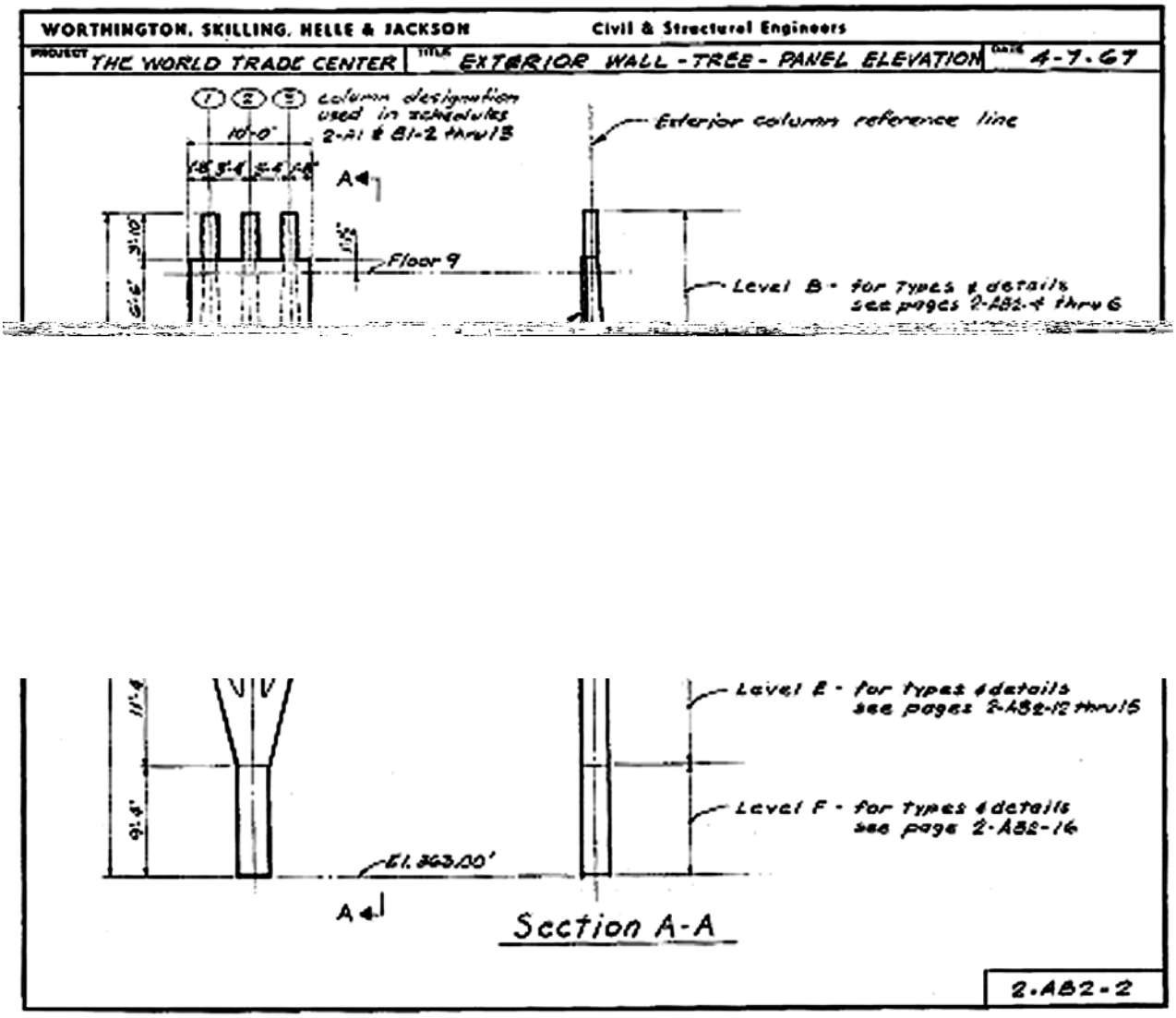
The exterior walls of WTC 1 and WTC 2, comprised of steel columns and spandrel plates, were designed to resist the lateral forces and a portion of the gravity forces. Above the 7th floor, the columns were welded steel plate box columns, spaced 3 ft 4 in. on center. The columns and spandrels were shop-assembled and welded into 36 ft high by 10 ft wide panels, which consisted of three columns and three spandrels as shown in Fig. 5–1 (WSHJ 1967a). These panels were erected on site by bolting the base plate of an upper column to a cap plate of a lower column. Such splices were staggered so that only one-third of the panels were spliced at each story level, except at the base of the building and at the mechanical floors where all of the panels were spliced at the same level. In such cases, supplemental welds were employed to improve connection capacity. Spandrels were connected at midspan with high-strength bolted shear connections.



Source: WSHJ 1967a. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–1. Exterior wall panels in WTC 1 and WTC 2.

Below the 7th floor, the columns were typically spaced 10 ft 0 in. apart. The transition from three columns to one column occurred just below the 7th floor level as illustrated in Fig. 5–2.[1] Below the 7th floor, where there were fewer perimeter columns, bracing was used in the core area to increase lateral stiffness, and the core columns were designed to resist a portion of the lateral forces.



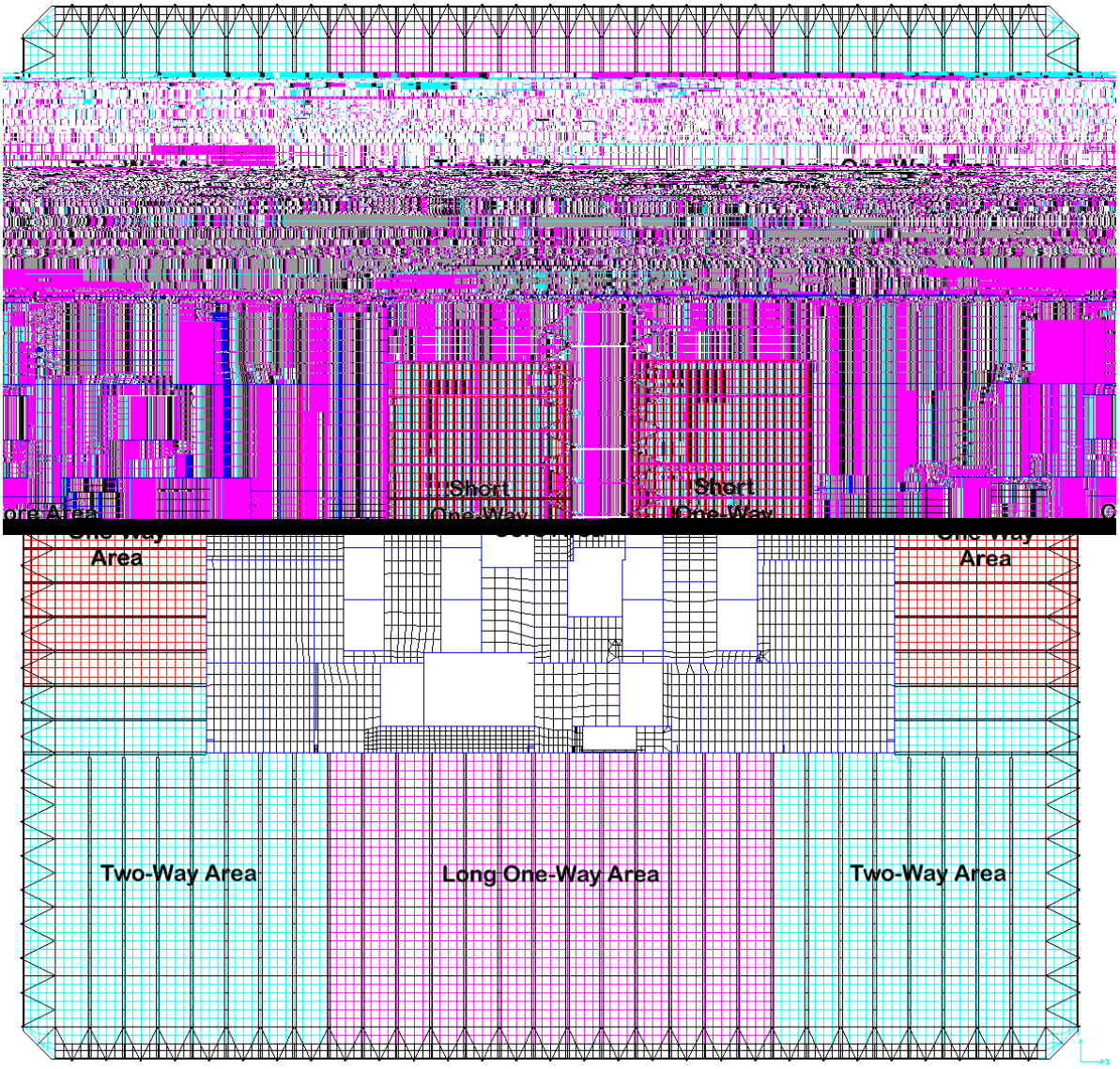
Source: WSHJ 1967b. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–2. Exterior wall panel transition in WTC 1 and WTC 2.

This structural system is considered to be a framed-tube system (closely spaced columns and deep spandrel members) (Khan 1983). In such systems, the frames parallel to the applied lateral forces act as the webs of the tube and resist the shear from the lateral forces through bending of the beams and columns in the frames. The floor system is considered a rigid diaphragm and is typically assumed to distribute the lateral forces to the elements of the tube according to their stiffness (although in the case of WTC 1 and WTC 2, no evidence was found from the calculations that diaphragm action was explicitly

[1] Structural drawing 2-AB2-2 (WSHJ 1967b).

considered in the design). Portions of the normal frames close to the corners of the tube act as flanges of the parallel frames. When subjected to lateral forces, the columns in the windward wall (flange) are subjected to tensile forces, while those on the leeward wall (flange) are subjected to compressive forces. Framed-tube systems do not behave as a true cantilever when subjected to lateral forces. The flexibility of the spandrel beams produces a shear lag that increases the axial forces in the corner columns and reduces the axial forces in the inner columns of both the flanges and the webs. A representative structural framing plan of a typical floor in WTC 1 or WTC 2 is shown in Fig. 5–3.



Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–3. Representative structural framing plan on a typical floor of WTC 1 or WTC 2.

WTC 1 and WTC 2 are early examples of super high-rise buildings that were designed based on the framed-tube concept. The first application of a framed-tube system was the 43-story DeWitt-Chestnut apartment building (later renamed The Plaza on DeWitt) in Chicago, which was completed in 1965. Designed by Skidmore, Owings & Merrill, this 395 ft tall building used reinforced concrete for the

structural framing system. Since then, many variations of this structural system were used in a number of buildings, which were constructed between the mid-1960s through the early 1970s. A number of major buildings that have incorporated the framed-tube concepts in the United States include:

- Brunswick Building, Chicago, Illinois. Completed in 1965, this 38 story, 550 ft tall reinforced concrete office building designed by Fazlur Khan of Skidmore, Owings & Merrill utilizes a tube-in-tube system. In this system, the shear walls in the core area form an inner tube and the closely spaced columns with deep spandrel beams at the perimeter of the building form the outer tube.

- John Hancock Center, Chicago, Illinois. Diagonal braces supplement the steel framed-tube system in this 100-story, 1,127 ft tall mixed-use building, which was completed in 1969. Skidmore, Owings & Merrill designed this building as well.

- One Shell Plaza, Houston, Texas. Skidmore, Owings & Merrill, also designed this 50 story, 714 ft tall building. Completed in 1971, it uses a tube-in-tube structural system of reinforced concrete.

- Aon Center, Chicago, Illinois. At 1,136 ft tall, this 83-story steel office building, which was formerly known as the Amoco Building and before that as the Standard Oil Building, was completed in 1973. This steel office building utilizes a framed-tube system. Perkins & Will was the structural engineer for this project.

- Sears Tower, Chicago, Illinois. A bundled tube system is used in this 108-story, 1,450 ft tall steel building designed by Skidmore, Owings & Merrill, which as completed in 1974. A series of tubes are interconnected to form the lateral-force-resisting system. In this system, wider column spacing than would be possible for only an exterior framed-tube was used.

5.3 DAMPING UNITS

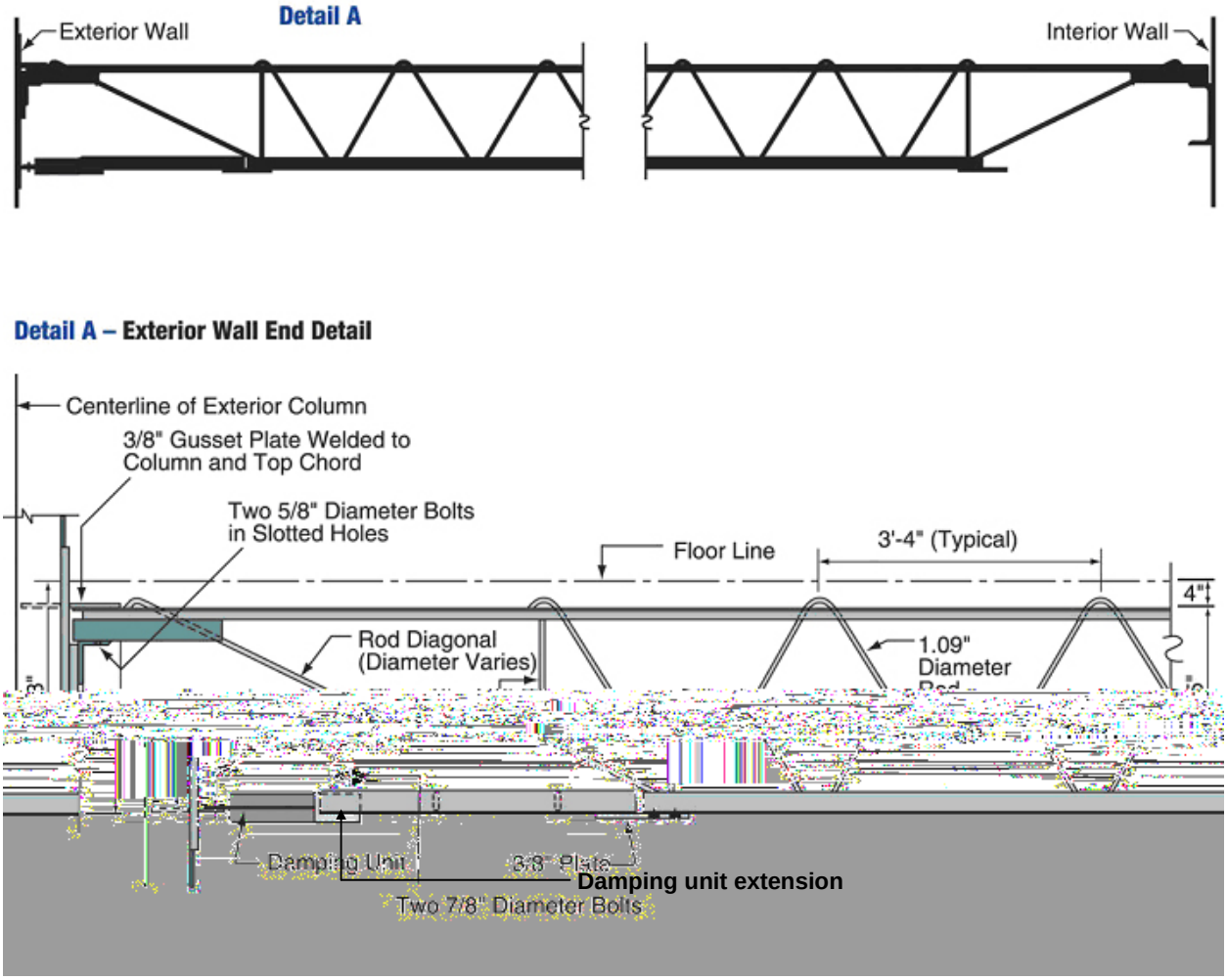
5.3.1 Overview

Viscoelastic damping units were part of the structural system in WTC 1 and WTC 2 to supplement the tubular steel frame in limiting wind-induced building oscillations to levels below human perception. According to Mahmoodi (1987), “The selection, quantity, shape, and location of the dampers was based on the dynamic analysis of the towers (computer modeling, wind tunnel, etc.), and of the damping required to achieve performance standards.” This may have been the first application of damping units for this purpose in tall building structures, and would certainly qualify it as an innovative system at that time.

The damping units were uniformly distributed throughout both of the buildings. Approximately 100 were used on each floor from the 7th to the 107th floor. The exact number and planned locations of damping units on the various floors of the buildings are contained in structural drawings D-AB1-2 through D-AB1-14.2 (WSHJ 1967b). As the buildings oscillated from the wind, part of the energy of oscillation was dissipated by shear deformations in the viscoelastic part of the damping units.

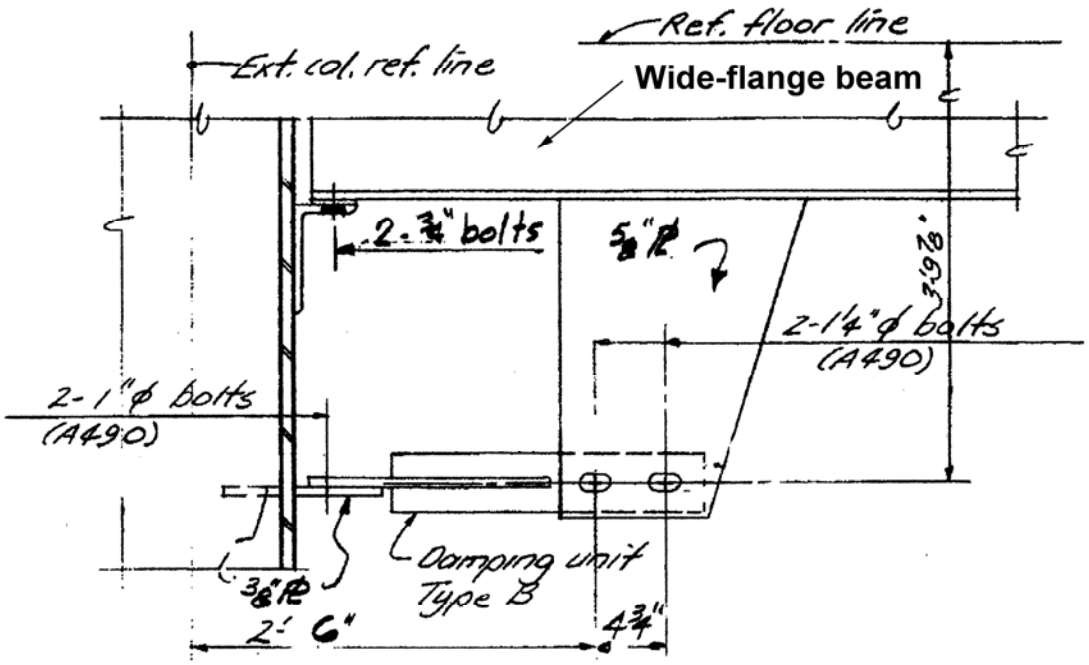
Two different types of damping units were used in WTC 1 and WTC 2. Type A damping units were used on floors with trusses spanning between the core and the outside wall, and were located between the

bottom chords of the floor trusses and the columns of the outside wall (Fig. 5–4). Type B damping units were used on floors that had wide-flange beams spanning between the core and the outside walls (i.e., floors 7, 9, 41, 43, 75, 77, and 107). This type of damping unit was located between the bottom flanges of the floor beams and the outside wall, as shown in Fig. 5–5. The details of a damping unit are illustrated in Fig. 5–6.



Source: McAllister 2002.

Figure 5–4. Floor truss member with Type A damping units.



Source: WSHJ 1967b. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–5. Wide-flange beam floor member with Type B damping units.

Type B damping units were slightly longer than Type A damping units. Also, the connections between Type A damping units and the floor trusses were different than those between Type B damping units and the wide-flange beams. Sheet DA-3 in the structural drawings shows specific details for each type of damping unit (WSHJ 1967b).

Worthington, Skilling, Helle & Jackson (WSHJ) initially inquired about different types of viscoelastic damping materials in a letter to Minnesota Mining and Manufacturing Company (3M) in 1964.[2] A follow-up letter from them to 3M contained the physical and mechanical properties required for the viscoelastic material, based on calculations they had performed.[3] Additional correspondence on various aspects of the damping units, including the results of tests that were run at 3M that measured the properties of the damper material and the strength of an assembled damping unit prototype, was exchanged subsequent to these letters.[4] In particular, it was noted that testing of an assembled truss damping unit by 3M was completed and that the results agreed with the theoretical predictions.[5]

[2] Letter dated July 16, 1964 from Alan G. Davenport of WSHJ to Carl A. Dahlquist of 3M (WTCI-450-L; see Appendix D).

[3] Letter dated November 23, 1964 from Richard D. Steyert of WSHJ to Carl A. Dahlquist of 3M (WTCI-450-L; see Appendix D).

[4] Various memos and letters in WTCI-450-L.

[5] Internal correspondence dated February 1966 by Richard D. Steyert of WSHJ (WTCI-450-L; see Appendix D).

Source: WSHJ 1967c. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–6. Damping unit details – Types A and B.

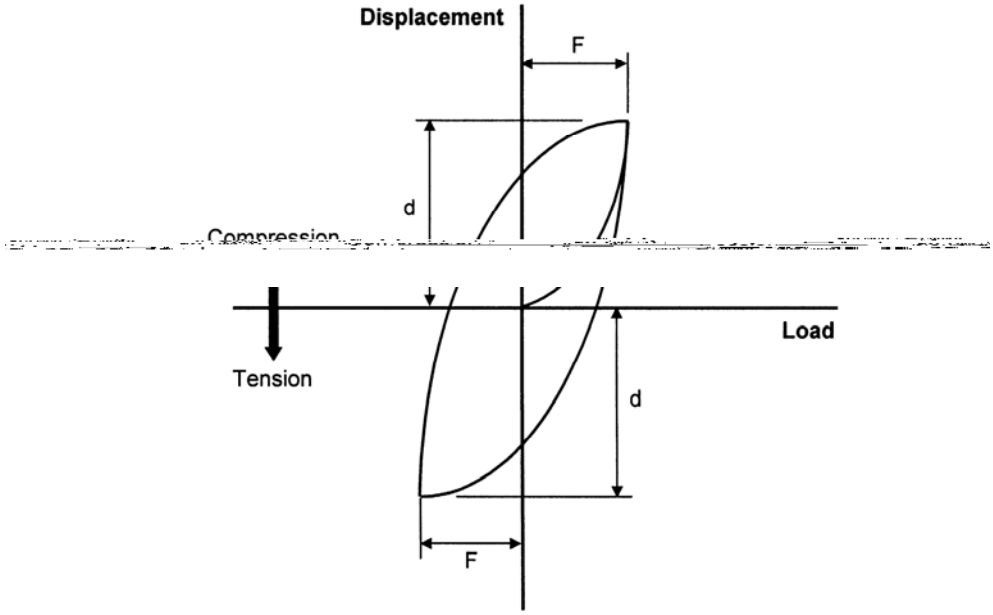
5.3.2 Specifications

A draft specification for the damping units was written by WSHJ in mid-1966[6], and comments and additions to the specification were supplied by 3M to WSHJ in late October of that year.[7]

In addition to the specifications, Skilling, Helle, Christiansen, & Roberton (SHCR) proposed to Port of New York Authority (PONYA) in 1967 a prototype test program for the damping units.[8] The report that was submitted to PONYA states the uniqueness of the proposed damping system and points out the value of having independent testing (i.e., tests in addition to those performed by 3M) to measure the performance of the damping units.

6

Included in the report were the test parameters that were needed for evaluating the effectiveness of the damping units, which included dynamic stiffness, loss factor, and temperature changes. These parameters are defined in Fig. 5–7. The hysteresis loop that is shown in this figure represents the results obtained from the tests that were performed on the damping units (see Sec. 3.3 of this report for a description of these tests).



F = stiffness = one-half of the double amplitude of the axial force in the damper subjected to a sinusoidal displacement with an amplitude of 0.020 in. at 0.1 Hz (lbs)

A = area of hysteresis loop (in.-lb)

d = extension (in.)

L = bonded length of viscoelastic slab = 10.0 in.

W = width of viscoelastic slab = 4.0 in.

T = thickness of viscoelastic slab = 0.050 in.

A_{ve} = viscoelastic shear area = 2WL = 80 in.^{2}

S = shear stress = F/A_{ve} = F/80 (psi)

γ = maximum shear strain = 0.4 in./in.

V = volume of viscoelastic material = 2WLT = 4 in.^{3}

G* = complex shear modulus = S/γ (psi)

G″ = loss shear modulus = (A x scale factors)/$\pi\gamma^2 V$ (psi)

G′ = elastic shear modulus = $[(G^*)^2 - (G'')^2]^{1/2}$ (psi)

Loss factor = G″/G′

Source: Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–7. Parameters related to mechanical properties of damping units.

The draft contract between 3M and PONYA, dated November 1, 1968, contained the technical specifications for the damping units (Appendix A of the contract).[9] In general, these specifications covered the manufacture and testing of the units. SHCR supplied comments on the draft contract to the PONYA.[10] Other adjustments were subsequently made to the specifications, and the final draft of the specifications was issued on November 6, 1969.[11]

The specifications were to prevail in the event that there was a conflict between any requirements in the specifications and the requirements on the contract drawings (Sec. 0.01 in the contract). No existing standards (such as ASTM International) covered the damping units that were used in this project. Damping units were accepted or rejected based on the requirements given in the specifications.

According to Sec. 21 of the contract, 3M was to conform to all orders, directions, and requirements of the Chief of the Planning and Construction Division of the World Trade Center of the World Trade Department of PONYA (referred hereafter, as in the contract, as the "Engineer"), and was to perform the requirements in the contract to the satisfaction of that person. The Engineer also had the power to alter the contract drawings and specifications.

The following is a summary of the requirements in Chapters 1 and 2 of the November 6, 1969 edition of the technical specifications. Unless otherwise noted, referenced section numbers are from the contract (PONYA 1969).

Chapter 1 – General Conditions

The materials and workmanship that went into the damping units were to conform to "the best modern practice" (Sec. 0.02). If the contract drawings, specifications, or directions of the Engineer left any doubt as to what was permissible or failed to note the quality of any construction, the interpretation that called for the best quality of construction was to be followed. Any errors or discrepancies in the contract drawings or specifications were to be reported to the Engineer as soon as possible (Sec. 0.04).

According to Sec. 0.06, Inspections, testing and storage operations were subject to inspection at any time by the Engineer or by inspectors acting as agents of the Engineer. 3M was required to give the Engineer at least 10 days notice prior to any testing required in accordance with the specifications.

The contract drawings were considered part of the specification (Sec. 0.08). Revised drawings of the structural tees (DA-1), structural bars (DA-2), and viscoelastic damping units (DA-3) were finalized on May 21, 1970. These drawings did not show all of the details of the components that made up the damping units, and were intended only to illustrate the character and extent of such units.

The responsibilities of 3M with respect to this contract are outlined in Sec. 0.09. They were responsible for (1) machining the structural tees and bars that were to be supplied by others, (2) applying the protective aprons to the viscoelastic material, bonding adhesives, and viscoelastic materials to the tee flange face and both sides of the bar, (3) assembling two tees and one bar into a damping unit, (4) shipping and bundling the completed units according to type (Type A or B), and (5) testing the units

[9] Draft contract WTC-224.00 for damper units dated November 1, 1968 between PONYA and 3M (WTCI-500-L).
[10] Letter dated April 4, 1969 from Leslie Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-501-L; see Appendix D).
[11] "Specification for Viscoelastic Damping Units" dated November 6, 1969 (PONYA 1969) (WTCI-501-L; see Appendix D).

in accordance with the requirements contained in the contract. 3M was not responsible for furnishing the structural tees or bars, painting the damping units, or installing them in the towers. Installation instructions were contained on structural drawing D-AB1-1.3 (WSHJ 1967b).

The structural tees and bars were fabricated from steel conforming to ASTM A 36-63T or ASTM A 572, Grade 42 (Sec. 0.10). Fabrication tolerances were to conform to the AISC *Specifications for the Design, Fabrication, and Erection of Structural Steel for Buildings* dated April 17, 1963 (AISC 1963), and to the requirements contained in the contract drawings and paragraphs C, D, and E in Sec. 0.10 of the specifications. Sections C and D contained the special requirements for the structural tees and structural bars, respectively. Section E required that certification be provided for all components that were supplied by others.

Chapter 2 – Technical Requirements

Approved materials to be used in the manufacture of the damping units are contained in Sec. 2.0 of the specifications and are summarized in Table 5–1 (PONYA 1969). The shop drawings for the structural steel tees and bars that were used in the damping units were considered to be part of the material specifications, even though 3M was not responsible for the manufacture of these members.

Table 5–1. Material specifications for damping units per WTC Contract WTC-224.0.[a]

Material	Specification
Viscoelastic material	3M Brand Vibration Damping Elastomer, #Y-9274[b]
Steel	ASTM A 36-63T or ASTM A 572 Grade 42
Assembly bolts	1/4 in. diameter bolts conforming to ASTM A 307 Standard Specification for Low-Carbon Steel Externally and Internally Threaded Standard Fasteners
Bonding adhesive	3M Scotchweld Brand Structural Adhesives EC 1614 and 3520
Protective aprons	3M Scotch Brand Pressure Sensitive Tape #465

a. Shop drawings for structural tees and bars were considered to be part of the material specifications.
b. Other viscoelastic materials could be used subject to approval of PONYA. Request for approval was to be accompanied by full technical data on the material including documentation of performance characteristics of the damping unit proposed for the work.

Quality Assurance Program— Section 5.0 contains the quality assurance program that was created for the damping units. This program included requirements for both initial and long-term (5 year) acceptance. It also included the test methods that were to be used to determine whether damping units met these requirements. A brief summary of each of the elements that made up the quality assurance program is given below.

- **Acceptance.** A lot of dampers would be deemed acceptable by PONYA after sampled dampers from that lot were tested in accordance with the procedures in Sec. 5.3 of the technical specification and were shown to meet the requirements in Sec. 4.1. An acceptance lot consisted of all dampers made in each calendar week from the same lot of viscoelastic material by the same process and submitted for acceptance testing at one time.

The acceptance requirements of Sec. 4.1 are summarized in Table 5–2 (PONYA 1969). Detailed test procedures for loss factor and stiffness, fatigue strength, and ultimate strength are given in Secs. 5.3.6.1, 5.3.6.2, and 5.3.6.3 of the technical specification, respectively. Methods on how to select a sample size for loss factor, stiffness, and fatigue tests are given in Sec. 5.1.3.1. Sample size for ultimate strength tests are provided in Sec. 5.1.3.2. In short, a single lot of dampers is accepted if the predetermined sample meets all of the criteria contained in Table 5–2.

Sampled dampers in an accepted lot that were not damaged during testing were to be delivered to PONYA. All dampers were to be labeled in accordance with the identification codes in Sec. 5.1.4. Dampers that were subjected to acceptance testing were labeled differently from those that were not subjected to testing.

Table 5–2. Acceptance requirements for damping units per WTC Contract WTC-224.0.

Item (units)[a]	Number of Dampers in Sample	Acceptance Requirement[b]
Loss Factor (dimensionless)	5	Requirement average = $0.7 + 0.948\sigma_i$[c]
	10	Requirement average = $0.7 + 0.670\sigma_i$
	15	Requirement average = $0.7 + 0.547\sigma_i$
Stiffness (lb)	5	$6{,}000 + 1.25\sigma_i <$ Requirement average $< 20{,}000 - 1.25\sigma_i$
	10	
	15	
Ultimate Strength (lb)	5	For an individual damper, ultimate strength > 40,000 lb at 75° F If 0 or 1 damper fails, the lot is accepted. If 2 fail, take a second sample of 5 dampers. All must pass.
Fatigue (lb)	5	$5{,}400 + 1.25\sigma_i <$ Requirement average $< 22{,}000 - 1.25\sigma_i$
	10	
	15	

a. See Fig. 5–5 for definition of terms.
b. Requirement average = limiting average value of the specified parameter determined from a given sample as set forth in the equations for each parameter.
c. σ_i = standard deviation computed from Eq. 3–1 or Eq. 3–2 in Sec. 3.2.

- **Five-Year Testing.** Unused (or virgin) dampers were also to be tested not less than 5 years nor more than 5 years and 3 months after all the dampers in a given 5 year lot were manufactured. In short, a number of dampers were to be set aside and tested within the time frame described above to determine whether any changes had occurred in stiffness, loss factor, or ultimate strength. Unlike in the acceptance requirements, fatigue tests were not required for the damping units in the 5 year lots.

  Damping units to be used in the 5 year tests were to be stored by 3M in conformance with the conditions outlined in Sec. 5.3 of the specifications.

After the samples from a 5 year lot were tested in accordance with Sec. 5.3 and the requirements in Sec. 4.2 were met, the lot was deemed to have passed the 5 year test. The requirements of Sec. 4.2 of the specifications are summarized in Table 5–3 (PONYA 1969).

Table 5–3. Five-year acceptance requirements for damping units per WTC Contract WTC-224.0.

Item (units)[a]	Number of Dampers in Sample	Acceptance Requirement[b]
Loss Factor (dimensionless)	10	Requirement average = $0.63 + 0.948\sigma_i$[c]
	20	Requirement average = $0.63 + 0.670\sigma_i$
	30	Requirement average = $0.63 + 0.547\sigma_i$
Stiffness (lb)	10	$5{,}400 + 1.25\sigma_i <$ Requirement average $< 22{,}000 - 1.25\sigma_i$
	20	
	30	
Ultimate Strength (lb)	13	For an individual damper, ultimate strength > 36,000 lb at 75° F If 0, 1, 2, or 3 damper fail, the lot is accepted. If 4 fail, take a second sample of 13 dampers. All must pass.

a. See Fig. 5–5 for definition of terms.
b. Requirement average = limiting average value of the specified parameter determined from a given sample as set forth in the equations for each parameter.
c. σ_i = standard deviation computed from Eq. 3–1 or Eq. 3–2 in Sec. 3.2.

A 5 year lot was one-fourth of the total number of dampers specified in the contract (Sec. 5.2.2). The number of dampers that were to be tested for loss factor and stiffness was determined in accordance with Sec. 5.2.3.1, while Sec. 5.2.3.2 of the contract contained the number of dampers that were to be tested for ultimate strength.

Similar to the acceptance testing, sampled dampers in an accepted lot that were not damaged during testing were to be delivered to PONYA. Dampers subjected to 5 year tests were to be labeled in accordance with the requirements in Sec. 5.2.4.

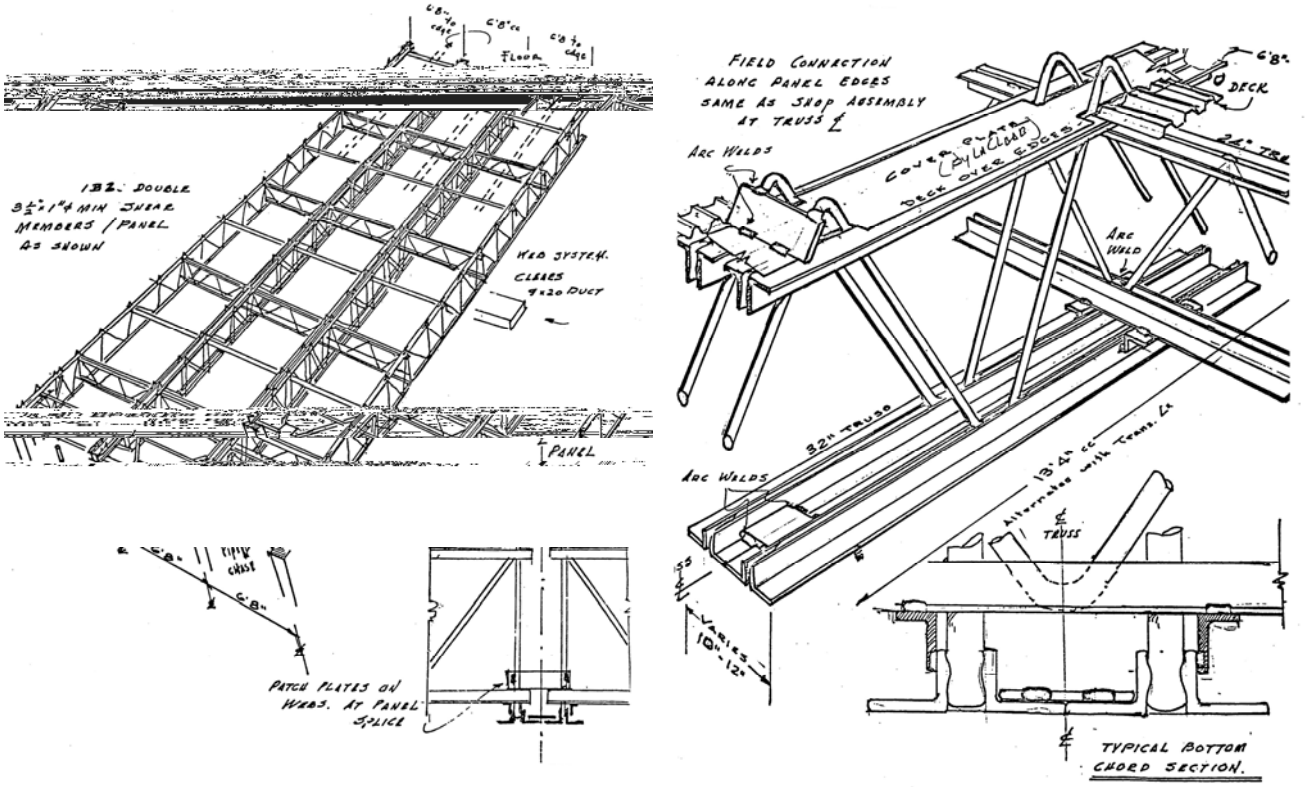
5.4 FLOOR TRUSSES

5.4.1 Overview

Outside of the central core area, floor construction of WTC 1 and WTC 2 typically consisted of 4 in. of lightweight concrete on 1 1/2 in., 22-gauge fluted metal deck supported by a series of composite floor trusses that spanned between the core and the exterior walls (see Fig. 5–8). A pair of main floor trusses, spaced 6 ft 8 in. apart on center, spanned either approximately 60 ft or 35 ft from the core to the exterior walls, where they were supported on every other column. At the core, floor trusses were supported on channels that were supported by the core columns. The metal deck spanned parallel to the main floor trusses and was supported on transverse (bridging) floor trusses that were spaced at 13 ft 4 in. on center and on deck support angles that were spaced at 6 ft 8 in. on center from the transverse (bridging) floor trusses. Pairs of flat bars (straps) extended diagonally from the top chord of the floor trusses to the perimeter columns (see Fig. 5–3). Figure 5–8 shows a typical 20 ft by 60 ft prefabricated floor unit that was used in the towers (PONYA 1967). As shown in this figure, the floor trusses consisted of double

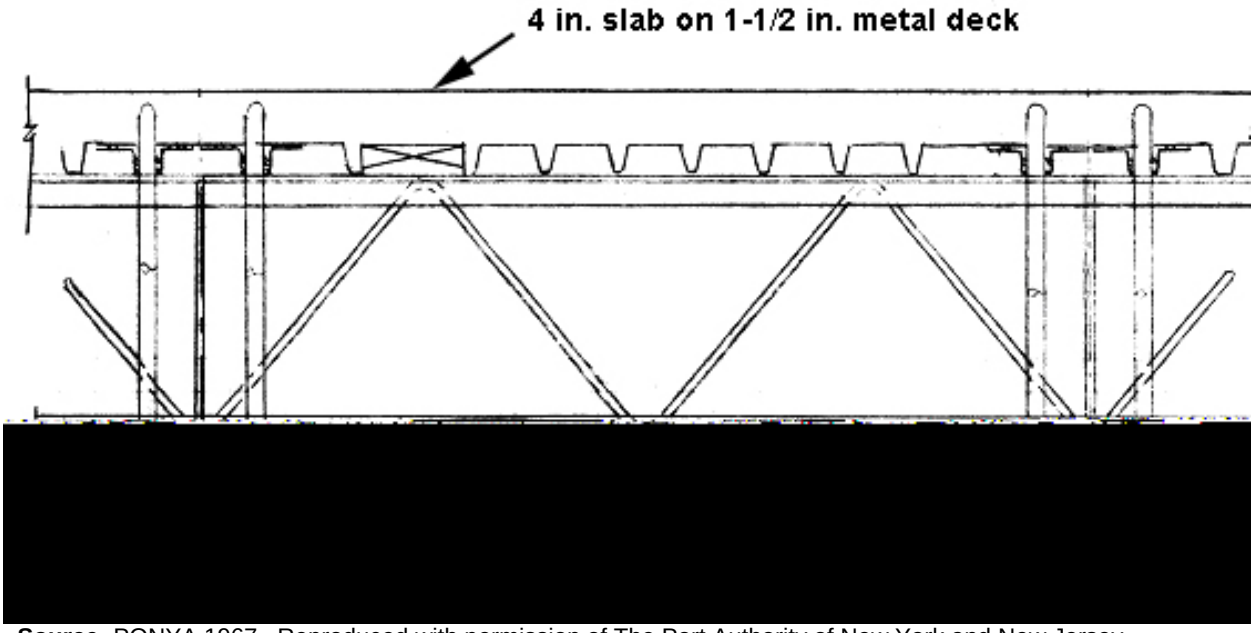
angles that were used for the top and bottom chords and round bars that were used for the diagonals. A section through the main double trusses is shown in Fig. 5–9.

What made the floor system in WTC 1 and WTC 2 innovative from a structural standpoint was the way that composite action was achieved between the floor trusses and the concrete slab. Truss diagonals were extended above the top chord, as shown in Figs. 5–4 and 5–8. This "knuckle" acted like a shear stud, which made the floor truss and concrete slab act in a composite manner.



Source: PONYA 1967. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–8. Prefabricated floor unit used in WTC 1 and WTC 2.



Source: PONYA 1967. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 5–9. Section through the main double trusses in the floor system of WTC 1 and WTC 2.

The first recorded tests on composite open-web steel joists were conducted under a project jointly sponsored by Granco Steel Products and Laclede Steel Company (who manufactured the trusses for WTC 1 and WTC 2) in September of 1964.[12] In this study, the overall performance of non-composite joists was compared with composite joists. The joists were manufactured with their webs projecting above the top chord. The tests revealed that the composite joists had greater moment capacities and smaller deflections than the non-composite joists.

Additional tests on open-web joists were performed at Washington University (Tide and Galambos 1968). The findings, which were reported in February of 1968, were similar to those reported from the previous tests. In particular, the specimens with extended web diagonals into the concrete slab serving as shear connectors were shown to be strong and stiff, and failure was due to crushing of the concrete near the connectors. Further tests conducted at Washington University are reported in Sen and Galambos (1968). In summary, the findings from this study confirmed those obtained from earlier research programs that are summarized in that report.

The composite floor trusses used in the WTC towers were similar to those that were tested only in the sense that the webs were used as shear connectors. Other than that, they were different in all other aspects, including member sizes and overall lengths. It may have been the first time that this type of floor construction was used in a high-rise building, especially of this size.

[12] See Sec. 1.1 of Sen and Galambos (1968).

5.4.2 Specifications

The contract between the Laclede Steel Company and PONYA, dated October 1967, contained the technical specifications for the trusses (PONYA 1967). The floor trusses, bridging, beams, and bracing supplied by Laclede were to conform to these specifications, and according to Sec. 15 of the contract, PONYA was to inspect these members at Laclede's plant prior to shipment.

According to Sec. 19 of the contract, Laclede was to conform to all orders, directions, and requirements of the Chief of the Planning and Construction Division of the WTC of the World Trade Department of PONYA (referred hereafter, as in the contract, as the "Engineer"), and was to perform the requirements in the contract to the satisfaction of that person. The Engineer also had the power to alter the contract drawings and specifications.

The following is a summary of the requirements in the technical specifications. Unless otherwise noted, referenced section numbers are from the contract (PONYA 1967).

Chapter 0 – General Requirements

The specifications were to prevail in the event that there was a conflict between any requirements in the specifications and the requirements on the contract drawings (Sec. 0.001).

The materials and workmanship that went into the floor trusses and other supplied members were to conform to "the best modern practice" (Sec. 0.003). If the contract drawings, specifications, or directions of the Engineer left any doubt as to what was permissible or failed to note the quality of any construction, the interpretation that called for the best quality of construction was to be followed. Any errors or discrepancies in the contract drawings or specifications were to be reported to the Engineer as soon as possible (Sec. 0.005).

According to Sec. 0.006, Laclede was to comply with all provisions of federal, state, municipal, local, and departmental laws, ordinances, rules, regulations, and orders that would affect the contract.

The contract drawings, as well as the structural details and design sheets, were considered part of the specification (Sec. 0.009).

As a substitute for the design shown in the contract drawings (Sec. 0.009B), which can also be found in Laclede Steel Company (1967), Laclede was allowed to detail and fabricate the floor members in accordance with the design criteria prepared by WSHJ in 1965 (WSHJ 1965) (Sec. 0.009A). These criteria were appended to the contract.

Items to be included and excluded from the contract are contained in Sec. 0.010. Laclede was responsible for the following items:

- Floor trusses
- Bridging trusses
- Transverse beams or angles to support steel deck and power/telephone cells or angles

- Horizontal wind bracing at exterior end of prefabricated floor unit
- Closure strips at top chord of floor trusses and bridging trusses
- Clips and patch plates required by the steel erector to assemble individual components into prefabricated panels
- End bearing connection material for floor truss seats at the exterior column and the core end of the floor trusses
- Connection material at the exterior end for damping units.

Field bolts, assembly of the floor trusses, connections, damping units, and welding electrodes were excluded from the contract.

Chapter 1 – General Provisions

The codes, standards, and specifications cited in the specification are contained in Sec. 101.300. Where specific dates are not cited, the latest edition or revision as of September 1, 1966 was to be used in accordance with Sec. 101.100. Where codes, standards, and specifications given in Sec. 101.300 cite other codes, standards, or specifications, the edition or revision cited shall be used (Sec. 101.200). In cases where specific editions or revisions are not cited, the Engineer had final say over the appropriate edition or revision to use.

The following codes and specifications are listed in Sec. 101.300:

- *Specification for the Design, Fabrication and Erection of Structural Steel for Buildings*, American Institute of Steel Construction, April 1963 (AISC 1963).
- *Code of Standard Practice for Steel Buildings and Bridges, American Institute of Steel Construction*, February 1963.
- *Code for Welding in Building Construction, D1.0-66,* American Welding Society, 1966.
- *Specifications for Welded Highway and Railway Bridges,* D2.0-66, American Welding Society, 1966 (only where specifically noted in the drawings).
- *Standard Specifications for Open Web Steel Joists and Longspan Steel Joists,* Steel Joist Institute and the American Institute of Steel Construction, 1965.

Requirements for the shop drawings are also contained in this chapter of the specifications.

Quality control and inspection requirements are given in Sec. 105. All fabrication and welding of the floor trusses was subject to continual visual inspection, surveillance, and supervision by qualified personnel of Laclede. Details of this quality control plan, which included full-scale load tests on completely fabricated truss components, are given in Chapter 6 of this report.

Chapter 2 – Materials

Steels conforming to the specifications listed in Sec. 201 were approved to be used in the manufacture of the floor trusses. Steels conforming to the ASTM grades A302, A441, A514, and A533 with the specific modifications listed in Sec. 202.100 were also allowed, as were the proprietary grades listed in Sec. 203 with the approval of the Engineer.

Specifications for bolts, welding materials, and structural steel pipe are contained in Secs. 204, 205, and 206, respectively.

Chapter 3 – Fabrication of Structural Steel

Structural steel was to be fabricated as shown in the contract drawings. Fabrication tolerances were to conform to the requirements of the American Institute of Steel Construction (AISC) Specification and American Welding Society (AWS) D1.0 as well as to the requirements in Sec. 304.100. Additional details on the fabrication requirements are contained in Sec. 6.3.1 of this report.

Chapter 4 – Welding of Structural Steel

According to Sec. 401.100, welding was to conform to the requirements of the AISC Specification and AWS D1.0, except where the requirements in these documents were modified or supplemented by information in the contract drawings or the specification.

Welders and welding operators had to pass the applicable AWS qualification tests prescribed in AWS D1.0, Appendix D, Parts II and III. Such tests were to be supervised and witnessed by an outside agency approved by the Engineer. This agency would issue certification papers for the welders based on the results of the tests.

Specific requirements for the welding operations are contained in Secs. 403, 404, and 405.

Chapter 5 – Bolted Structural Joints

All bolts and washers for applicable structural joints were to conform to ASTM A325, except in locations where ASTM A307 or ASTM A490 bolts and washers were specifically called for in the structural drawings (Sec. 501.100).

High-strength bolts and washers were to be installed in conformance with *Specifications for Structural Joints Using ASTM A325 or A490 Bolts*, Research Council on Riveted and Bolted Joints of the Engineering Foundation, 1966.

Chapter 6 – Painting

According to Sec. 601.100, all floor trusses, bridging angles, and incidental structural items in the floor system were to receive a uniform shop coat of protective paint applied within one year or less of the delivery date in accordance to the requirements in this chapter. The protective paint was to be applied by the electro-phoresces process involving a direct current through a deionized water paint bath, which was

to provide an average dry film of 1 mil thickness. Chord angles for trusses were to be cleaned by shot blasting prior to painting (Sec. 602.100).

The shop paint was to be in accordance with Pittsburgh Plate Glass (PPG) Company Standard RF-2184 initial tank charging material with PPG red power primer RF-2184 replenishing material or Laclede Standard Red Chromate Steel Primer, Specification LREP 10001. The red shop paint was to withstand 150 hours of 5 percent salt fog (equivalent to a normal exposure of 18 months) when applied to a clean rolled steel panel at 1 mil dry film thickness. It was to be tested in accordance to ASTM B 117-64 Salt Fog Test, and the maximum failure allowed was to be in accordance with ASTM D 714-56. Other requirements for the painting system and painting of erection marks are contained in Secs. 604 and 605, respectively.

5.5 REFERENCES

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PONYA (Port of New York Authority). 1969. *Viscoelastic Damping Units for North and South Towers*. World Trade Center Contract WTC-224.00. (WTCI-501-L).

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WSHJ (Worthington, Skilling, Helle & Jackson). 1965. *Design Criteria for WTC 1 and 2*. (WTCI-2-L and part of WTCI-50-L).

WSHJ (Worthington, Skilling, Helle & Jackson). 1967a. Structural drawings of WTC 1 and 2, Book 4. (WTCI-17-L).

WSHJ (Worthington, Skilling, Helle & Jackson). 1967b. Structural drawings of WTC 1 and 2. (WTCI-50-L).

WSHJ (Worthington, Skilling, Helle & Jackson). 1967c. *The World Trade Center – Viscoelastic Damping Units*. Report No. DU-1. July (WTCI-17-L).

Chapter 6
FABRICATION AND INSPECTION REQUIREMENTS AT THE FABRICATION YARD

6.1 OVERVIEW

This section contains the fabrication and inspection requirements at the fabrication yard for the structural members in World Trade Center (WTC) 1, 2, and 7.

The discussion in Sec. 2.1.1 of this report points out that the Port of New York Authority (Port Authority or PONYA) instructed the consultants to revise their designs for WTC 1 and WTC 2 to comply with the second and third drafts of the new New York City Building Code (the Code) and to undertake any revisions necessary to comply with such provisions. The Code contains provisions that govern the fabrication and inspection of materials used in buildings. Section 6.2 of this report contains summaries of these provisions as they relate to WTC 1 and WTC 2. Section 6.3 contains summaries of fabrication and inspection requirements obtained from contracts between the Port Authority and the steel fabricators for the towers. Unless otherwise noted, all referenced article and section numbers are from the 1968 New York City Code. Fabrication and inspection requirements pertaining to WTC 7 are contained in Sec. 6.4.

6.2 SUMMARY OF CODE REQUIREMENTS FOR FABRICATION AND INSPECTION

Section C26-1000.7, Materials and methods of construction, gives the requirements for inspection of materials and assemblies in Table 10-1. According to the table, all structural elements and connections of structural steel are not subject to controlled inspection. Footnote c to the table states that mill, manufacturer's, and supplier's inspection and test reports are accepted as evidence of compliance with the provisions in the Code for all structural materials and assemblies not subject to controlled inspection. Therefore, this footnote is applicable to structural steel. Additional information on inspection is provided in Sec. 6.2.2 of this report.

Section C26-1000.7 also requires steel to conform to the provisions in Sub-Article 1005.0, Steel. According to C26-1005.1, structural steel must meet the requirements in Reference Standard RS 10-5, which is the 1963 AISC *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings* (AISC 1963). Reference Standard RS 10-5 also contains modifications that were made to the American Institute of Steel Construction (AISC) Specification. The following sections give summaries of the fabrication and inspection requirements in the AISC Specification, and include the modifications to the requirements as set forth in Reference Standard RS 10-5.

6.2.1 Fabrication Requirements

Section 1.23 of the AISC Specification contains minimum fabrication requirements for the following:

- Straightening material
- Gas cutting
- Planing of edges
- Riveted and bolted construction – holes
- Riveted and high strength bolted construction – assembling
- Welded construction
- Finishing
- Tolerances

One minor modification was made to these requirements, which has to do with the reference made to American Welding Society (AWS) D1.0 (AWS 1964) in Sec. 1.23.6 , Welded Construction.

6.2.2 Inspection Requirements

Section 1.26 in the AISC Specification contains the inspection requirements for structural steel. Reference Standard RS 10-5 deletes this entire section of the AISC Specification.

One of the main requirements given in Sec. 1.26 of the AISC Specification is that "Materials and workmanship at all times shall be subject to the inspection of experienced engineers representing the purchaser." As noted above in this report, C26-1000.7 does not require controlled inspection for structural steel.

Also, Sec. 1.26 of the AISC Specification gives minimum requirements for inspection of welding, which was to be performed in accordance with Sec. 6 of the *Standard for Welding in Building Construction* of the AWS. Table 10-2 in C26-1000.7, which would have governed in the case of WTC 1, 2, and 7, lists the inspection methods for welded and bolted construction, which is based on the ratio of the calculated stresses in the welds or bolts to the allowable stresses.

6.3 SUMMARY OF FABRICATION AND INSPECTION REQUIREMENTS AT THE FABRICATION YARD FOR WTC 1 AND WTC 2

The following sections of this report summarize the fabrication and inspection requirements that were used at the fabrication yard, which were obtained from the major contracts between the Port Authority and the steel fabricators for WTC 1 and WTC 2. In general, the requirements from the specifications in the various contracts are at a minimum equivalent to those in the Code, and in many cases they are more

comprehensive and stringent than the corresponding provisions in the Code. The details of these requirements are summarized in the next sections.

6.3.1 Floor Trusses

As discussed above in Sec. 5.3.2 of this report, the contract between the Laclede Steel Company and the Port Authority contained the specification for the manufacture of the floor trusses that were used in WTC 1 and WTC 2 (PONYA 1967a). Included in these specifications were requirements for fabrication (Chapter 3) and a quality control and inspection program (Sec. 105). General requirements for welding of the structural steel are given in Chapter 4 of the specifications. Applicable sections from the contract are reproduced in Appendix E of this report, starting on page 266.

6.3.2 Box Core Columns and Built-up Beams

The contract between the Stanray Pacific Corporation and the Port Authority (PONYA 1967b) contains the specifications for the box core columns and built-up beams from the 9th story to the penthouse roof. Requirements for fabrication and welding of structural steel are in Chapters 3 and 4 of the specifications, respectively, and inspection and quality control requirements are in Sec. 105 of the contract. These requirements can be found in Appendix E of this report, starting on page 276.

In addition to the inspection requirements in the contract, requirements were also stipulated for inspection, testing, coordination, and supervision by an independent testing agency at Stanray Pacific's fabrication plant. According to Skilling, Helle, Christiansen, & Robertson (SHCR), these additional requirements were necessary because the Port Authority was required by the contract to inspect and accept the members before they left the fabrication yard and because a major portion of the steel used for the members was to be produced in Japan and England.[1] A comprehensive program for "supervision, coordination, inspection, and testing based on the use of the personnel and facilities of a local independent testing agency supervised by a Resident Engineer (a professional engineer employed full time by SHCR)" was attached to the letter sent from Leslie Robertson of SHCR to Malcolm P. Levy of PONYA (see footnote 1). The scope of this program was two-fold:

- To provide PONYA assurance through adequate documentation that fabricated steel conformed to the contract documents and to assure on-time delivery of fabricated steel.
- To provide detailed inspection by checklist and by non-destructive testing prior to final acceptance of the members.

The details of this program can be found in Appendix E, starting on page 301. In particular, the Resident Engineer was responsible for the following items related to supervision:

- Prior to fabrication, performing a complete study of the fabricator's quality control procedures, proposed fabrication procedures, provisions for storage of incoming material, and provisions for loading and shipping of completed building components.

[1] Letter dated June 5, 1967 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-491-L; see Appendix E).

- Acting as liaison between the Port Authority and SHCR with respect to preparation and approval of shop drawings.
- Ensuring proper interpretation of the contract drawings and specifications.
- Directing the work performed by the independent testing agency and its inspectors.
- Performing surveillance of the quality of work on a continuous basis.

With respect to coordination, the Resident Engineer was responsible for the following:

- Examining the approved progress schedule.
- Checking and accepting each unit from the beginning of fabrication through loading for shipment.

The duties of the independent testing agency, which was the U.S. Testing Company of New Jersey, appeared in Appendix I of the draft contract of the United States Testing Company.[2] The duties of the inspectors as outlined in that document were as follows:

- Assist the Resident Engineer in analyzing and cross-checking advance bills of material and certified mill test reports.
- Check each plate upon arrival at the receiving and storage yard for (1) heat number and specification conformance and (2) condition (edge defects, surface defects, and damage).
- Check each built-up member during fabrication for (1) conformance to dimensional and tolerance requirements, (2) defects, (3) conformance to welding specifications, and (4) finishing.
- Final check of built-up members for (1) conformance to dimensional and tolerance requirements, (2) defects, (3) protection of milled surfaces, and (4) accurate and clear marking.

The structural engineer (SHCR) also recommended that an independent testing agency be hired for mill inspection of Japanese steel.[3] The main responsibility of the testing agency was to verify the accuracy of the certified mill testing reports by witnessing tests at the manufacturing mill. Procedures were established for witnessing the tests at both Stanray Pacific and Pacific Car and Foundry (see Sec. 6.3.3 of this report for Pacific Car and Foundry) in the United States. The Port Authority subsequently contracted with Superintendence Inc., an international inspection agency with affiliate firms in Japan and Great Britain who provided the mill inspections in both countries.[4]

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[2] Draft contract between United States Testing Company and PONYA dated August 25, 1967 (WTCI-493-L; see Appendix E for the first page of the contract and Appendix I of this document).

[3] Letter dated April 5, 1967 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-489-L; see Appendix E).

[4] Letter dated September 21, 1967 from R. M. Monti of PONYA to R. E. Morris of the Stanray Pacific Corporation (WTCI-490-L; see Appendix E).

The Port Authority set forth requirements for the independent testing portion of the mill inspection program.[5] The requirements, which were part of PONYA's overall quality control program on fabricated steel for the WTC, depended on whether the steel was from a domestic source or from a foreign source. For steel obtained from domestic sources, the independent testing portion of the mill inspection program consisted of the following:

- For steel with yield points less than 50,000 pounds per inch (psi), one tensile test and one check analysis on samples selected at random from 1 out of 10 heats.
- For steel with yield points of 50,000 psi and higher, one tensile test, one bend test, and a check analysis on samples selected at random from 1 out of 10 heats.

For steel obtained from foreign sources:

- For steel with yield points less than 50,000 psi, one tensile test and one check analysis on samples selected at random from 1 out of 10 heats to performed abroad. In addition, one sample suitable for a tensile test from 1 out of 4 heats was to be shipped by the inspection agency to a laboratory in the United States for tensile testing and check analysis.
- For steel with yield points of 50,000 psi and higher, one tensile test, one bend test, and a check analysis on samples selected at random from 1 out of 10 heats to be performed abroad. In addition, one set of samples suitable for machining into a tensile specimen and a bending specimen was to be selected at random from 1 out of 4 heats and shipped by the inspection agency to a laboratory in the United States for testing.

6.3.3 Exterior Wall from Elevation 363 ft to the 9th Floor Splice

The Pittsburgh-Des Moines Steel Company (PDM) fabricated the column trees, as depicted in Fig. 5–2 of this report, from elevation 363 ft to the 9th floor splice. Specifications were established for both quality control and welding procedures.

The initial quality control and testing program was submitted to PONYA on October 21, 1966.[6] Three subsequent amendments were made to the original program (see Appendix E, page 326) based on comments made by SHCR. The final draft of the quality control program was submitted to PONYA on September 28, 1967 and was subsequently approved by SHCR.

Requirements were also developed by PDM for welding procedures. Different specifications were written by PDM for the different types of welds that were to be used in the manufacture of the column trees. These specifications were reviewed and approved by SHCR, usually after modifications were made by SHCR. The Port Authority gave final approval on the use of the specifications, based on the recommendations from SHCR.[7]

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[5] Letter dated November 13, 1967 from M. R. Monti of PONYA to R. E. Morris of Stanray Pacific Corp. (WTCI-498-L; see Appendix E).

[6] Letter dated October 21, 1966 from PDM to James R. Endler of Tishman Realty and Construction Company Inc. (part of WTCI-745-L [second page and enclosure appear to be missing]; see Appendix E).

[7] Examples of the welding specifications and subsequent approvals that are in WTCI-741-L can be found in Appendix E.

6.4.1 Fabrication

According to Sec. 5A.9.1 of the specifications (WTC 7 Project Specifications 1984), structural steel for WTC 7 was to be fabricated in accordance with the applicable requirements in the following codes and standards:

- New York City Building Code (1968)
- *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings*, AISC
- *Specifications for Structural Joints using ASTM High Strength Bolts, ASTM A 141 Rivets, and ASTM A 307 Unfinished Bolts*, Research Council on Riveted and Bolted Structural Joints
- *Specifications for Structural Joints using ASTM A 325 or A 490 Bolts,* AISC
- *Code of Standard Practice,* AISC (except that the first sentence of Sec. 4, paragraph d shall not apply)
- *Code of Arc and Gas Welding in Building Construction*, AWS Standard Code D1.1, American Welding Society
- *Steel Structures Painting Manual*, Vols. 1 and 2, Steel Structures Painting Council
- *Handbook of Bolts, Nut and Rivet Standards*, Industrial Fasteners Institute

Work was to be of "highest quality" performed by mechanics skilled in the type of work required. Structural steel was to be fabricated and assembled in the shop to the "greatest extent possible."

Mill test reports were to be furnished by the contractor (Sec. 5A.5 of the specification). These reports were to cover the chemical and physical properties of the steel. Also, mechanical and chemical tests were to be performed for all materials regardless of thickness or use. Specifics on these tests are not given in the specifications.

Section 5A.12.14 of the specification contains the following modifications that were made to AWS D1.1:

- The words "except as amended by these Specifications" was added to paragraph 6.7.4.
- A paragraph was added after paragraph 6.19.5.2 that contained additional requirements for evaluation of discontinuities. The ultrasonic testing method was to be used to determine the extent of the discontinuity.
- A paragraph was added after paragraph 6.19.7.1 that contained additional acceptability requirements for weld discontinuities.

6.4.2 Inspection

Section 5A.2.2 notes that there was a separate contract for testing and inspection. This contract was not found. However, specific requirements for inspection of shop and field welds by a testing agency are found in Sec. 5A.12.13 of the specification:

- Examination of welds: All welds shall be visually inspected. All groove welds, except only 25 percent of those at moment connections, shall be examined by the ultrasonic method for 100 percent of their length.

- Lamination testing: Ends of plates, 2 in. or more in thickness, which were to be butt welded, shall be tested for lamination by the ultrasonic method prior to welding.

- Joints in which material is 2 in. or more in thickness shall not have the weld interrupted after operation has started, unless at least two-thirds of its length, or its full depth, has been completed without an interruption of more than one hour. Welding was allowed to be interrupted for longer periods, provided the preheat temperature was maintained for the full length of the joint for the entire time welding was interrupted.

Additional inspection was required when defects were found or suspected (Sec. 5A.12.15). The inspection method to be used was at the discretion of the testing agency. Additional inspection of welds was required when either the structural engineer or the testing agency had reason to question the quality of the weld.

6.5 REFERENCES

AISC (American Institute of Steel Construction). 1963. *Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings.* New York, NY.

AWS (American Welding Society) 1964. *AWS Building Code(changed to Structural Welding Code).* New York, NY

PONYA (Port of New York Authority). 1967a. *Fabricated Steel Floor Trusses, Bridging, Beams and Bracing for Prefabricated Floor Units for North and South Towers*. World Trade Center Contract WTC-221.00. (WTCI-71-I).

PONYA (Port of New York Authority). 1967b. *Fabricated Steel Box Core Columns and Built-Up Beams From the 9th Story Splice to the Penthouse Roof for North and South Towers*. World Trade Center Contract WTC-217.00. (WTCI-244-L).

PONYA (Port of New York Authority). 1967c. *Fabricated Steel Exterior Wall From the 9th Story Splice to Roof for North and South Towers*. World Trade Center Contract WTC-214.00. (WTCI-242-L).

PONYA (Port of New York Authority). 1967d. *Fabricated Steel Rolled Core Columns, Interior Columns, Louver walls Struts and Rolled Beams for North and South Towers.* World Trade Center Contract WTC-226.00. (WTCI-243-L).

WTC 7 Project Specifications. 1984. (WTCI-187-P).

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Chapter 7
INSPECTION PROTOCOL DURING CONSTRUCTION

7.1 OVERVIEW

Construction of World Trade Center (WTC) 1 and WTC 2 was overseen and managed by the Tishman Realty & Construction Company (TRCC), acting as the construction manager. In that role, TRCC as the general contractor coordinated the scheduling of the various activities required on the project, including the day-to-day construction activities at the site. The Port of New York Authority (Port Authority) required that all correspondence pertaining to administration of a prime contractor's contract, including contract changes, matters pertaining to field problems, job progress, and schedule be submitted to TRCC.[1] Karl Koch Erecting Co. (KKE) performed structural steel erection work (WTC Contract 230.00).

Section 5A.14 of the WTC 7 specifications (WTC 7 Project Specifications 1984) contains general erection requirements for fasteners, anchor bolts, column bases, installation, and bracing. No inspection requirements during construction are given in the specifications.

7.2 ERECTION MARKS AND MARKING SYSTEM

To facilitate steel erection, a marking system for structural steel in WTC 1 and WTC 2 was developed by the Port Authority and Nassau Bridge Detailers. This system was to be used by the fabricators to properly identify the different steel members/pieces that went into the towers.[2]

7.3 QUALITY CONTROL AND INSPECTION PROGRAM

A quality control and inspection program was developed by KKE and submitted to the Port Authority for approval. The Port Authority requested that Skilling, Helle, Christiansen, & Robertson review and submit comments on this program.[3]

The quality control and inspection program included information on the following:

- Survey control
- Control of construction and erection loads
- Field welding
- Bolting of structural steel

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[1] General instructions from Malcolm P. Levy of PONYA to prime contractors for WTC contracts (WTCI-239-P; see Appendix F).

[2] General instructions on erection marks and marking system for structural steel from the Port Authority to steel fabricators/suppliers for WTC 1 and WTC 2 (WTCI-495-L; see Appendix F).

[3] Memo dated July 26, 1968 from David L. Brown of PONYA to James White of SHCR (WTCI-515-L; see Appendix F).

- Control of stud welding operations
- Erection procedures
- Control of workmanship
- Control of erection tolerances
- As-built drawings
- Safety programs

A number of problems were encountered during the erection of WTC 1 and WTC 2. These problems typically were due to structural members that did not fit or were not aligned properly. A number of these cases are cited in Chapter 8 of this report.

7.4 REFERENCE

WTC 7 Project Specifications. 1984. (WTCI-187-P).

Chapter 8
DEVIATIONS GRANTED BY THE PORT AUTHORITY

8.1 OVERVIEW

The Port of New York Authority (Port Authority or PONYA) approved numerous deviations to contract drawings and specifications in the fabrication and erection of structural members in World Trade Center (WTC) 1 and WTC 2. The general procedure for deviation requests was as follows. In general, deviations were submitted by the fabricators or erector to the Office of the Construction Manager of the PONYA as a result of difficulties encountered in complying with the contractual requirements for fabrication or erection. Deviations were also requested when, in the opinion of a fabricator or erector, an alternative detail or procedure was warranted. Such requests were usually submitted at the same time to the structural engineer (Skilling, Helle, Christiansen, & Robertson [SHCR]).

Typically, the Office of the Construction Manager approved deviations after SHCR reviewed the details of the deviation and granted their approval. In many cases, SHCR submitted alternative methods, which were incorporated into the deviation.

The deviations that were granted may be categorized into the following groups:

- Fabrication/erection tolerances
- Defective (cracked, laminated, misfit) components
- Fabricator/erector-preferred procedure
- Material substitutions
- Frequency/rate of weld inspections

No variance requests related to the New York City Building Code were found.

8.2 DEVIATIONS RELATING TO FABRICATION/ERECTION TOLERANCES

The following is a list of specific requests relating to deviations for fabrication and erection tolerances of box beams, box columns, and floor trusses.

- SHCR notified the United States Testing Company that the deviation of the end tolerances of column 604-9 was approved.[1] This permitted one flange to be offset 3/16 in. instead of 1/8 in. as specified on page 3-04 of the Stanray Pacific contract (PONYA 1967).

[1] Letter dated December 27, 1967 from Richard Chauner of SHCR to Robert Dempsey of United States Testing Company (WTCI-499-L; see Appendix G).

- SHCR notified the Port Authority that tolerances recommended by Mosher Steel Company (WTC Contract 215.00) for box beams were approved.[2] Approval was also granted for a maximum 1/4 in. twist in the fabrication of box columns.

- SHCR notified Laclede Steel Company that their request for the "hold exact" dimension on the top seat connection at the core end of 20 trusses to less than 4.5 in. was approved, as long as this dimension was not less than 4 in. (see the figure on page 407 in Appendix G)[3] This approval was subject to Laclede's acceptance of rectifying any possible problems with the Karl Koch Erecting Company during erection.

- SHCR notified the Port Authority that the schedule for the maximum allowable tolerances required to set floor truss seats was approved.[4] This was in response to the letter from Karl Koch Erecting Company to Tishman Realty and Construction Company, Inc. outlining their inability to place truss seats in accordance with the contract drawings for type "G" panels on floors 10 through 51 in WTC 1. The letter claimed that Laclede was fabricating C32T6 floor trusses at tolerances that did not permit truss seats to be placed in a plumb position and accurate location. The letter further stated that these discrepancies caused numerous field problems as well as "criticism" from inspection personnel. Approval was also granted for the repair details submitted by Karl Koch Erecting Company for the vertical struts near the ends of 64 of the C32T6 floor trusses fabricated by Laclede.

- SHCR notified the Port Authority that the request by Laclede to change the tolerances for the height above the top chord of the end stiffeners V3 and V4 in floor trusses from 3 in., ±1/8 in. to 3 in., +1/8 in., -3/8 in. was approved.[5] This was done to speed up the fabrication process.

- SHCR notified the Port Authority that the request by Laclede for a tolerance of 3/8 in. for the 2 7/8 in. or 1 3/4 in. dimension at the top chord intersection of the inclined strut of 24T-type floor trusses only was approved.[6]

- The Port Authority notified Laclede Steel Company of numerous changes that were made in the field welding of connections for bridging trusses and bridging angles at panel joints.[7] These changes were instituted after on-site difficulties in field welding were observed in WTC 1 due to misalignment and the addition of erection tolerances in the field. Laclede was also informed of changes that were to be made in their fabrication process to avoid these problems in the future.

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[2] Letter dated December 22, 1967 from James White of SHCR to R. Monti of PONYA (WTCI-499-L; see Appendix G).

[3] Letter dated June 20, 1969 from James White of SHCR to R. Bay from Laclede Steel Company (WTCI-506-L; see Appendix G).

[4] Letter dated November 17, 1969 from James McGuiness of SHCR to R. Monti of PONYA (WTCI-506-L; see Appendix G).

[5] Letter dated October 16, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L; see Appendix G).

[6] Letter dated October 20, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L; see Appendix G).

[7] Letter dated June 16, 1969 from Malcolm Levy of PONYA to Carl Weber of Laclede Steel Company (WTCI-506-L; see Appendix G).

8.3 DEVIATIONS RELATING TO DEFECTIVE COMPONENTS

The following is a list of specific requests relating to deviations for defective components of column trees and floor trusses:

- SHCR notified the Port Authority that the 22 plates that were fabricated for truss connectors that were 1/4 in. narrower than the required width were approved.[8]

- SHCR notified the Port Authority that 160 of the C32T11 floor trusses that were fabricated by Laclede with fillers at the core end of the trusses located approximately 1 in. (2 in. in three cases) closer to the center of the truss than shown in the contract drawings was approved.[9] These floor trusses were originally approved by the inspection company PTL subject to approval by SHCR.

- SHCR notified the Port Authority that the repair procedure submitted by Laclede for the vertical struts of the 32 in. floor trusses was approved.[10] Repair welds were to be made as required after fabrication to adjust the top end of the vertical struts, which had a tolerance of ± 1/4 in.

- SHCR notified the Port Authority that the repair procedure submitted by Laclede for the floor truss bearing ends was approved.[11] Repair welds were to be made to adjust the bearing depth of the seats, which had a tolerance of ± 1/8 in.

- SHCR notified the Port Authority that the method submitted by Laclede for the repair of 24 of the C32T1A floor trusses by double-strutting the diagonal strut on the column end with a 3/4 in. diameter bar was approved.[12] These floor trusses were originally fabricated with 1.09 in. web stock instead of 1.14 in. web stock as shown in the contract drawings.

- SHCR notified the Port Authority that the repair method submitted by Pittsburgh-Des Moines Steel Company (PDM) for laminations in Plate "d" in Panel 230B (part of column tree) was approved.[13]

- SHCR notified the Port Authority that the repair procedure submitted by PDM for a crack that developed in Plate "b" of Panel 300B (tree column) was accepted.[14]

- SHCR notified PDM that the sub-assembly for Column 3, Panel 200B was acceptable as fabricated and may be incorporated into Panel 200B.[15] No other information was found concerning the condition of this sub-assembly.

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[8] Letter dated June 20, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L; see Appendix G).
[9] Letter dated December 15, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L; see Appendix G).
[10] Letter dated July 7, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L; see Appendix G).
[11] Letter dated July 3, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L; see Appendix G).
[12] Letter dated March 31, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L; see Appendix G).
[13] Letter dated June 6, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-736-L; see Appendix G).
[14] Letter dated May 19, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-736-L; see Appendix G).
[15] Letter dated May 5, 1969 from R. Monti of PONYA to H. Fish of PDM (WTCI-735-L; see Appendix G).

- SHCR notified the Port Authority that the repair method submitted for Plate "b" of Panel 339D was approved.[16] No other information was found on the condition of the originally fabricated plates.

- SHCR notified the Port Authority that the repairs proposed by PDM to Panels 227B and 230B (column trees) were approved.[17] Both repairs required the addition of 2 by 1/4 in. bars welded to the original fabricated plates.

- SHCR notified the Port Authority that the repair method proposed by PDM for a crack that developed in Plate "V^R" of Panel 224B was approved.[18]

- SHCR notified the Port Authority that the repair method for laminations in Plate "U_R^L", Panel 130B and Plate "V^L" of Panel 139B was approved, based on the ultrasonic tests performed by PDM.[19]

- SHCR notified the Port Authority that the repair method of Plate "af^L" of Panel 412B submitted by PDM was approved.[20] No other information was found on the reasons why repairs were required on this plate.

- SHCR notified the Port Authority that the repair method for Plate "b" in Panel 339b submitted by PDM was approved, based on non-destructive testing of the repaired plate.[21]

- SHCR notified the Port Authority that the repair method developed by SHCR for a 6 ft long crack in the weld between Plates "a" and "b" in Column 327B (column tree) at elevation +372 ft 6 in. to elevation +378 ft 6 in., which was fabricated by PDM, was successful.[22] A probable triggering mechanism that initiated the crack was the lower ductility of submerged arc weld metal subjected to an undercut notch and possible metallurgical notch along the weld line, coupled with cold weather. Freezing of water in the column was not totally discounted as a possible triggering mechanism, although, according to SHCR, its contribution was believed to be small.

- SHCR notified the Port Authority that the repair procedure for laminations in Plate "d" shown in PDM shop drawing MP506 was approved.[23] These laminations were discovered after the plates were welded into a complete column tree assembly.

- SHCR notified the Port Authority that the weld repair procedure for Plate "V^L" of Panel 209A developed by PDM was approved.[24] The plate was inadvertently cut 6 in. too short when originally fabricated.

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[16] Letter dated March 20, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-738-L; see Appendix G).
[17] Letter dated June 6, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-736-L; see Appendix G).
[18] Letter dated May 16, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-735-L; see Appendix G).
[19] Letter dated June 9, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-736-L; see Appendix G).
[20] Letter dated May 16, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-735-L; see Appendix G).
[21] Letter dated May 16, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-735-L; see Appendix G).
[22] Letter dated July 15, 1971 from James White of SHCR to R. Monti of PONYA (WTCI-736-L; see Appendix G).
[23] Letter dated August 21, 1968 from James White of SHCR to R. Monti of PONYA (WTCI-740-L; see Appendix G).

- SHCR notified the Port Authority that the repair method for the butt welds at 18 separate locations in corner panels 100A, 200A, 300A, and 400A proposed by PDM was approved.[25]

Twenty-three additional deviations, which from a structural point of view would be considered less significant than those covered above, were found in documents labeled as WTCI-490-L, WTCI-506-L, WTCI-735-L, WTCI-748-L, WTCI-748-L, WTCI-756-L, WTCI-759-L, and WTCI-736-L through WTCI-739-L.

8.4 DEVIATIONS RELATING TO ALTERNATE FABRICATION/ERECTION PROCEDURES

The following is a list of specific requests relating to deviations for alternate fabrication and erection procedures of core columns, floor trusses, exterior wall columns, and beam seats:

- The Port Authority notified the Stanray Pacific Corporation that their request to splice core columns every 18 ft was approved.[26]

- The Port Authority notified the Laclede Steel Company that their request to use Hobart automatic CO_2 welding equipment and procedure was approved, provided that the requirements of the contract documents were met.[27]

- SHCR notified the Port Authority that the elimination of clipped corners of stiffener plates in the exterior wall columns, as proposed by Pacific Car & Foundry, was approved.[28]

- SHCR notified the Port Authority that 8 by 6 by 1 in. angles were approved to be used for beam seat types 7440 through 7494 instead of 8 by 6 by 7/8 in. angles, which were originally required in the contract drawings for Pacific Car & Foundry.[29]

8.5 DEVIATIONS RELATING TO PRODUCT SUBSTITUTIONS

The following is a list of specific requests relating to deviations for product substitutions in the exterior wall:

- SHCR notified the Port Authority that 24 steel plates with yield strengths ranging from 42 ksi to 100 ksi were allowed to be substituted for specific plates that were originally fabricated by Pacific Car & Foundry for use in the exterior wall.[30]

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[24] Letter dated October 7, 1968 from James White of SHCR to R. Monti of PONYA (WTCI-738-L; see Appendix G).

[25] Letter dated October 18, 1968 from James White of SHCR to R. Monti of PONYA (WTCI-739-L; see Appendix G).

[26] Letter dated September 21, 1969 from R. Monti of PONYA to W. Gibson of Stanray Pacific Corporation (WTCI-490-L; see Appendix G).

[27] Letter dated October 16, 1969 from R. Monti of PONYA to Robert Bay of Laclede Steel Company (WTCI-506-L; see Appendix G).

[28] Letter dated December 15, 1967 from James White of SHCR to R. Monti of PONYA (WTCI-748-L; see Appendix G).

[29] Letter dated May 26, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-756-L; see Appendix G).

[30] Letter dated May 2, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-756-L; see Appendix G).

- SHCR notified the Port Authority that 3/4 in. thick plates may be substituted for 5/8 in. and 1/2 in. thick plates shown on the drawings for Plate TD7 of the top spandrels at reference level D (7th floor level) fabricated by PDM.[31]

- The Port Authority notified PDM that they were granted approval to increase the plate thickness for certain "E-1" plates for 11 specified columns.[32]

- The Port Authority notified PDM that they were allowed to use Lukens American Society for Testing and Materials (now ASTM International) A 441 Modified steel for 36 plates in lieu of the steel originally specified.[33]

8.6 DEVIATIONS RELATING TO INSPECTION PRACTICE

The following is a list of specific requests relating to deviations in inspection practice for the exterior wall and welds:

- SHCR notified the Port Authority that the PDM request to revise the radiographic inspection provisions that were included in the PDM control program as they relate to the full-penetration butt weld joining of spandrel plate D4 and E3 was not approved.[34] Instead, SHCR suggested an alternate program to be followed.

- SHCR notified the Port Authority that the Stanray Pacific request to revise their quality control program with respect to the minimum inspection rate for welds was approved.[35]

8.7 REFERENCE

PONYA (Port of New York Authority). 1967. *Fabricated Steel Box Core Columns and Built-Up Beams From the 9th Story Splice to the Penthouse Roof for North and South Towers*. World Trade Center Contract WTC-217.00. (WTCI-244-L).

[31] Letter dated June 11, 1968 from James White of SHCR to R. Monti of PONYA (WTCI-739-L; see Appendix G).
[32] Letter dated December 18, 1967 from R. Monti of PONYA to H. Fish of PDM (WTCI-745-L; see Appendix G).
[33] Letter dated December 18, 1967 from R. Monti of PONYA to H. Fish of PDM (WTCI-745-L; Appendix G).
[34] Letter dated May 3, 1968 from James White of SHCR to R. Monti of PONYA (WTCI-742-L; see Appendix G).
[35] Letter dated April 18, 1968 from James White of SHCR to R. Monti of PONYA (WTCI-483-L; see Appendix G).

Appendix A
SUPPORTING DOCUMENTS FOR CHAPTER 2

This appendix contains the supporting documents that are referenced in Chapter 2 of this report. All of the documents contained in this appendix are reproduced with permission of The Port Authority of New York and New Jersey. Table A–1 contains a summary of supporting documents and their location within this appendix. The footnote numbers given in the table correspond to those in Chapter 2.

Table A–1. Supporting documents for Chapter 2.

Footnote Number	Document Title	Page(s)
	Section 2.1 – Building Codes Used In Design	
1	Letter dated May 15, 1963 from Malcolm P. Levy (Chief, Planning Division, World Trade Department) to Minoru Yamasaki (Minoru Yamasaki & Associates)	132
2	Letter dated February 18, 1975 from Joseph H. Solomon (Emery Roth & Sons) to Malcolm P. Levy (Chief, Planning Division, World Trade Department)	133
3	Letter dated September 29, 1965 from Malcolm P. Levy (Chief, Planning Division, World Trade Department) to Minoru Yamasaki (Minoru Yamasaki & Associates)	136

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EMERY ROTH & SONS
850 THIRD AVENUE, NEW YORK, N.Y. 10022 (212) 753-1733

RICHARD ROTH, Sr., F. A. I. A.
HARRY J. HARMAN, A. I. A.
RICHARD ROTH, Jr., A. I. A., R. I. B. A.
JOSEPH H. SOLOMON, A. I. A.

JULIAN ROTH
ADMINISTRATION
ESTELLE BEAL
CONTROLLER
PHILIP MARTINES
CHIEF DRAFTSMAN

February 18, 1975

Mr. Malcolm P. Levy
General Manager
World Trade Center Operations
Port Authority New York, New Jersey
1 World Trade Center
New York, New York 10047

RE: WORLD TRADE CENTER

Dear Mal:

In accordance with the instructions issued by the Port Authority at the start of the project, construction drawings for the World Trade Center were to conform with requirements of the Building Code of New York City, and any variations therefrom were to be called to the attention of the Port Authority for final decision and authorization. This procedure has been followed in production of the contract drawings and, with the exceptions authorized by the Port Authority noted below, the drawings are in accordance with the new Building Code adopted in December, 1968. The Building Department reviewed the tower drawings in 1968 and made six comments concerning the plans in relation to the old code. Specific answers noting how the drawings conformed to the new code with regard to these points were submitted to the Port Authority on March 21, 1968.

We were instructed by the Port Authority to deviate from code with respect to the following areas:

1. Omission of vents from closed shafts. Noted to the Port Authority by letter dated April 20, 1967.

2. Demising partitions to stop at suspended ceiling or bottom of truss instead of running from slab to slab. Noted to the Port Authority by letters dated November 9, 1967 and June 6, 1969 with response on December 12, 1967. Prior instruction on procedure from Port Authority dated January 26, 1966.

3. Omission of fire protected openings on exterior walls with separation of less than 30 feet. Noted to Port Authority by copy of letter to MYA dated January 26, 1966.

4. Treatment of concourse level as "Underground Street" noted by letter to the Port Authority on April 6, 1971, January 11, 1972 and May 7, 1973.

Fire detection and protection requirements specified for the World Trade Center meet or exceed Building Code requirements prior to the adoption of Local Law #5. Most other office towers in the City of New York meet the minimum code requirements:

A. Telephone system for Fire Department use connecting pump room and gravity tank room with all floors. A six inch gong provided at permanent telephone at pump room, first floor and gravity tank room. Telephone jacks at all other floors protected by break glass boxes.

B. Standpipe signalling device: an eight inch gong located in the pump room and every 10 floors in the elevator shaft; an approved closed circuit strap key enclosed in a sheet metal box at each telephone station for fire department use.

The Building Code permits the use of louvered doors on toilet rooms, janitor and electric closets located in 1 hour rated corridors. There is no size limit specified for the louver, but the Board of Standards and Appeals permits louvers of 2 square feet in 3/4 hour rated doors (which are required in 1 hour rated partitions). Up until about 1968 most office buildings had 1 hour minimum rated enclosures and louvered doors in telephone closets and sleeves or small slots through the floor. Since 1968, about 25 percent still have louvers in the doors. In more recent buildings the floor openings have been slabbed over.

Since corridor construction is required by code to be 1 hour rated, it follows that louvered doors were acceptable in tele-

phone closets. Corridor partitions in the Trade Center Towers, however, were designed to meet 2 hour rated construction at the request of the Port Authority, to forestall any problems with dead end limitations in the new code. It would require investigation of individual floor tenant layouts to determine if the dead end limitation of 50 feet for 1 hour construction has been exceeded.

The original contract drawings, dated 7/31/67 and the Contract Bid Sets dated 12/18/67 and 2/9/68 indicate 2 hour rated enclosures for the telephone closets with louvers in a FPSC, 1-1/2 hour label door. The hollow metal door specification written in 1967 and received by the Port Authority on 10/24/67 called for fusible link dampers on louvers in labeled doors. Letters to the Port Authority dated 8/23/67 and 9/6/67 indicated that variances had been obtained for omission of dampers and requested instruction regarding this advice. The requirement for dampers was deleted from the final draft of the specification reviewed by the P.A. in May, 1968. Requirement to meet provisions of underwriter's labs, B.S.A. and Building Department was retained, however, for doors with F.P.S.C. and hourly ratings.

Based on Port Authority comments on drawings received 4/17/69 and pursuant to a letter from the Port Authority to Tishman Construction Company dated 4/28/69 instructing that such changes be made, the wall of the telephone closet was changed to 1 hour rated construction on 5/23/69 and the door was changed to F.P. with a 1-1/2 hour rating. Since the telephone closet was no longer a shaft with a 2 hour rated enclosure, all floor openings left for future installation of cables had to be firestopped. This admonition was reiterated in a letter to the Port Authority dated June 25, 1973.

Please inform us if any additional information is desired.

Sincerely,

EMERY ROTH & SONS

Joseph H. Solomon

JOSEPH H. SOLOMON

JHS:am
CC: Mr.R. Monti, Chief Engineer/ PA

6211
R 110-4

THE PORT OF NEW YORK AUTHORITY

111 Eighth Avenue at 15th Street New York NY 10011

620-8233

WORLD TRADE CENTER

Malcolm P. Levy
CHIEF, PLANNING DIVISION

Richard C. Sullivan
DIRECTOR

September 29, 1965

Mr. Minoru Yamasaki
Minoru Yamasaki & Associates
1025 East Maple Road
Birmingham, Michigan 48011

Dear Yama:

We have decided to adopt the new Building Code presently existing in second and third draft form for The World Trade Center.

The Roth office is requested to revise floor plans as quickly as possible and on an accelerated basis to comply with the provisions of this code. It is my understanding that the

Appendix B
SUPPORTING DOCUMENTS FOR CHAPTER 3

This appendix contains the supporting documents that are referenced in Chapter 3 of this report. All of the documents (with the exception of the Laclede Steel Company correspondence) contained in this appendix are reproduced with permission of The Port Authority of New York and New Jersey. Table B–1 contains a summary of supporting documents and their location within this appendix. The footnote numbers given in the table correspond to those in Chapter 3.

Table B–1. Supporting documents for Chapter 3.

Footnote Number	Document Title	Page(s)
	Section 3.3 – Damping Unit Tests	
2	Letter dated June 22, 1967 and enclosure from Don Caldwell of 3M to Peter Chen of SHCR (WTCI-501-L; reproduced without appendices that are contained in WTCI-501-L)	139
3	"Test Program for World Trade Center Viscoelastic Damping Units," by Stephen H. Crandall of MIT, May 20, 1968 (WTCI-501-L)	146
4	"Test of Viscoelastic Damping Units for World Trade Center Tower Buildings," S.H. Crandall and L.E. Wittig, April 23, 1969 (Box 9, 233 Park Ave.)	158
5	Letter dated August 29, 1968 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-501-L)	179
6	Letter dated May 22, 1969 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-501-L)	182
7	Letter dated June 2, 1969 from Stephan H. Crandall of MIT to John M. Kyle of PONYA (WTCI-501-L)	185
8	"World Trade Center Report No. DU-3, Viscoelastic Damping Units," by SHCR, June 2, 1969 (WTCI-501-L; reproduced without appendices that are contained in WTCI-501-L)	189
9	Letter dated November 5, 1971 from Malcolm P. Levy of PONYA to Don Caldwell of 3M (WTCI-513-L)	196
	Section 3.4 – Floor Truss Tests	
10	Letter dated April 3, 1969 from David B. Neptune of the Laclede Steel Company to W.C. Borland of PONYA (WTCI-503-L)	197
11	Internal Laclede Steel Company memo dated May 15, 1969 from David B. Neptune to R.D. Bay (part of WTCI-82-I)	198
12	Internal Laclede Steel Company memo dated September 7, 1967 from J.R. Paul to A.C. Weber (WTCI-85-I)	202
13	Letter dated August 10, 1967 from A. Carl Weber of the Laclede Steel Company to Wayne Brewer of SHCR (WTCI-235-L)	203
14	Letter dated April 19, 1968 from Wayne A. Brewer of SHCR to R.M. Monti of PONYA (WTCI-87-I)	205
15	Internal Laclede Steel Company memo dated March 18, 1969 from David B. Neptune to R.D. Bay (part of WTCI-82-I)	207
	Section 3.5 – Stud Shear Connector Tests	
16	Letter dated November 3, 1969 from James White of SHCR to Lester S. Feld of PONYA (part of WTCI-253-L)	208
17	Contract dated January 6, 1970 from Guy F. Tozzoli of PONYA to Roger G. Slutter of the Fritz Engineering Laboratory, Lehigh University (part of WTCI-253-L)	210

GENERAL OFFICES • 2501 HUDSON ROAD • ST. PAUL MINNESOTA 55119 • 331-733-1110

I. Introduction

Vibrational motion of tall buildings and structures can be damped out by the employment of dampers as non-load carrying elements in the structure.

Most of the dampers are designed so that they convert part of the mechanical energy into heat and thus reduce the amplitude of motion. The medium in which this transfer of energy takes place is generally either a viscoelastic material or liquid.

In this report we discuss only a particular damper employing a viscoelastic material as the damping medium.

II. Damper Shape and Desired Characteristic

In general the damper is comprised of two viscoelastic layers bonded between three rigid surfaces, planar on at least one surface (Figure 1).

The damper will be placed such that the application of the load generates shear deformation in viscoelastic material such as shown in Figure 1.

Due to specific requirements of the World Trade Center, the dampers should meet the following requirements within the temperature range 72-78°F and up to 50% R.H. (see technical specification).

a. Average Stiffness

The damper should have a total average stiffness of at least 12,000 lbs. axial load at the specified frequency of 0.1 C/sec. and at a deflection of 0.02".

b. Average Loss Factor (tan δ)

The average damping factor or loss tangent should be at least 0.6 at 0.1 C/sec.

c. Fatigue

After 100 cycles at 20×10^{-3} amplitude and 0.1 C/sec. G" shall not decrease by more than 20% when the damper temperature has returned to its initial value (first cycle).

d. Ultimate shear strength

The damper, when loaded in shear should be able to withstand 48,000 lbs. of load - this includes both static plus dynamic load.

e. Static and dynamic deformation

Maximum amplitude of vibration i.e. viscoelastic shear deformation will be around 20×10^{-3} inches dynamic and 30×10^{-3} inches static.

In order to fullfill the above mentioned requirements a viscoelastic material with the proper dimension was selected. Figure 1 shows the actual damper with all the dimensions.

III. Test Objective and Procedure

a. Test objective

For the purpose of establishing the effectiveness and the efficiency of dampers the following properties were selected for evaluation.

1. G", loss shear modulus as a function of temperature (T) and fatigue cycle (N).

2. W_1 and W_{100} and W_t, work done in the first and one hundreth cycles and total work done in 100 cycles respectively.

3. Temperature rise accompanying fatigue (100's and 1000 cycles).

4. Loss tangent as a function T and N.

5. G' and G* storage and complex shear modulus as a function of T and N.

6. Total heat production in viscoelastic material.

7. Ultimate shear strength.

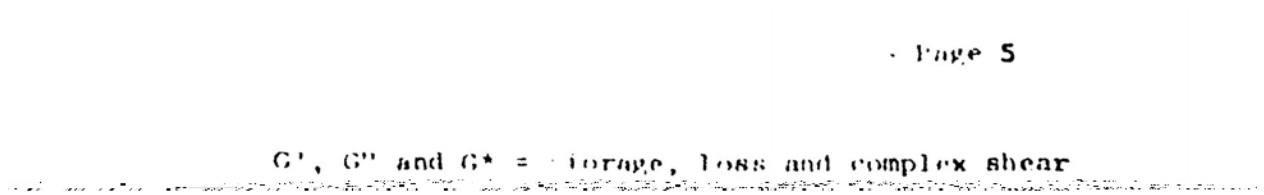
b. Test procedure

Twenty-two full size dampers were prepared for testing. For the purpose of monitoring the temperature of viscoelastic material in the damper a thermocouple was imbedded in the center of viscoelastic part as shown in Figure 2.

The shear deformation was detected by an L.V.D.T.

IV. Analysis of Test Results

The results obtained from these tests were in the form of hysteresis loops (H.L.) - force vs. displacement as shown in


Page 5
G', G" and G* = Storage, loss and complex shear

and the heat generated Q_t is

$$Q_t = W_{total}/778.2 \text{ BTU}$$

The total heat generated Q_t can be divided into two parts,

Test Program

for

World Trade Center Viscoelastic Damping Units

Proposed by

Stephen H. Crandall

May 20, 1968

1. Test Samples

Fifty-two sample damping units shall be fabricated and delivered to the Acoustics and Vibration Laboratory, Room 5-024, M.I.T. These units shall be identical to those which are to be supplied for installation in the World Trade Center towers under Contracts WTC-219.00 and WTC-224.00, except that each test sample shall have one thermocouple embedded in the viscoelastic material. The thermocouple specifications shall be delivered to Professor Crandall.

The test samples shall be numbered according to a random pattern and ten of the units shall be sent to the Port of New York Authority for storage and subsequent testing for aging effects.

2. Test Objectives

The major portion of the test shall be devoted to determining the statistical distribution of the following basic mechanical properties of the damping units:

Loss factor for steady cycling at 0.1 Hz.

Dynamic stiffness for steady cycling at 0.1 Hz.

Ultimate load when deformed at the rate of 0.5 in. per min.

Ultimate displacement when deformed at the rate of 0.5 in. per min.

Thirty samples shall be tested to determine these properties. Before beginning these tests four samples shall be cycled for 10,000 cycles (if failure does not occur earlier) to determine the possibility of fatigue failures for the dampers. If fatigue failures do occur in these four samples, it will be proposed that some of the thirty samples for the basic

statistical tests be used to obtain additional fatigue information (after loss factor and dynamic stiffness measurements have been made). These samples will not then be available for the ultimate load test under deformation at the rate of 0.5 in. per min. The decision as to how many samples to divert to fatigue testing in this manner shall be made by Professor Crandall in consultation with all interested parties.

In addition to the fatigue test and the basic test for statistical distribution, supplementary tests shall be made on the remaining eight samples to obtain additional engineering information concerning the behavior of the damping units. These supplementary tests are designed to elicit information on how the energy absorbtion of a damper is affected by:

(i) Preload on the damper.

(ii) Preliminary high frequency cycling.

3. Test Facilities

All cycling tests shall be performed on a special test frame in which one or two damping units can be cyclically deformed as the structure is sheared by a motor-driven eccentric. The test frame shall simulate the average local elasticity of the damping-unit connectors in the World Trade Center towers. The amplitude of the test-frame deformation shall be controlled by the size of the eccentric. The amplitude of the damping unit deformation depends on the dynamic stiffness of the damping unit and will vary from element to element and will vary with temperature for any one element. Damping unit test amplitudes shall be specified in terms of an equivalent amplitude measured on a steel dummy unit whose

stiffness is 650,000 pounds per inch. The frequency of the cycling shall be controlled by the choice of sprockets in the chain drive between the motor-driven reducer and the eccentric drive-shaft. Forces in the damping units shall be measured by strain-gage load cells and deformations of the units shall be measured by L.V.D.T.'s. Force-displacement curves shall be recorded on an on-line X-Y plotter. The special test structure shall be disassembled at the conclusion of the tests and sent to the New York Port Authority for storage.

The ultimate load tests shall be performed on a manually operated hydraulic testing machine with a capacity of 100,000 pounds. The instrumentation shall be the same as in the cycling tests. The operator shall endeavor to maintain the rate of deformation at a nearly uniform rate as close as possible to 0.5 in. per min. The actual rate of deformation shall be recorded.

4. Specifications for Fatigue Tests

These tests on four units chosen at random shall be performed prior to the basic statistical tests described in Section 5 below.

(a) The cycling rate shall remain within ± 2% of a fixed value lying within the range from 0.08 to 0.11 Hz (4.8 to 6.6 cycles per minute).

(b) The mean load on the damping unit during a cycle shall be zero.

(c) The cyclic amplitude of the test-frame displacement shall remain within ± 2% of a fixed value lying within the following ranges.

(i) Two damping units shall be tested with equivalent

amplitudes in a range from 0.018 to 0.022 inches.

(ii) Two damping units shall be tested with equivalent amplitudes in the range from 0.027 to 0.033 inches.

(d) The ambient temperature and humidity and the temperature of the viscoelastic material shall be recorded at hourly intervals during the fatigue tests.

(e) Force-displacement curves for each specimen shall be recorded by an on-line X-Y plotter at hourly intervals during the fatigue tests. Clocktime and cycle number shall be noted.

(f) If at the end of 10,000 cycles a unit has not obviously failed and its force-displacement curve has not altered dramatically the cycling shall be stopped and the unit shall be removed from the cycling test structure and placed in the ultimate-load test machine. There it shall be subjected to an approximately uniform rate of deformation as near to 0.5 in. per min. as possible. Force and displacement shall be recorded until failure occurs.

If all four units survive 10,000 cycles and if their subsequent ultimate loads are each greater than 35,000 pounds it shall be concluded that fatigue is not a serious hazard and no further considerations shall be given to fatigue in this test program.

If, however, one or more of the four units fail to meet the above requirements, it shall be necessary to consider very carefully whether additional fatigue testing should be carried out. Such additional fatigue tests would be carried out (on random samples from the 30 basic statistical test-samples) in lieu of the ultimate-load test.

5. Specifications for Basic Statistical Tests

These tests shall be performed on thirty specimens. To determine dynamic properties of the damping units under uniform cycling each sample shall by cycled for 100 cycles at a uniform rate. The sample shall then be allowed to cool down to its initial temperature before going through two additional cycles. Force-displacement curves and temperature data shall be recorded as described below. After the cycling test each sample shall be deformed to failure in an ultimate-load test (if additional fatigue testing is decided upon, some fraction of the samples shall be given fatigue tests in lieu of ultimate load tests).

The following specifications apply to the tests for dynamic properties under uniform cycling.

(a) The cycling rate shall remain within ± 2% of a fixed value lying with the range from 0.08 to 0.11 HZ (4.8 to 6.6 cycles per minute).

(b) The mean load on the damping unit during a cycle shall be zero.

(c) The cyclic amplitude of the test-frame displacement shall remain within ± 2% of a fixed value lying within the following ranges.

(i) Twenty units shall be tested with equivalent amplitudes in the range from 0.018 to 0.022 inches.

(ii) Ten units shall be tested with equivalent amplitudes in the range from 0.027 to 0.033 inches.

(d) The ambient temperature and humidity and the temperature of the viscoelastic material shall be recorded for the 1^{st}, 10^{th}, 20^{th}, 50^{th}, 100^{th} and 101^{st} cycles for each specimen.

(e) Force-displacement curves shall be recorded by an on-line

X-Y plotter for the 1st, 2nd, 10th, 20th, 50th and 100th cycles for each specimen. At the end of the 100th cycle, the deformation shall be suspended until the viscoelastic material returns to its initial temperature, plus or minus 0.2° F. The time required to reestablish the initial thermal condition shall be recorded. Then cycling shall be resumed for an additional two cycles. Force-displacement curves for cycles 101 and 102 shall be recorded.

The following specifications apply to the ultimate-load test.

(f) The damping units shall be transferred from the cyclic-test frame to a 100,000 pound hydraulic test machine. Half of the units shall be tested in tension and half in compression.

(g) Ambient temperature and humidity and the temperature of the viscoelastic material shall be recorded at the beginning of each ultimate-load test.

(h) The testing machine shall be manually controlled to provide a nearly uniform rate of deformation as near as possible to 0.5 inches per minute.

(i) Force-displacement curves to failure shall be recorded on an on-line X-Y plotter. The time history of displacement shall also be obtained.

(j) Failure modes shall be noted and photographed where informative.

6. Supplementary Tests

Four specimens shall be tested to investigate the effect of preload on the energy absorbtion of the damping units. These tests shall be

similar to the cycling portion of the basic test with the exception that instead of cycling about a mean load of zero the cycling shall take place around non-zero tensile and compressive loads.

The specifications for the preload test are given below.

(a) The cycling rate shall remain within ± 2% of a fixed value lying with the range from 0.08 to 0.11 Hz (4.8 to 6.6 cycles per minute).

(b) The damping units shall be inserted into the test frame in such a manner that the mean deformation of the element during the cycle takes on the following values.

(i) One unit shall be tested with a cyclic mean equivalent elongation in the range between 0.009 and 0.011 inches.

(ii) One unit shall be tested with a cyclic mean equivalent elongation in the range between 0.018 and 0.022 inches.

(iii) One unit shall be tested with a cyclic mean equivalent compression in the range between 0.009 and 0.011 inches.

(iv) One unit shall be tested with a cyclic mean equivalent compression in the range between 0.018 and 0.022 inches.

(c) The cyclic amplitude of the test frame shall remain within ± 2% of a fixed value which shall produce an equivalent amplitude within the range from 0.018 to 0.022 inches.

(d) The ambient temperature and humidity and the temperature of the viscoelastic material shall be recorded for the 1^{st}, 10^{th}, 20^{th}, 50^{th}, 100^{th} and 101^{st} cycles for each specimen.

(e) Force-displacement curves shall be recorded by an on-line X-Y plotter for the 1^{st}, 2^{nd}, 10^{th}, 20^{th}, 50^{th}, and 100^{th} cycles for each

specimen. At the end of the 100th cycle, the deformation shall be suspended until the viscoelastic material returns to its initial temperature, plus or minus 0.2° F. The time required to reestablish the initial thermal condition shall be recorded. Then cycling shall be resumed for an additional two cycles. Force-displacement curves for cycles 101 and 102 shall be recorded.

Four specimens shall be tested to investigate the effect of higher frequency cycling on the energy absorbtion of the damping units. Each specimen shall by cycled for ten cycles at the standard amplitude and frequency. Then the frequency shall be increased and the amplitude decreased (or left unchanged) and the units cycled for 100 cycles before returning to the standard amplitude and frequency. Force-displacement curves shall be recorded before and after the high frequency cycling as described below.

Specifications for the high-frequency test are given below.

(f) All four specimens shall be cycled for ten cycles at a fixed frequency between 0.08 and 0.11 Hz with an equivalent amplitude between 0.018 and 0.022 inches.

(g) Ambient temperature and humidity and the temperature of the viscoelastic material shall be recorded for the 1st and 10th cycles.

(h) Force-displacement curves shall be recorded on an on-line X-Y plotter for the 1st and 10th cycles.

(i) For two samples the equivalent amplitude shall be decreased to a fixed value within the range from 0.009 to 0.011 inches and the cycling frequency shall be increased to

(i) A value between 0.23 and 0.27 Hz for one sample.

(ii) A value between 0.46 and 0.54 Hz for one sample.

For the other two samples the equivalent amplitude shall be maintained within the range 0.018 to 0.022 inches and the cycling frequency shall be increased to

(iii) A value between 0.23 and 0.27 Hz for one sample.

(iv) A value between 0.46 and 0.54 Hz for one sample.

The specimens shall be cycled for 100 cycles at the higher frequencies indicated.

(j) Ambient temperature and humidity and the temperature of the viscoelastic material shall be recorded at the 1^{st}, 10^{th}, 20^{th}, 50^{th} and 100^{th} high-frequency cycles.

(k) Force-displacement curves shall be recorded for the 1^{st}, 50^{th}, and 100^{th} high-frequency cycles.

(l) The frequency and equivalent amplitude for each specimen shall now be returned to the values established in (f) above. The time elapsed while making this change shall be noted. The specimens shall then be cycled for ten cycles as in (f). The measurements in (g) and (h) shall be repeated.

7. Report of Test Results

The dynamic characteristics of the viscoelastic damping units as determined by these tests shall be reported as follows. For each of the parameters listed below a statistical distribution diagram shall be given along with values for the mean and standard deviation.

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(a) For the first and one hundred and first cycles of steady cycling at nominal frequency of 0.1 Hz and nominal equivalent amplitude of 0.02 inches (and 0.03 inches) the following parameters.

(i) Dynamic stiffness

(ii) Loss tangent

(iii) Energy dissipated

(b) For ultimate testing at a nominal rate of displacement of 0.5 inches per minute (tension and compression) after previously enduring 102 cycles at nominal frequency of 0.1 Hz and nominal equivalent amplitude of 0.02 inches (and 0.03 inches) the following parameters.

(i) Ultimate strength in pounds

(ii) Ultimate deformation in inches

The results of the fatigue investigation shall be described. Either the ability of these units to endure repeated loadings shall be verified or an S-N type diagram shall be given.

The results of the preload investigation shall be described. The

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In addition to giving dynamic characteristics for the damping units separately a discussion shall be given of the cyclic test frame and its

Test of Viscoelastic Damping Units for World Trade Center Tower Buildings

by S. H. Crandall
L. E. Wittig

Summary

Tests have been performed on 39 samples of the viscoelastic damping units proposed by 3-M for the World trade Center Towers to determine the distribution of their mechanical properties and to ascertain their effectiveness under a range of off-design operating conditions. It was found that although there is considerable variability of properties from unit to unit in a batch and from one batch to another, the energy absorbing capabilities of the elements are generally adequate to provide the expected damping under design conditions and that the elements do perform satisfactorily under limited variations of loading conditions

TABLE OF CONTENTS

I. Introduction

In order to control the tendency of the World Trade Center Towers to sway under the action of high winds it is planned to increase the inherent structural damping of the buildings by attaching viscoelastic damping elements at the major structural joints connecting floors and columns. The damping elements are bolted between the columns and the lower members of the floor trusses in such a way that the elements are forced to elongate (or shorten) whenever the buildings sway. These damping

In addition to the standard test, 19 additional tests were performed to investigate the endurance capabilities of the elements and to investigate their operation under conditions different from the design conditions prescribed in the standard tests. The conditions tested included variations in amplitude and frequency, variations in ambient temperature and the effect-of-superposing a static preload on the simple harmonic loading employed in the standard cycling test.

The principal differences between the standard cycling tests of this report and those of reference [1] arise from the differences in test facilities. The tests of Reference [1] were performed in a servo-controlled testing machine which maintained a fixed (single) ampli-

stiffness of 600 kips/inch was measured and c e equivalent amplitude. During the actual tests the elongation amplitude for the viscoelastic elements were greater or less than the equivalent amplitude depending on the stiffness of the element under test. Three different sized eccentrics were employed. The standard tests were performed using an eccentric which produced an equivalent amplitude of 0.019 inches. The other eccentrics produce equivalent amplitudes of 0.010 inches and 0.023 inches. The frequency of cycling during the standard tests was approximately 0.1 Hz (actually 0.0989 Hz). This corresponds to a period of 10 seconds per cycle (actually 10.11 seconds per cycle). Other tests were also run at two and a half times this frequency, and at five times this frequency.

II. Description of Tests

A. Test Frame

All cyclic tests were performed on a special test frame (see Fig. 1). This special frame was constructed for these tests because it was felt that the damping units should be tested in a structural

with 1-inch diameter A490 bolts in single shear on one end and with 7/8 inch diameter A325 bolts in double shear on the other end, corresponding to their installation in the buildings. A 1300 ft-lb. impact wrench was used to tighten the bolts (see Fig. 5) according to turn-of-the-nut regulations [2]. The main requirement of these regulations is

During a standard test the damping units were cycled 100 times and data was taker on the 1st, 2nd, 10th, 20th, 50th and 100th cycles. The units were then allowed to relax for 20 minutes and more data was taken on the 101st and 102nd cycles.

Damper extensions and contractions were measured with an LVDT (linear variable differential transformer).. The LVDT was mounted as shown in Fig. 3 so that the total motion between the two ends of the damper was measured along the central axis. It should be noted that in this respect these tests differ from those of 3-M where only the relative motion between two internal points within the damper was measured. The axial force applied to the damper was measured with a strain gage dynamometer located in the angles that connect the dampers to the truss. The temperature of the viscoelastic layer was monitored by a thermocouple embedded in the viscoelastic material. The LVDT and the force gage were calibrated for each test.

Outputs from the LVDT and the force gage were fed into the same x-y recorder shown on the left of Fig. 6. Because of the viscoelastic behavior of the damper there is a phase shift between the force signal and the elongation signal. The phase shift causes the force-elongation plot to form a closed hysteresis loop during each cycle of oscillation. The area of the loop is directly proportional to the energy dissipated during the cycle. The loss factor and the dynamic stiffness of the damper can also be determined from this plot. The output from the thermo-

C. Special Cycling Tests

Besides the standard statistical tests, some additional cyclic tests were performed to determine further properties of the damping units. Four different types of tests were carried out: (i) endurance tests, (ii) preload tests, (iii) higher frequency tests, and (iv) one endurance test at an elevated temperature.

The purpose of the endurance tests was to check the fatigue life of the damping units. These tests were quite smmilar to the standard tests described earlier except that the total number of cycles was much greater. Two tests were run with an equivalent amplitude of

the standard equivalent amplitude of 19 mils. The frequency of the forced oscillation was then changed to either 0.25 Hz or to 0.50 Hz; the equivalent amplitude was either held the same or reduced to 10 mils. The specimens were cycled 100 times under these new conditions. After these 100 cycles the frequency wss returned to 0.10 Hz and the equivalent amplitude was returned to 19 mils. The specimens were cycled 10 more times to see if there was any noticeable change in the damper properties since the original 10 cycles.

The last special cyclic test that we performed was an endurance type test with the exception that the ambient temperature was 10°F above the normal 75°F. The results of this single test were discussed in some detail in a preliminary report which is included here as Appendix D.

D. Ultimate Load Tests

All of the damping units from the standard statistical tests and the endurance tests were subjected to an ultimate load test. The ultimate load test consists of stretching or compressing the dampers until they are physically broken. The purpose of these tests was to see if the specimens still met the acceptance levels established by 3M Company after they had been through the cyclic tests. These tests were performed on a manually controlled hydraulic testing machine with a capacity of 200,000 pounds (Figs. 7, 8). The axial force and elongation of the damper were recorded on an x-y recorder during the test. An additional x-y recorder was used to monitor the rate of axial elongation of the specimen. This rate of axial extension was held as close as possible to 0.5 inches per minute. Half of the specimens from the standard statistical tests were broken in tension and half were broken

in compression. All of the specimens from the endurance tests were broken in tension. The grips for these tests used 1 inch diameter A490 bolts in single shear at one end of the specimen and 7/8 inch diameter A325 bolts in double shear at the other end. From the recorded results statistical information on the ultimate loads and the ultimate extensions of the dampers has been obtained.

III. Results of Tests

A. Standard Statistical Tests

The major portion of this test program was devoted to measuring some basic mechanical properties of the damping units. The damping unit properties that were obtained are their loss factor, dynamic stiffness, ultimate load, and ultimate extension. The amount of energy dissipated per cycle by the dampers and the amplitude of the periodic displacement between the ends of the damping units was also measured. Statistical distribution curves for the dynamic stiffness, loss factor, energy absorbed per cycle and the amplitude of the periodic displacement are given in Figures 9, 10, 11 and 12. The results of the ultimate load tests are discussed in Section III-C. For sake of comparison, results of tests conducted by 3M Company are included in the same figures.

The data used for the statistical information of this investigation was taken from measurements made during the tenth cycle of oscillation. Hysteresis loops recorded during first and second cycles were usually not closed, and therefore, data from these first two cycles is not as accurate as data from the tenth cycle. Also, since it is quite probable that oscillation of the Trade Center Towers will occur in groups of several cycles (this is typical of narrow band random vibration), we feel that the tenth cycle information is more meaningful. The results of tests

The effect of misaligning the damper specimen in the test frame was also investigated. Misalignments of the order of 1/4 inch, so that the dampers can be easily pushed into place by hand, appear to have a negligible affect on the amount of energy which the dampers absorb.

For the benefit of future users of the test frame, a sample of the data reduction for a standard test has been included in Appendix B.

B. Special Cycling Tests

Four different endurance tests were conducted. Two of these tests were run with an equivalent amplitude of 10 mils, and two were run with an equivalent amplitude of 19 mils. The results of a low amplitude test are shown in Figure 14. As can be seen, the properties of the damping element did not change appreciably in the course of 10,000 cycles. The properties did fluctuate somewhat, but this was probably due to small changes in the ambient temperature. During the second low amplitude endurance test, the frequency of oscillation was increased so that the total rate of energy dissipation would be about the same as it was during the high amplitude endurance tests. Even after this higher rate of energy dissipation the specimen did not appear to be damaged.

The results of a high amplitude (19 mils equivalent amplitude) endurance test are shown in Figure 15. These results show that there is some definite damage to the damper at about the 1000th cycle. This test was probably too severe. SHCR estimate that on the average there will be only 15 cycles a year with amplitudes greater or equal to to amplitude used in this test. Furthermore, the test frame used in these tests tends to overstretch the damper when it softens (see Appendix A). For the above reasons it appears that chances of fatigue failure of the dampers are unlikely.

All of the tests conducted for this report were made with the assembly bolts of the dampers in a finger tight condition. After the element mentioned above had fatigued, we found that tightening the assembly bolts seemed to restore some of the life of elements. Also, we found that if the assembly bolts were only finger tight before the element was bolted into the test frame, then vibration caused by the impact wrench completely loosened them. For these reasons we highly recommend that the assembly bolts of the damping units be kept tightened at all times. We also checked to see if tightening the assembly bolts affected the amount of energy dissipated by the dampers, and found that tightening them decreased the energy dissipated about 10%.

The preload tests indicated that forcing the dampers to oscillate about a nonzero mean displacement does not appear to reduce their effectiveness. The average energy dissipated during the 10th cycle of the preload tests was 581 in. lbs., whereas the average energy dissipated

was tested in tension. Two peaks appear in the load-elongation curve (Fig. 17) because after one side of the element separated the other side continued to load for a while longer. The displacement vs. time curve (Fig. 18) shows that the rate of elongation was quite close to the desired 0.5 inch per minute.

Statistical distribution curves for the ultimate loads and ultimate extensions of dampers from the standard statistical tests are shown in Figures 19 and 20. The results of 13 tests conducted by 3M Company and reported in Reference 1 are also shown.

It may be noted that the average ultimate load (47.7 kips) that we measured is greater than the value (45 kips) stated in the Qualification Requirements [3]. The spread of the distribution is quite large. The standard deviation (9.3 kips) is sufficiently large that had these dampers been representative of the samples used to determine Acceptance [3] there is a good chance that the initial sample would not meet the manufacturing control limit for ultimate shear strength. In our tests half of the units were broken in tension and half were broken in compression. The average ultimate load for the tension units only was 51.0 kips and the average ultimate load for the compression units only was 44.4 kips. The average for both tension and compression was 47.7 kips.

The most common mode of failure for the specimen was separation at the bond between the metal and the viscoelastic material. All of the elements that were tested in tension, and about half of the elements tested in compression, failed in this manner. Another mode of failure that occurred during the compression tests was for the viscoelastic bond to break on one side of the element and then for the other side of the element to buckle (Fig. 21). Only one element that was tested buckled

on both sides. The buckling and the breaking of the viscoelastic bonds were the only modes of failure that occurred.

Ultimate load tests were also conducted on the elements from the endurance test. The two elements from the low amplitude (10 mils equivalent amplitude) endurance tests both broke at loads that were slightly higher than the average ultimate load of 47,700 lbs. However, the two elements from the high amplitude (19 mils equivalent amplitude) endurance tests broke at loads of 22,000 lbs. and 14,000 lbs. which is considerably lower than average. This further verifies that prolonged cycling of the damping units at high amplitudes does result in permanent damage.

IV. Conclusions

The most important characteristic of the damping elements is their capacity to absorb energy under oscillations at amplitudes and frequencies which are probable for the World Trade Center Towers. Ideally they should absorb adequate energy no matter when the oscillations occur or what the ambient conditions are during the oscillations. In our tests we have not been able to cover all possible operating conditions but we have shown that this particular batch of elements do absorb an average of W = 574 inch-lbs under standard test conditions with respect to amplitude, frequency and temperature. Furthermore, the energy absorbtion is not significantly impaired by modest variations in amplitude, frequency and temperature.

Our major concern in the beginning centered around the endurance capability of the elements. We found that the elements could withstand 10,000 cycles of 10 mils equivalent amplitude with no indication of permanent damage. At large equivalent amplitudes (19 and 23 mils) we did

obtain evidence that prolonged cycling caused a growing breakdown of the bond between the viscoelastic material and the steel which was reflected by a reduction of the element's stiffness and its ultimate load capacity. See data for Specimens No. 3, No. 4 and No. 5. In spite of the alteration of properties which occurs we conclude that the units will provide adequate energy absorbtion for at least 1000 cycles of 19 mils equivalent amplitude at temperatures in the vicinity of 75°F. When the ambient temperature is in the vicinity of 85°F the bond breakdown is apparently accelerated somewhat. At this temperature (see Appendix D) it appears that the units will provide adequate energy absorbtion for 500 cycles of 19 mils equivalent amplitude. If present estimates of the number of large oscillations to be expected are not excessively optimistic, it does not appear that there is any real danger of a loss in element effectiveness due simply to the accumulation of cycles of oscillation.

An unknown factor is the effect of aging on the viscoelastic elements. Our tests were completed within a six month period. We had no opportunity to observe any long time deterioration of the elements.

Another unknown factor is the effect of extreme heat or extreme cold on the viscoelastic elements.

When the elements are installed in the towers it is essential that the bolts be tightened meticuluosly. Any slip in the joints would vitiate the usefulness of the dampers. Careful alignment of the element attachment points should be maintained. Our tests indicated that up to 1/4" of misalignment did not affect the energy absorbtion capability of the element. We recommend that the element assembly bolts be tightened with a small hand wrench after installation rather than being left finger-tight. This may decrease the energy absorbed by the element in small amplitude cycles by up to 10 percent but it will serve to protect

the element against deterioration under large amplitude cycles.

Because of the wide spread in damper properties from batch to batch and from unit to unit within a batch, it is suggested that a program of testing sample units be instituted to check on element parameter values as the various batches are delivered. The most important single parameter is the energy dissipated in a cycle of 10 seconds duration under a known equivalent amplitude. It is this parameter which is directly proportional to the increase in overall tower damping ratio provided by the damping unit. It would be desirable if W, the energy loss per cycle, for 19 mils equivalent amplitude was never less than 400 inch lbs. A desirable average value of W for all batches would be 575 inch lbs. (i.e., about the same as that of the batch reported on here).

V. Suggestions for Further Testing

A program of periodic testing of random samples of installed elements and of the stored unused elements should be instituted. All the endurance tests performed so far have been accelerated life tests. The effect of the passage of years on used or unused elements is still an unknown factor.

The calcualted effectiveness of the dampers depends on the magnitude of the local frame stiffness almost as much as it does on the damping unit parameters. If the local frame stiffness were only 200 kips/inch instead of the design value of 600 kips/inch (as was the case for the test frame) the energy absorbed by the damper would only be one-fourth of that predicted. In the case of the test-frame this was compensated for by using a larger eccentric. In the actual towers no such compensation is possible. Therefore, it seems imperative to check

the actual stiffness of the local frame at a few typical damping element locations as soon as possible. If the actual frame stiffness is significantly smaller than the design stiffness the damping units would have to be redesigned. To measure the local frame stiffness one could substitute a turnbuckle and a forcegage for the damping unit and then use the LVDT from the test frame to measure the contraction as the turnbuckle was tightened.

There are a number of tests which would be very interesting to the profession and which would be useful for the benefit of future designers. These are listed below in the order of their desirability.

1) The natural frequencies, damping ratios and mode shapes of the towers should be measured. These can be measured in a few days time by simultaneously recording the outputs of two sensitive seismometers placed at various locations in the buildings and then digitally processing the tapes. Such a service is available from the Structural Sciences Division of Earth Sciences (A Teledyne Company). See literature in Appendix E. The damper oscillation has been designed on the basis of a natural mode and natural frequency computed during the early design of the building and on the basis of an educated guess as to the inherent damping of the towers. A comparison with the measured values would be very informative.

2) Permanent recorders should be installed near the tops of both buildings to monitor the motions (acceleration levels) throughout a period of several years. This would provide valuable feedback for the elaborate wind tunnel and statistical studies which were employed to arrive at the levels of motion used in the design of the damper installation. This would also give the building owner increasing confidence in the sway resistance of his building (if the design is in fact successful and the motion amplitudes remain small).

There are slow speed tape recorders which go continuously and only need to have the tape changed once every three months, and there are other instruments like strong motion seismographs which remain inactive most of the time and only begin to record when a certain threshold level is reached. See Appendix E for literature.

3) One or two damping units in the towers could be modified so that they could provide force and motion signals at the damper which could be compared with the tower motion. In the simplest modification all that would be necessary would be to replace the pair of angle irons running from the element to truss by the instrumented angle irons from the test frame. The force and elongation signals would provide energy loss loops which permit an estimation of how much damping the viscoelastic units were actually providing. These results would be even more meaningful if the local building frame stiffness had been verified in situ with a turnbuckle as described above.

References:

1. SHCR Report No. DU-1, The World Trade Center Viscoelastic Damping Units, July 17, 1967.

2. Specification for Structural Joints Using ASTM A325 or A490 Bolts. Approved by Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation, September 1, 1966. Endorsed by American Institute of Steel Construction, Inc. Endorsed by Industrial Fasteners Institute.

3. Technical Specifications for Visco-Elastic Damping Units for the World Trade Center, 3786.

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

August 29, 1968

Mr. Malcolm F. Levy
Port of New York Authority
World Trade Center Planning
111 Eighth Avenue
New York, New York 10011

Reference: The World Trade Center
MIT Test Program

Dear Mal:

On the afternoon of August 28, 1968, the writer visited MIT to examine the damping unit test rig and to evaluate progress to date.

First, in response to inquiries from MIT, the writer transmitted the following information:

1. All high-tensile bolts must be tightened using the turn-of-the-nut technique.

2. For 1" ASTM A490 bolts, required torque could be 1400 ft-lbs or higher.

3. Washer requirements for ASTM A325 high-tensile bolts are as follows:

   a. With holes 1/16" larger than the nominal bolt diameter, no washers are required.

   b. For all other cases, 7/16" thick plate washers are required under both bolt head and nut.

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4. Washer requirements for ASTM A490 high-tensile bolts are as follows:

   a. With holes not more than 1/8" larger than the nominal bolt diameter, standard hardened washers are required under both bolt head and nut.

   b. For all other cases, 1/2" thick plate washers are required under both bolt head and nut.

This information was given to Mr. Larry Wittig, as Professor Crandall was not expected in the laboratory for the remainder of the week.

Next, the equipment was examined and the following comment submitted to Mr. Wittig:

1. The quality of welding varies from poor to inexcusable. Every defect known to the writer and detectable by casual visual examination was found in profusion. Since stress levels are very low, the quality of welding may not adversely affect test results. Still, the writer recommended that key welds be cleaned by wire brush and examined from time to time throughout the test program.

2. The device intended to provide transverse stability is totally inadequate if stiffness in the transverse direction is required. Suitable techniques for improving the transverse stiffness were proposed, should remedies be required.

3. The basic geometry of the "trusses" is far from ideal. The writer pointed out eccentricities which should affect truss stiffness by a substantial margin. Such eccentricities, of course, will not exist in the building construction.

4. The lack of adequate stiffness in the test frame was discussed. The introduction of flange bending, the effects of stress concentration and the like, and the effects of the quality of welds (see 1. above) on the behavior of the frame were discussed in some detail.

5. Mr. Wittig pointed out that the drive bearing lacked the capability to resist side thrust and that his repeated efforts had been unsuccessful in preventing the drift of the bearing. This drift results in a sudden impact on the test rig, causing transverse oscillation and rendering the rig useless. Mr. Wittig stated that he was prepared to order a new bearing and that delivery of such bearing should be accomplished within a week.

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Brewer
Consultants
Harold L. Worthington
Joseph F. Jackson

May 22, 1969

Port of New York Authority
World Trade Center Planning
111 Eighth Avenue
New York, New York 10011

Attention: Mr. Malcolm P. Levy

Reference: The World Trade Center
Damping Units

We have reviewed the report, "Test of Viscoelastic Damping Units for World Trade Center Tower Buildings", by S. H. Crandall and L. E. Wittig, dated April 23, 1969. This is an excellent report confirming in a general way the test results obtained by SHCR-3M. Also, this report gives additional data which are relevant to an evaluation of the performance of the damping units in the system environment of the intended installation.

From the photographs of the specimens in Figures 8 and 21, we surmise that

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Port of New York Authority
Attention: Mr. Malcolm P. Levy - 2 - May 22, 1969

9.3 kips and that this combination of values would have failed to meet the Acceptance Requirements proposed in our letter dated May 2, 1969. The results of the compression tests conducted by 3M Company had a mean of 54.1 kips with a standard deviation of 4.5 kips and these values would meet the proposed requirement of mean Ultimate Strength = 45.0 +1.5 (S.D.) kips in compression. This comment should be considered prior to forwarding copies of this document to 3M for shop use. Also, when conditions will permit

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Port of New York Authority
Attention: Mr. Malcolm P. Levy -3- May 22, 1969

We note that our copy of this report does not include Appendix E. We assume that other omissions, if any, have no bearing on the conclusions of the report.

We will report to you further as our proposals for additional testing become solidified. In the interim, should you have further questions

STEPHEN H. CRANDALL
PROFESSOR OF MECHANICAL ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE MASSACHUSETTS

June 2, 1969

Mr. John M. Kyle, Chief Engineer
The Port of New York Authority
111 Eighth Avenue at 15th Street
New York, New York 10011

Dear Mr. Kyle:

This letter is written in response to the letter from Mr. L. E. Robertson of SHCR dated May 22, 1969, and addressed to Mr. M. P. Levy. In his letter Mr. Robertson raises some questions in connection with our report "Test of Viscoelastic Damping Units for World Trade Center Tower Buildings" by Crandall and Wittig, April 23, 1969. I shall try to answer these questions.

ultimate load registered on the dial of the testing machine (this value is noted at the bottom of figures such as Fig. 17) and the peak of the force-displacement curve. The greatest discrepancies (specimens 14 and 16) occurred where compressive failure was accompanied by large amounts of buckling. The measured

The LVDT would be moved from station to station until the influence coefficient was no longer measurable. Using superposition and this set of influence coefficients it is a simple matter to predict the deflection of the entire truss-system when loaded uniformly at all the stations. If time is available it would be desirable to repeat the entire measurement at other "typical" locations

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THE WORLD TRADE CENTER
Report No. DU-3
VISCOELASTIC DAMPING UNITS

Introduction

The importance of the action of wind on tall buildings has been generally recognized for many years. This action was traditionally conceived and treated as static forces by the community of building designers. However, measurements on existing buildings by various investigators have shown that the responses of tall buildings to strong wind are predominantly dynamic. More recently, the static and dynamic responses of the twin towers of The World Trade Center were studied by means of static and aeroelastic models in a micro-meteorological wind tunnel [1]. The experiments showed that, for the wind directions critical for the structural design, the deflections, and hence the stresses, are primarily caused by dynamic oscillation of the building. It has been established that the amplitudes of the oscillation are inversely proportional to the square root of the critical damping ratio for lightly damped buildings in turbulent wind.

The critical damping ratios intrinsic in buildings were measured by several researchers. A table of the data found in the literature is included in Appendix 1. Based on the reported data, it was estimated that the intrinsic critical damping ratio of The World Trade Center towers is [redacted] for design against excessive stresses. In order to increase the mechanical damping of the towers, viscoelastic damping units were developed for installation in the floor system. These damping units have been

described previously in Report DU-1 [2]. The viscoelastic damping units

June 2, 1969 Page 3

TABLE I

References

1. The World Trade Center Wind Report, Final Chapter, July, 1966, by Worthington, Skilling, Helle, & Jackson, Consulting Engineers, New York, N. Y. (now Skilling, Helle, Christiansen, Robertson).

2. Viscoelastic Damping Units, Report No. DU-1, The World Trade Center, July 17, 1967, by Skilling, Helle, Christiansen, Robertson, Consulting Engineers, New York, N. Y.

3. Test of Viscoelastic Damping Units for World Trade Center Tower Buildings, April 23, 1969, a report to The Port of New York Authority by S. H. Crandall and L. E. Wittig.

THE PORT OF NEW YORK AUTHORITY

World Trade Department

November 5, 1971

Minnesota Mining & Manufacturing Corp.
3M Center
St. Paul, Minnesota 55101

Attention: Mr. Don Caldwell

Re: THE WORLD TRADE CENTER - CONTRACT WTC-224.00 -
TESTING OF 12 DAMPING UNITS REMOVED FROM
FLOORS 26, 27, 29 & 30 - TOWER A

Gentlemen:

This will confirm oral information given to you by our Mr. Feld on 11/4/71:

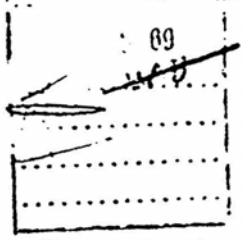
3M is to perform an equivalent Acceptance Test series on the subject group of units (see Schedule X1 attached). These units were all installed in November of 1970 and remained in place for the past year in unheated space throughout a "cold" winter. We are attempting to ascertain if the units have actually been affected by the "cold" and are in fact capable of passing an equivalent acceptance test. The number and sequence of testing for loss factor and stiffness, fatigue loss and ultimate strength are to be determined by 3M.

We would appreciate your expediting this series of tests upon receipt of the units. All work is to be performed under the unit price provisions for testing under the subject Contract. Please advise this office as to your testing schedule.

Sincerely,

Malcolm P. Levy

cc: Messrs. W. Borland, D. Brown, P. Chun(SHCR), I. Feld, R. Monti, J. White(SHCR), F. Wernecke - all w/att.



Laclede Steel Company

General Offices Arcade Building

St. Louis, Missouri 63101

CONTRACT WTC-221.00
WORLD TRADE CENTER
THE PORT OF NEW YORK AUTHORITY
LACLEDE CONTRACT 67-J-31301

Mr. W. C. Borland
Coordinator of Construction
The World Trade Center
The Port of New York Authority
111 Eighth Avenue
New York, New York 10011

DATE April 3, 1969

TRANSMITTAL LETTER NO. 10

TRANSMITTAL OF FLEXURAL TESTS

Transmitted herewith is one copy each of the sequentially numbered flexural test reports listed below. Submission is in accordance with the sixth paragraph of Paragraph 105.102 "Resistance Welding" of our Contract WTC-221.00.

Flexural Test No.	Date of Test
23	12/17/68
24	12/17/68
25	12/17/68
26	12/19/68
27	12/19/68
28	12/31/68
29	12/31/68
30	1/ 7/69
31	1/ 7/69
32	1/ 7/69
33	1/24/69
34	1/24/69
35	1/24/69

For Robert D. Bay
Director of Technical Services

CC: ✓ Mr. James White
Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10017

Mr. Al Guttentag, Project Engineer
Tishman Realty & Construction Co., Inc.
30 Church Street - 11th Floor
New York, New York 10007
(COPY NOT SENT)

May 15, 1969

R. D. BAY

RE: WTC-221.00
FLEXURAL TESTS
SHIPMENT NO. 2

The results of all Flexural Tests performed for Shipment No. 2 are shown on the attached sheet 1 of 2 dated May 15, 1969. This sheet shows the comparative deflections for incremental loads of 500 lbs. for each truss tested. Sheet 2 of 2 gives the backup data for Sheet 1.

David B. Neptune

1p

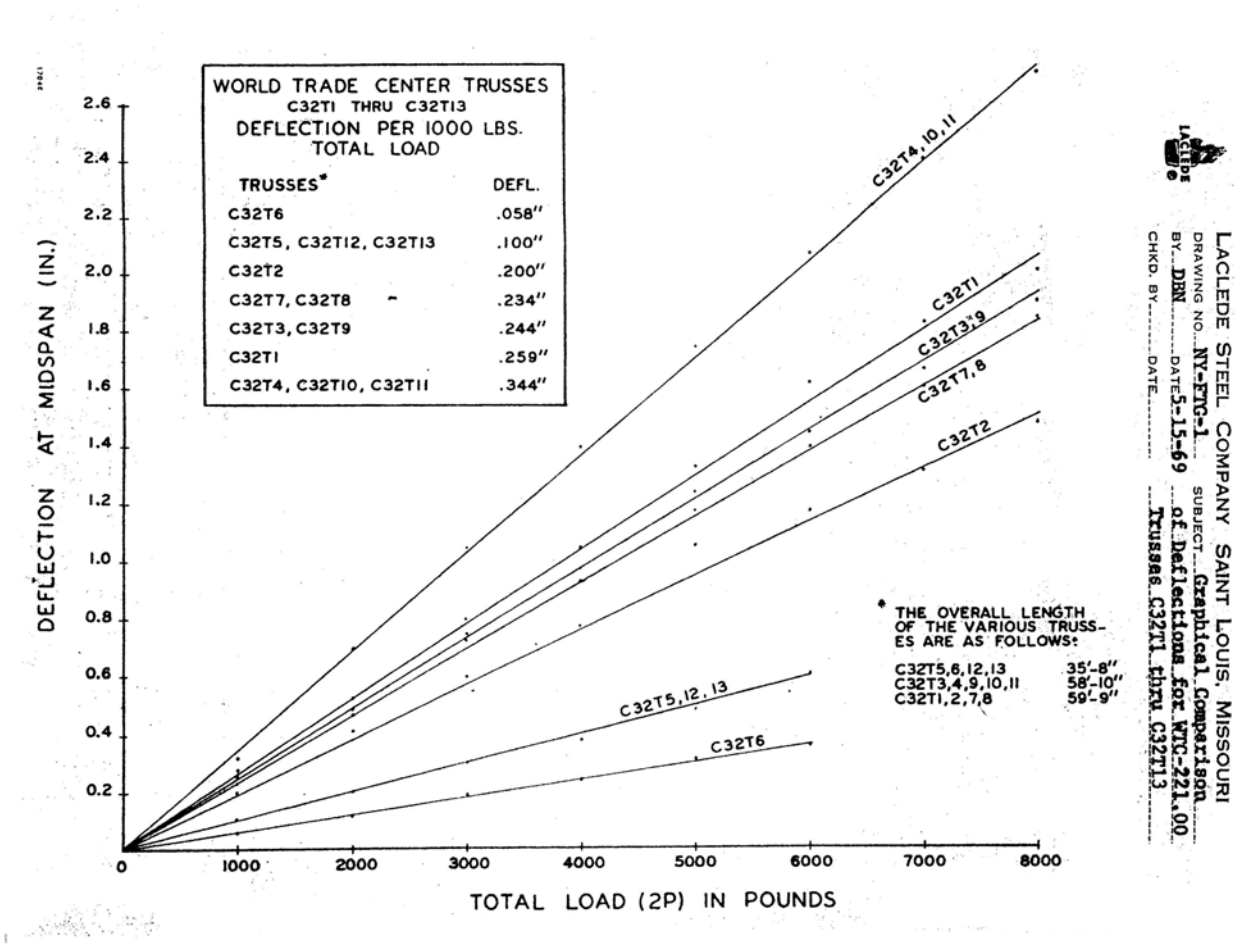
WORLD TRADE CENTER
FLEXURAL TESTS
NOS. 23 THRU 40

May 15, 1969
Page 1 of 2

Comparative Deflections+ in Inches for
Incremental Target Loads of 500 Pounds

(1)	(2)	(3)	(4)										
TRUSS MARK NO.	TEST NO.	DESIGN DEFL In.	DESIGN LOAD Psf	TARGET LOAD IN POUNDS (5)									
				500	1000	1500	2000	2500	3000	3500	4000	4500	5000
C32T1A	24	2.000	58	.246	.551	.802	1.060	1.335	1.605	1.910	2.170	2.447	2.751
C32T2A	23	2.063	62	.207	.408	.595	.775	.997	1.165	1.335	1.535	1.752	1.962
C32T3	27	2.063	62	.262	.490	.715	.995	1.178	1.414	1.646	1.888	2.120	2.367
C32T4	29	0.750	62	.370	.708	1.029	1.357	1.683	2.033	2.372	2.743	-	-
C32T5	33	0.375	54	.104	.201	.299	.395	.500	.602	-	-	-	-
C32T6	35	0.938	62	.064	.118	.171	.226	.279	.334	.390	.446	-	-
C32T7A	25	2.063	62	.281	.510	.747	.977	1.227	1.440	1.675	1.920	2.174	2.437
C32T8A	26	2.000	62	.286	.541	.807	1.083	1.321	1.575	1.839	2.122	2.400	2.700
C32T9	28	1.938	62	.261	.501	.742	.983	1.233	1.462	1.700	1.943	2.208	2.445
C32T10	30	1.688	62	.360	.711	1.042	1.371	1.699	2.023	2.377	2.729	-	-
C32T11	31	1.313	62	.400	.742	1.070	1.414	1.756	2.095	2.437	2.793	-	-
C32T12	32	0.250	62	.113	.204	.293	.385	.478	.570	-	-	-	-
C32T13	34	0.438	62	.109	.199	.289	.378	.467	.554	-	-	-	-
C32T14AL	38	2.000	58	.281	.565	.841	1.103	1.377	1.649	1.921	2.226	2.490	2.812
C32T16AL	39	2.063	62	.273	.511	.738	.977	1.214	1.465	1.716	1.987	2.241	2.519
C32T21L	40	1.375	62	.416	.765	1.117	1.464	1.825	2.165	2.575	2.917	-	-
C32T23L	36	0.375	54	.116	.224	.326	.430	.533	.638	-	-	-	-
C32T26L	37	0.875	62	.072	.134	.195	.258	.322	.387	.449	.513	-	-

+Values represent maximum deflection at midspan


WORLD TRADE CENTER TRUSSES
C32TI THRU C32TI3
DEFLECTION PER 1000 LBS.
TOTAL LOAD
TRUSSES* DEFL.
C32T6 .058"
C32T5, C32TI2, C32TI3 .100"
C32T2 .200"
C32T7, C32T8 .234"
C32T3, C32T9 .244"
C32TI .259"
C32T4, C32TI0, C32TI1 .344"
DEFLECTION AT MIDSPAN (IN.)
TOTAL LOAD (2P) IN POUNDS
C32T4,10,11
C32TI
C32T3,9
C32T7,8
C32T2
C32T5,12,13
C32T6
* THE OVERALL LENGTH OF THE VARIOUS TRUSSES ARE AS FOLLOWS:
C32T5,6,12,13 35'-8"
C32T3,4,9,10,11 58'-10"
C32TI,2,7,8 59'-9"
LACLEDE STEEL COMPANY SAINT LOUIS, MISSOURI
DRAWING NO. NY-ENG-1 SUBJECT Graphical Comparison
BY DBN DATE 5-15-69 of Deflections for WTC-221.00
CHKD. BY DATE Trusses C32T1 thru C32T13

NOTES

(1) There are three different lengths of trusses tested. These three lengths are shown below along with the mark numbers of the trusses which have that particular length.

59'9"	58'11"	35'8"
C32T1A	C32T3	C32T5
C32T2A	C32T4	C32T6
C32T7A	C32T9	C32T12
C32T8A	C32T10	C32T13
C32T14AL	C32T11	C32T23L
C32T16AL	C32T21L	C32T26L

(2) Refer to this test number to obtain more information about the truss and the test results.

(3) Refer to S.H.C.R. drawing number 7-AB1-54 dated 2-15-68 and revised 11-25-68 which gives the camber at midspan for each type of 32" truss.

(4) Refer to Laclede Contract WTC-221.00 (October, 1967) pages TF1-2, 3, 4 and 21. Design loads were not given for trusses C32T14AL, 16AL, 21L, 23L and 26L. Their design loads were obtained from Gene Chorny of S.H.C.R.

(5) Two equal, concentrated loads were applied to each truss. Each load was applied at a panel point. The target load shown in the Table on page one is the magnitude of each applied concentrated load; the total load on the truss would be double this value. This target load is not the actual load at which the deflection listed below it occurs because the load cell reading in pounds does not equal the load applied to the truss by each hydraulic jack. The target load is very close to the actual load and is used for clarity in the table. The corresponding actual load for each target load is as follows:

Target Load	Actual Load
500	499.8
1000	999.6
1500	1499.8
2000	1999.2
2500	2499.0
3000	2998.8
3500	3498.6
4000	3998.4
4500	4498.2
5000	4998.0

For information on testing procedures, equipment used and positioning of loads for each truss, refer to Flexural Test Sheets Nos. 23 thru 40.

CC: R. D. Bay
J. R. Paul

September 7, 1967

A. C. WEBER

WORLD TRADE CENTER
SHEAR KNUCKLE TEST

Enclosed are Sheets 1 and 2 dated September 7, 1967.

Sheet 1 of 2 gives the results of transverse loading of shear knuckles. Lightweight concrete similar to the type to be used on the World Trade Center was used in this test. Specimen #2 (compressive strength of 2600 psi at 27 days) failed at 30,100#. Support brackets were not used on this test and rotation of the slabs obviously lowered the ultimate capacity. Specimen #1 had a 6 day compressive strength of 1330# and a total shear capacity of 37,070#. The side slabs were restrained from rotation on Specimen #1. The average shear transfer per knuckle for the two tests was 16,800#.

Sheet 2 of 2 gives the results of longitudinal loading of shear knuckles. Standard concrete (average strength of 3800 psi) was used in this test. The average maximum load resisted by five specimens was 55,230# or 27,615#/shear knuckle.

J. R. Paul

sak

Laclede Steel Company

General Offices, Arcade Building

St. Louis, Missouri 63101 August 10, 1967

Mr. Wayne Brewer
Skilling, Helle, Christiansen
and Robertson
230 Park Avenue
New York, New York 10017

Dear Wayne:

Shear Connectors
World Trade Center Floor Trusses

We are sorry that you could not get to St. Louis last Tuesday to witness some of the testing on the shear members and the application of the fireproofing to the painted open web trusses.

I presume Jim White has told you about the application of the insulating material on the joists which apparently worked very well.

In our conversation with the plastering contractor who handled the test application and the representatives of the Zonolite Division of the W. R. Grace Company, it seems that the loss because of the round webs was far less than they anticipated and total loss of material with the system as they applied it would be under 15%. This application involves less material than a solid section of the same dimensions and is no different from angle or structural section trusses attempted previously.

For your information, on the shear member testing we have averaged the bearing values for the shear members with 2,850 psi concrete and find that a 28,810# average value has been obtained with some running as high as 33,000#. This is well over the 17 kips we discussed and since the bearing of the shear members is solely a function of the concrete compressive strength, the 3,000# material you have specified for the World Trade Center towers should find excellent transference of top chord compression stresses to the floor slab. On one of the tests witnessed by Jim White of a six-day concrete with a strength of only 1,330 psi

DE STEEL COMPANY

Mr. Wayne Brewer
Skilling, Helle, Christiansen
and Robertson Page 2 August 10, 1967

the loading across or normal to the shear members developed a 18,500# average value for shear connector bearing.

One of these specimens is being retained to 28 day strength although we are not too sure that the very lightweight mix will be developing much more than 1,800# to 2,000# in the concrete.

Dr. Galambos at Washington University who has been performing the Steel Joist Institute composite joist and truss tests, has told us, and I believe confirmed this to Jim White, that approximately the same shear value for the Laclede extended web connectors could be expected in all directions when the shear connector is attached in a normal concrete top slab. This means with the 3,000# concrete we could expect a 28 kips transference value across, as well as in line with the extended web panel point shear member.

As an aside, I believe Dr. Galambos told Jim White that in his tests he has had no measurable stress in the steel top chords of Laclede joists and trusses indicating that the shear members have been sufficiently good to take all the compression in the concrete top slab of the composite design.

We hope to be hearing from you shortly regarding sizing of members and the design of transverse trusses in the tower corners where it seems likely that shear members may be limited as you had planned it, to the primary floor trusses with transverse trusses furnished without extended web panel points.

Yours very truly,

LACLEDE STEEL COMPANY

A. Carl Weber
Vice President

ACW:pjz

cc: Mr. Jim White
Skilling, Helle, Christiansen and Robertson

Mr. Lester Feld
Port of New York Authority

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John. V. Christiansen · Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

April 19, 1968

Mr. R. M. Monti
Port of New York Authority
Office of the Construction
Manager - Room 1119
30 Church Street
New York, New York 10007

Reference: The World Trade Center
Contract WTC-221.00, Laclede
Load Tests

Dear Ray:

Attached are load test sketches 1BV and 1BH dated 4/16/68, prepared by Laclede Steel Company.

The test pieces and procedures indicated on these sketches are acceptable for use in tests to establish the strength of the 24T to C32T truss connections, subject to the following additional requirements:

Sketch 1BV

1. C32T top chords 7"± apart.

2. Tests be conducted with weld X of 1/4"x3", 5/16"x3" and 3/8"x3".

3. Two sets of tests to be conducted -

   a. with "knuckle" restrained as shown on 1BV. (SHCR feels that a load cell can be substituted for the restraint shown, if practical.)

   b. without "knuckle" restrained. This will allow evaluation of the joint strength for the construction loading conditions.

WAYNE A. BREWER
P. S. A. FOSTER
FRANK HOELTERHOFF
ROBERT E. LEVIEN
V. A. PRISADSKY
KENT R. ROGERS
CHARLES SANDUSKY
WILLIAM D. WARD
E. J. WHITE, JR.
LORENTS L. WIDING

SEATTLE OFFICE: 1840 WASHINGTON BUILDING, SEATTLE, WASHINGTON 98101

WTCI-87-1

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

Mr. R. M. Monti

April 19, 1968

Sketch 1BH

1. Tests to be conducted with weld X of 1/4"x3", 5/16"x3" and 3/8"x3".

2. Load to be applied 1/2" from top of angle (center of gravity).

3. Support of C32T web members close to top chord, as shown on 1BH, will require test results to be adjusted for the flexibility of these web members. We understand that this support location is limited by the test machine size. This location of the support will, however, allow an evaluation of the lateral bending of the vertical leg of C32T top chord angle, and is therefore acceptable.

Except for weld X sizes to be tested, these additional requirements were discussed with Carl Weber by telephone on 4/18/68. Information in boxes on 1BV and 1BH was added by SHCR.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Wayne A. Brewer

WAB:s
cc: Messrs. A. C. Weber, B. Bay, Laclede
Mr. L. S. Feld, PNYA
Mr. A. J. Guttentag, TRCC

Enclosure

CC: T. M. Chura
D. B. Neptune
File Copy

March 18, 1969

R. D. BAY

RE: TESTS FOR BEARING CAPACITY
OF WORLD TRADE CENTER TRUSSES

The attached sheets summarize the tests conducted Friday, March 7 at the Madison plant. These tests are broken down into two groups. Group No. 1 consists of seven (7) tests on various bearing ends of scrapped trusses to determine the bearing capacity of our World Trade Center trusses. The results of these tests are on page one while a general sketch of how the bearing end was tested is shown on page three (Figure 1). The following is a summary of the test results:

1. Only one test resulted in a broken weld and this was at a load 18K greater than the load which caused the initial bending of the angles.
2. Using a 2" plate instead of a 4" plate for the bearing surface results in a more critical loading condition and an earlier angle deformation.
3. The core end withstands a greater load before failure than the column end. This can probably be attributed to a smaller L/R ratio and a more compact section.
4. Arc welding the bottom of the vertical VI strut decreases the possibility of a weld failure. The failure which occurs is then a failure of the bearing angle which begins to deform noticeably at approximately 30K.

Group No. 2 consists of four (4) tests on bearing ends having only arc welding joining the web and angles together; i.e., no resistance welding was used. The purpose of these tests was to determine the strength of repaired bearing ends that would be welded onto our trusses at the jobsite. Two types of tests were performed. The first type of test shown in Figure 2-A, page 4 tested the capacity of the end as a unit. The second type of test shown in Figure 2-B, page 4 tested the strength of each joint in the bearing end. The results of these tests seem to indicate that those bearing ends and welded to the trusses at the jobsite will be strong enough to support the required load if the welding is performed by a qualified welder under good supervision.

David B. Neptune

ds

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Brewer

Consultants
Harold L. Worthington
Joseph F. Jackson

November 3, 1969
File: WTC-235C

Mr. Lester S. Feld
Port of New York Authority
World Trade Center Planning
111 Eighth Avenue
New York, New York 10011

Reference: The World Trade Center
Contract WTC-235.00, Bethlehem Fabricators
Stud Shear Connector Capacity with Rollform Type "B" Steel Deck

Dear Lester:

At your request, we are forwarding to your attention the following information regarding a test program to establish the capacity of 3/4 inch diameter by 4½ inch long stud shear connectors when welded through the valleys of Rollform Type "B" steel deck.

Two 15 foot long test beams conforming to Attachment #1 are required. During the testing operation, the load-deflection and load-slip behavior for each beam should be determined using three (3) 0.001 dial gages and eight (8) SR-4 type A-1 strain gages in accord with Attachment #3.

Load should be applied in 4 kip increments and readings at all gages should be recorded before the next increment of load is applied.

Six 4'-3" long pushout specimens are required in accord with Attachment #2, four (4) with steel deck and two (2) with solid slabs. The load-slip behavior of each specimen should be determined by using two (2) 0.001 inch dial gages, one for each pushout slab. Dial gages should be mounted as shown in Attachment #2, and readings should be recorded for each 4 kip increment of loading.

Lightweight concrete required for the test specimens and test cylinders will amount to approximately 85 cubic feet. We recommend use of Nytralite lightweight aggregate, Master Builders Pozzolith 100R and MBVR, and Type III (high-early) cement of the brand on hand at the local ready mix concrete source chosen to supply

THE PORT OF NEW YORK AUTHORITY

II. The Authority has arranged for the following items to be furnished by others and delivered to the Laboratory by November 19, 1969:

A. Two (2) 15 foot long test beams with steel deck and studs installed by others prior to delivery.

B. Four (4) 4'-3" long pushout specimens with steel deck and studs installed on both flanges by others prior to delivery.

C. Two (2) 4'-3" long pushout specimens with studs installed on both flanges by others prior to delivery.

D. Approximately 3000 pounds of Nytralite Lightweight Aggregate.

E. Approximately two gallons of Master Builders [illegible] for use as admixture.

III. As full compensation for the performance of all

THE PORT OF NEW YORK AUTHORITY

the services performed hereunder, unless you first obtain the written approval of the Authority. Such approval may be withheld if for any reason the Director, in his sole discretion, believes that the publication of such information may be harmful to the public interest or in any way whatsoever undesirable.

VII. The Laboratory shall promptly and fully inform the Director of any patents or disputes, whether existing or potential, of which you have knowledge, relating to any idea, design, method, materials, equipment, or other matter involved in the services hereunder.

VIII. All drawings, specifications, reports, computations, records, data, charts, documents or other papers, or any type whatsoever, whether in form of writing, figures or delineations, which are prepared by the Laboratory at any time, either prior or subsequent to signature of this Agreement, by the Authority, its Commissioners, officers, agents or employees, is not given in confidence and may be

the Laboratory shall receive no compensation for any services not performed, and the Laboratory shall be paid as full compensation for services performed an amount computed as above set forth.

XIII. This Agreement shall be effective as of November 14, 1969. All of the services hereunder shall be performed as expeditiously as possible. The services shall in any case be completed on or about February 1, 1970. Time is of the essence of performance of all your

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Appendix C
SUPPORTING DOCUMENTS FOR CHAPTER 4

This appendix contains the supporting documents that are referenced in Chapter 4 of this report. All of the documents contained in this appendix are reproduced with permission of The Port Authority of New York and New Jersey. Table C–1 contains a summary of supporting documents and their location within this appendix. The footnote numbers given in the table correspond to those in Chapter 4.

Table C–1. Supporting documents for Chapter 4.

Footnote Number	Document Title	Page(s)
1	Memorandum of Understanding Between the New York City Department of Buildings and the PANYNJ, 1993	216
2	Supplement to Memorandum of Understanding Between the New York City Department of Buildings and the PANYNJ, 1995	221

prepared drawings, plans and any other documents required in connection with the review of the Project from the standpoint of Code conformance. In the case of any Project being effectuated by a tenant of the Port Authority (a "Tenant Project") such file shall also include the Tenant Alteration Application prepared by the Tenant. In the case of any project administered by a line department of the Port Authority, such file shall include any construction application prepared in connection with such Project. The Line Departments of the Port Authority are currently its World Trade, Aviation, Interstate Transportation, Port, and Regional Development Departments.

3. Project Certification. For each Tenant Project, the Port Authority shall require the Tenant to obtain the certification of a New York State licensed architect or engineer that such Project was constructed in accordance with the approved plans and specifications for such Project. For any Project effectuated by the Port Authority, the Chief Engineer or his successor in duties shall certify that the Project was constructed in accordance with the approved plans and specifications for the Project. Certifications for each Project shall be maintained in the Project File.

4. Copies of Project File. The Department may at any time request the Port Authority to provide it with a copy of any Project File and the Port Authority shall promptly provide a copy of the Project File to it.

5. Variances. The Port Authority shall promptly advise the

information or interpretation which it may receive from tenants of the Port Authority with respect to any Project.

8. No Personal Liability. No Commissioner, officer, agent or employee of the Port Authority or the Department shall be held personally liable under any provision of this Agreement or because of its execution or attempted execution or because of any breach or alleged breach thereof.

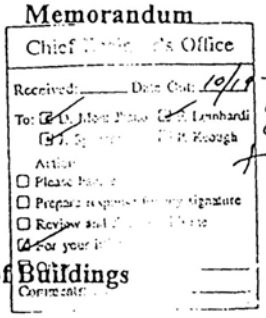
IN WITNESS WHEREOF, the parties hereto have caused this instrument to be signed, sealed and attested.

ATTEST: THE PORT AUTHORITY OF NEW YORK

THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY
Commercial Litigation Division (68E)

Memorandum

OCT 18 AM : 02



TO: Lysa Meduri, Acting Secretary
FROM: Walter M. Frank
DATE: October 16, 1995
SUBJECT: **Transmittal of Letter Agreement - NYC Department of Buildings**

Copy to: J. Green, N. Chanfrau, P. Cooper, W. Goldstein, H. Henschel, F. Lombardi

Transmitted for the official records of the Port Authority is a Letter Agreement between the Port Authority and the New York City Department of Buildings providing for a change to the recent Supplement to the Basic Memorandum of Understanding between the Department and the Port Authority in connection with the Port Authority's Tenant Self-Certification Program at the World Trade Center.

Walter M. Frank
Deputy Chief
Commercial Litigation Division

WMF:gk

Encl.

THE PORT AUTHORITY OF NY & NJ

One World Trade Center
New York, N.Y. 10048

William H. Goldstein
Deputy Executive Director/
Capital Programs
(212) 435-8415
(201) 961-6000 x8415

September 15, 1995

Honorable Joel A. Miele, Sr., Commissioner
Department of Buildings
City of New York
60 Hudson Street
New York, New York 10013

Dear Commissioner Miele:

As you know, the Port Authority of New York and New Jersey (the "Port Authority") and the New York City Department of Buildings (the "Department") recently executed a supplement (the "Supplement") to the Memorandum of Understanding between the Department and the Port Authority to provide that the Port Authority's tenant at the World Trade Center could, in lieu of any review by the Port Authority, use New York State licensed architects or engineers meeting qualifications to be

SUPPLEMENT TO MEMORANDUM OF UNDERSTANDING
BETWEEN THE NEW YORK CITY DEPARTMENT OF
BUILDINGS AND THE PORT AUTHORITY OF NEW
YORK AND NEW JERSEY

In November, 1993 the New York City Department of Buildings (the "Department") and the Port Authority of New York and New Jersey (the "Port Authority") entered into the attached Memorandum of Understanding (the "Memorandum") establishing certain procedures for the purpose of helping to assure conformance of construction projects to be undertaken at buildings owned or operated by the Port Authority in New York City with the standards set forth in the New York City Building Code.

Recently, the Department implemented its own optional plan review system providing for professional certifications of applications and plans and subsequent construction work falling under its jurisdiction.

The purpose of this Supplement to the Memorandum is to provide under the Memorandum for the adoption by the Port Authority of a procedure under which any Port Authority tenants at the World Trade Center may utilize New York State licensed architects or engineers to certify, in lieu of any review by the Port Authority, that (i) the tenant's construction plans are in conformance with the standards set forth in the New York City Building Code, and (ii) construction has been performed in accordance with such plans, it being understood that the persons making the certifications described in (i) and (ii) shall not be the same.

Accordingly, the Department and the Port Authority hereby agree that the Memorandum is amended as follows:

1. Professional Certification. Notwithstanding anything to the contrary in the Memorandum, the Port Authority may, in lieu of any reviews or certifications by the Port Authority provided for in the Memorandum, provide procedures pursuant to which its tenants at the World Trade Center may utilize New York State licensed architects or engineers meeting qualifications to be established by the Port Authority to (A) prepare and review such tenant's plans for the construction of any project and certify that such plans conform with the building standards set forth in the New York City Building Code and (B) certify that such project has been constructed in accordance with the approved plans and specifications for such project. The person or firm performing the review and certification described in (A) above shall not be the same person or firm providing the certification described in (B) above.

2. Other Provisions. Except as provided herein, all the terms and conditions of the Memorandum shall remain in full force and effect.

3. No Personal Liability. No Commissioner, officer, agent or employee of the Port Authority or the Department shall be held personally

liable under any provision of this Supplement or because of its execution or attempted execution or because of any breach or alleged breach thereof.

IN WITNESS WHEREOF, the parties hereto have caused this instrument to be signed, sealed and attested.

ATTEST:

SECRETARY

DATE: 6/7/95

THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY

By: _____
Executive Director

WITNESS:

FRANK M. SCHWARTZ
Notary Public, State of New York
No. 41-4632586
Qualified in Queens County
Commission Expires Jan. 31, 19 97

DATE: 6/1/95

THE NEW YORK CITY DEPARTMENT OF BUILDINGS

By: _____
Commissioner

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Appendix D
SUPPORTING DOCUMENTS FOR CHAPTER 5

This appendix contains the supporting documents that are referenced in Chapter 5 of this report. All of the documents contained in this appendix are reproduced with permission of the The Port Authority of New York and New Jersey. Table D–1 contains a summary of supporting documents and their location within this appendix. The footnote numbers given in the table correspond to those in Chapter 5.

Table D–1. Supporting documents for Chapter 5.

Footnote Number	Document Title	Page(s)
	Section 5.3 – Damping Units	
2	Letter dated July 16, 1964 from Alan G. Davenport of WSHJ to Carl A. Dahlquist of 3M (WTCI-450-L)	226
3	Letter dated November 23, 1964 from Richard D. Steyert of WSHJ to Carl A. Dahlquist of 3M (WTCI-450-L)	227
5	Internal correspondence dated February 1966 by Richard D. Steyert of WSHJ (WTCI-450-L)	231
7	Letter dated October 31, 1966 from Don Caldwell of 3M to James White of WSHJ (WTCI-501-L)	232
8	Letter dated October 30, 1967 and enclosure from Leslie E. Robertson of SHCR to John H. Kyle (Chief Engineer), PONYA (WTCI-501-L)	240
10	Letter dated April 4, 1969 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-501-L)	248
11	"Specification for Viscoelastic Damping Units" dated October 6, 1969 (PONYA 1969) (WTCI-501-L)	252

WORTHINGTON, SKILLING, HELLE & JACKSON

Consulting Civil and Structural Engineers • 1660 Washington Bldg., Seattle, Wash. 98101 • Ma. 3-7223

Harold L. Worthington • John B. Skilling • Helge J. Helle • Joseph P. Jackson • John V. Christiansen

July 16, 1964

Mr. Kari Dahlquist
3-M Company
Minnesota Mining and Manufacturing Company
2501 Hudson Road
Minneapolis, Minn.

Reference: Viscoelastic Damping Material

Dear Mr. Dahlquist:

We have an important requirement for a viscoelastic material suitable for damping low frequency mechanical vibrations. It is proposed that this material shall be used in a sandwich between two surfaces and the load will be applied to the damping material by shear. The frequency of vibration is in range 0.1 - 1.0 cycles per second. The operational temperature range will be 0° F - 80° F. It will have a chemical and mechanical stability such that its action is unimpaired over the course of many years.

We would be grateful if you could suggest what range of materials might be available for such a purpose, their approximate cost and all their pertinent mechanical properties. We have a hunch that an asphaltic or rubber based material might be suitable.

We require to know the storage and loss moduli (c.f. p. 36-18 of "Shock and Vibration Handbook" by Harris and Crede, McGraw-Hill, 1959) over the above operating temperatures and frequencies. (We are looking for a material with a loss modulus probably of the order of 10^2 lb/sq. in.) We would also like to know the chemical composition of the material and its melting point.

If the material is adopted it will be used in considerable quantities. We would be grateful, therefore, if you would also indicate approximately bulk costs and availability. Your early reply to this inquiry will be appreciated.

Yours very truly,

Alan G. Davenport Ph.D.

AGD:sb

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Consulting Civil and Structural Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

Harold L. Worthington · John E. Skilling · Heige J. Helle · Joseph F. Jackson · John V. Christiansen · Leslie E. Robertson

November 23, 1964

Mr. C. A. Dahlquist
Minnesota Mining and Manufacturing Company
2501 Hudson Road
Minneapolis, Minnesota

Reference: Viscoelastic Damping Material

Dear Mr. Dahlquist:

Thank you for the information which you provided during our phone conversation of November 11. We have enclosed a sheet which lists the types of viscoelastic damping materials and the properties desired. We have also enclosed a sheet which reviews the properties of the #466 Transfer Tape.

We would greatly appreciate any information which you would be able to provide on other materials produced by the Minnesota Mining and Manufacturing Company. Such information would be appreciated at your earliest convenience.

Sincerely yours,

WORTHINGTON, SKILLING, HELLE & JACKSON

Richard D. Stoyert

cc: Mr. Caldwell

RDS:cd

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Material:	**#466 Transfer Tape**
Producer:	**Minnesota Mining and Manufacturing Company**
Parameters:	**G_2 from 200 to 300**
	from 1.2 to 1.5
	t = .0015 in.
	Max ≅ 20
Cost:	**$1.52 to $2.00/sq. yd.**
Additional Properties:	**Bonds to steel, wood, or concrete**

Call To Mr. Dahlquist Nov. 10
Gen. Office 700 Grand Ave, Ridgefield N.J.

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Physical & Mechanical Properties Required of Visco-Elastic Material

1. Type A. Ease of placement into void either by pouring or pumping under pressure and/or heat and capable of bonding to concrete, steel or wood.

   Type B. Available in sheets.

2. A high degree of durability and stability under normal operating conditions for extended periods. (It is possible that the containing space can be sealed hermetically.)

3. Non-combustible.

Parameters Desired

1. Loss of modulus in shear, G_2 $10^2 - 10^5$
   Loss factor , $n = G_2/G_1$
   for temperature range 30° - 80° F.
   vibration frequency .1 - 1.0 cycles/second.

2. Stress or strain or fatigue limitations.

3. Cost.

Thermo Plastic Low

Note: Quantities to be used 1,000 c. f.
plus or minus by a factor of 10.

Adhesive — #466 Transfer Tape
Pressure Sensitive, on light coated
Bought as Tape.
Comes on line
Unroll
1½ Thousands
.031
@ 30° G_2 ≈ 200 - 300
n = 1.2, 1.5
ϵ = 20
Very Smooth, 1 Thousands
Use it to Bond Tape
c. 1.52 TO 2.00 / yd²

WORTHINGTON, SKILLING, HELLE & JACKSON Civil & Structural Engineers	THE WORLD TRADE CENTER THE PORT OF NEW YORK AUTHORITY MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT	DATE II.66 PREPARED BY RDS APPROVED	Sheet No.

REVIEW OF STATUS OF DAMPING WORK DONE BY R. STEYERT

Work done prior to Nov. '65

Well ordered and filed

Work done subsequent to Nov '65

Not yet ordered

Key calculations of interest

On truss $WD_4|40$ to $WD_4|44$ and $WD_4|49$

Note: Although I have cross checked this work sufficiently to feel it is consistent with the assumptions made, these few pages should be carefully checked and understood by someone else. The work is of a simple nature, not involving the computer.

On column $WD_2|25$ to $WD_2|29$

Note: I have checked this work, but not extensively. There appears to be a discrepency between Dick Taylor's work and my work in this area. The work is of a simple nature, not involving the computer.

WORTON, SKILLING, WORLE & JACKSON — Civil & Structural Engineers	THE WORLD TRADE CENTER — THE PORT OF NEW YORK AUTHORITY	DATE II.66	Sheet No.
MINORU YAMASAKI & ASSOC. — MINORU YAMASAKI, ARCHITECT	EMERY ROTH & SONS — RICHARD ROTH, ARCHITECT	PREPARED BY RDS	
		APPROVED	

Contact with 3M-Company

There has been a long series of calls over the past months. Contact has been with Don Caldwell and Alex Donaldson. There is a file of notes on these conversations. Dick Taylor has been in on all recent conversations. The general status is the following:

Initial tests for selection of visco-elastic material have been completed. The material tentatively selected has $G' = 495$ psi, $\eta = .69$ @ $f = 10$ cps. @ 23°C.

Initial cost estimates were made and revised. Initially truss damper unit was $75. and column damper $65. As revised, truss damper is $65. and column damper $55.

Testing of an assembled truss damping unit has been completed an results agree with theoretical predictions. We should now review our design of the damper unit and forward this design to 3-M. 3-M is anxiously awaiting a go-ahead on the column damping system. At present they are up in the air about our intentions. They also are quite anxious to get suggestions

3M COMPANY

GENERAL OFFICES • 2501 HUDSON ROAD • ST. PAUL, MINNESOTA 55119 • TEL. 733-1110

Industrial Tape Division

October 31, 1966

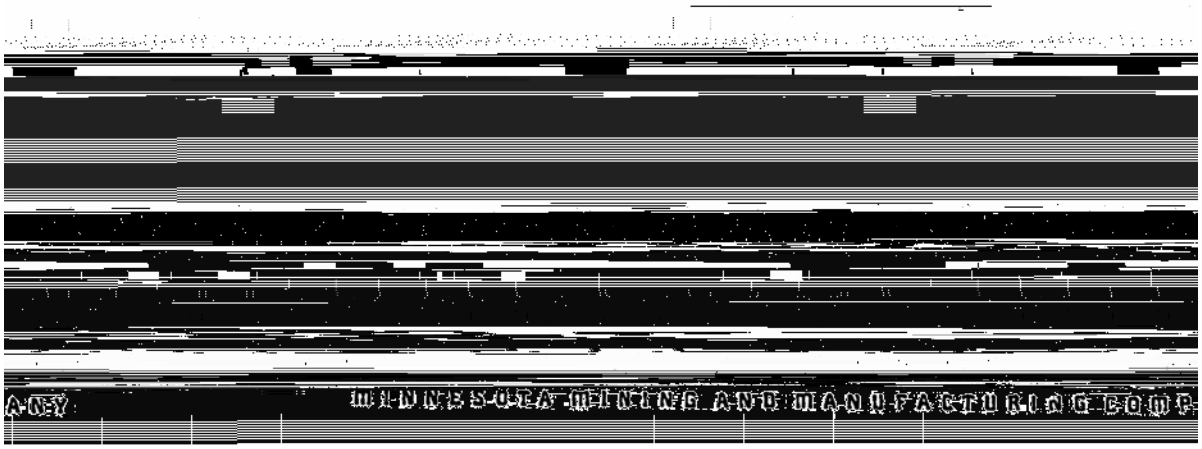
Mr. James White
Worthington, Skilling, Helle & Jackson
230 Park Avenue
New York, New York 10017

Dear Jim:

The paragraphs below contain our proposal for the qualification section of the specification, a revised Acceptance Testing and Sampling Plan and a section on the burning and melting of the visco-elastic material. In addition, confirming our telephone conversation of 10/4, we agree to loosen the location tolerance of the four corner holes in the T-Sections from ± 1/64" to ± 1/32". Our Engineering Department is producing revised drawings which will be sent to you when complete.

Substitute the following paragraphs for section three entitled "Qualification of Dampers" that was contained in the rough specification outline given you at the time of your visit:

"A damper may be qualified by presentation of data gathered from tests of at least one damping unit. The tests must be conducted according to the following procedure and meet the requirements listed in this specification. Report the values in sections 9, 10, 11 and 14



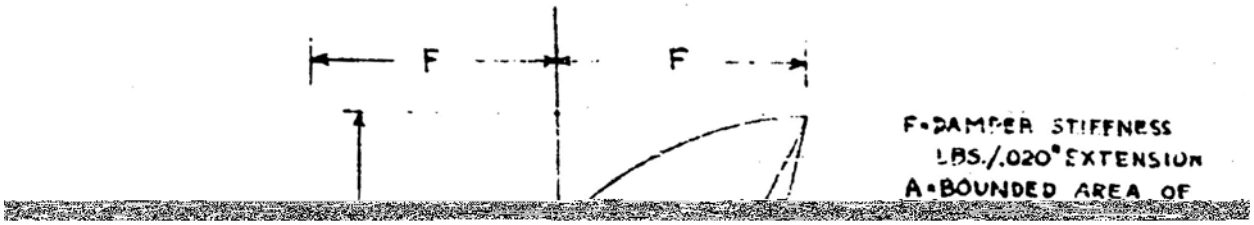
QUALIFICATION TESTING PROCEDURE

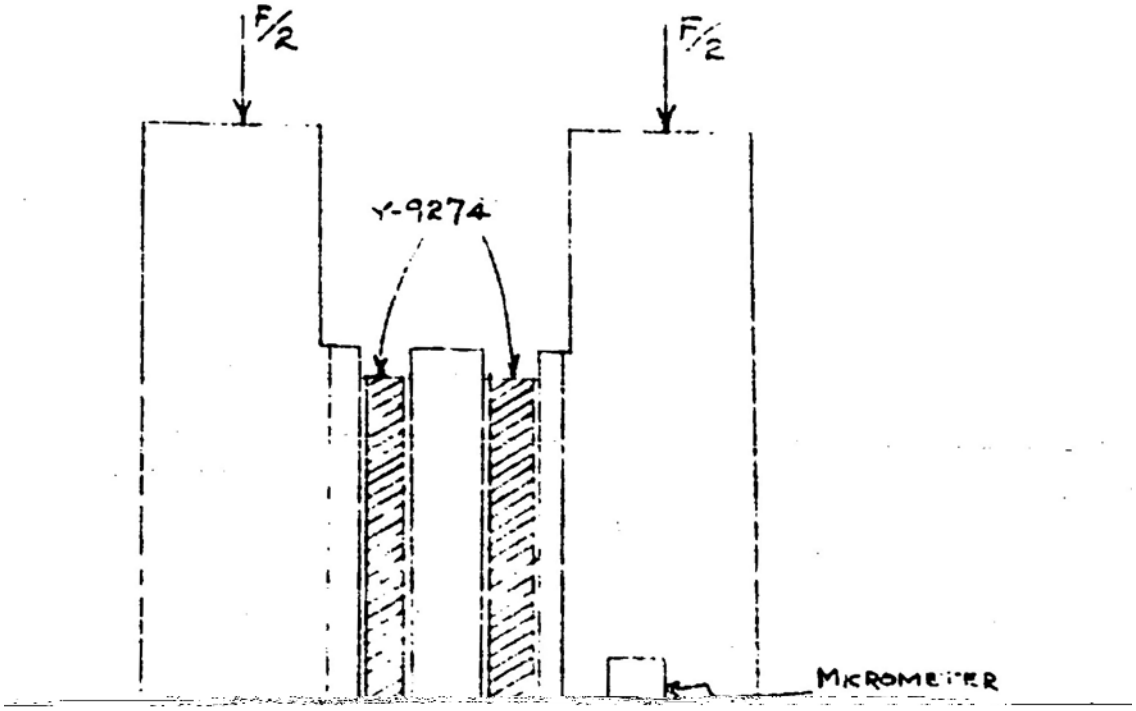
1. Clamp an assembled full scale damper in the jaws of the Instron.

2. Bolt the micrometer head to one of the T-sections of the damper using previously drilled holes. Bolt the arm holding the extensometer to the bar. (See attached sketch)

3. Connect the output of the extensometer to the chart recorder.

4. Record the displacement and force in one side of the damper (the two sides are assumed identical) alternately in compression and tension for one complete cycle. The Instron is reversed at the pre-selected displacement of .020" both in compression and tension. A typical hysteresis loop is shown on the bottom of this page.




F/2
F/2
Y-9274
MICROMETER

5. Measure the bounded area of the loop. Calculate the strain, ε_o and volume, V, in the visco-elastic layers.

6. Calculate G" from the equation $G'' = \frac{A}{\pi \varepsilon_o^2 V}$

7. Calculate G* from the equation $G^* = \frac{\frac{F}{a}}{\frac{d}{t}}$

8. Calculate G' from the equation $(G')^2 = (G^*)^2 - (G'')^2$

9. Calculate loss tangent, tan δ, from the equation.

$$\tan \delta = \frac{G''}{G'}$$

10. Record the value F taken from the chart recorder.

11. Run at least 100 successive cycles of the hysteresis loop test at a displacement amplitude of 0.020". Calculate the loss modulus, G", as shown above, for the first and the last cycles. Calculate the percent change of the last cycle from the first.

12. Place an assembled damper in the jaws of a Baldwin test machine

Substitute the following under the section entitled "Acceptance Testing and Sampling Plan".

ACCEPTANCE TESTING & SAMPLING PLAN:
"The plan assures that dampers having average loss tangent, stiffness, fatigue resistance and ultimate shear strength values less than the guaranteed minimums will not be accepted more than 5% of the time.

Lot: A lot shall consist of all dampers made from the same lot of

OPERATING CHARACTERISTIC CURVE
PROBABILITY OF ACCEPTING TAN δ = 0.70 IS 0.05

1. The curve gives <u>average</u> values of <u>lots</u> that have been estimated from samples of five (chosen at random of a run of one per day)

6. The average loss tangent for experimental dampers tested to date is 1.1. It is obvious that we really have a high confidence of meeting the minimum loss tangent of 0.7. Using the five damper sample plan, the producer's risk point (95% probability of accepting, 5% chance of rejecting unknown to 3M) occurs at a loss tangent of .92. The

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John B. Skilling · Helge J. Helle · John. V. Christiansen · Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

October 30, 1967

Mr. John M. Kyle
Chief Engineer
Port of New York Authority
World Trade Center Planning
111 Eighth Avenue
New York, New York 10011

Reference: The World Trade Center
Damping Units

Dear Jack:

Enclosed is a program outlining a test series to be used for the damping units between floor and column elements of The World Trade Center.

We had hoped that a much more comprehensive program could be developed. However, test equipment specifications have proven to be a much higher hurdle than had been expected because of the difficulty in allowing for reasonable flexibility in selecting a laboratory and for contracting for the work. We have, therefore, deleted this facet of the program and have

THE WORLD TRADE CENTER

Report No. DU-2

PROTOTYPE TEST PROGRAM OF VISCOELASTIC DAMPING UNITS

October 27, 1967


PROTOTYPE TEST PROGRAM OF

shall be identical to the bonding agents to be used in the final production of the damping units.

The ends of the structural tees shall be connected to the test jig by

III. Monitoring of Fabrication and Testing Operation

All work shall be done under the surveillance of the S-H-C-R Resident

5. Maximum displacement and ultimate strength of the damping units in compression.

V. Tests for Dynamic Stiffness and Loss Factor

1. The ambient temperature and the temperature of the viscoelastic slabs at the beginning of each test shall be 75°F ± 3°F. The temperature of the viscoelastic material shall be measured by a

shall be recorded for the 1st, 10th, 20th, 50th, 100th, and 101st cycles for each specimen.

6. One specimen shall be selected at random from the specimens to be tested at 0.020" amplitude and another specimen shall be selected at random from the specimens to be tested at 0.030" amplitude for extended testing as follows: Sinusoidal displacement shall continue to be applied beyond the 102nd cycle until the 500th cycle. Force-displacement curves as well as the ambient temperature and the temperature of the visco-

2. The mean value of the absolute dynamic stiffness of all specimens for the first cycle shall be at least 400,000 pounds per inch but less than 800,000 pounds per inch.
3. The standard deviation of the absolute dynamic stiffness of all specimens for the first cycle shall not exceed:

$$\text{(a)} \quad \frac{1}{3}\ \overline{K}_d - 60{,}000 \text{ pounds per inch}$$

$$\text{and} \quad \text{(b)} \quad 400{,}000 - \frac{1}{3}\ \overline{K}_d \text{ pounds per inch}$$

where $\overline{K}_d$ is the mean value of absolute dynamic stiffness.

4. The limits set forth in (1), (2) and (3) above shall also be applied to the 101st cycle.
5. Ultimate strength of the damping units as measured in Section VI shall have a mean value not less than 48,000 pounds and a standard deviation not greater than $\{ \frac{1}{3}\ \overline{P} - 12{,}000 \}$ pounds, where $\overline{P}$ is the mean ultimate strength in pounds.
6. Maximum displacement at ultimate strength as measured in Section VI shall have a mean value not less than 0.16 inch and a standard deviation not greater than $\{ \frac{1}{3}\ \overline{D} - 0.04 \}$ inch, where $\overline{D}$ is the mean value of the maximum displacement in inch.

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Brewer

Consultants
Harold L. Worthington
Joseph F. Jackson

April 4, 1969

Port of New York Authority
World Trade Center Planning
111 Eighth Avenue
New York, New York 10011

Attention: Mr. M. P. Levy

Reference: The World Trade Center
Contract WTC-224.00, 3M
Viscoelastic Damping Units

Gentlemen:

We have reviewed the draft of Contract WTC-224.00, Viscoelastic Damping Units for North and South Towers, dated November 1, 1968. Our comments on this draft contract are the subject of this letter.

1. Draft page 3 COMPENSATION:
The number of damping units to be installed in North and South Towers is 19,423, exclusive of units required for Acceptance Tests and Guarantee Tests. The Guarantee Tests require 360 units. The number of units required for Acceptance Tests is variable and it depends on the quality of the submitted lots and on the number of days of production. Units which are not damaged in the Acceptance Tests will be returned to inventory. However, since it is expected that damping units will be damaged in the ultimate strength tests, all such specimens should be discarded.

   In order to control the upper limit of the cost of Acceptance Tests we suggest that the contract include a clause such as, "Vendor shall not be paid the fees for acceptance tests performed on lots which are rejected as a result of the tests."

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

Port of New York Authority
Attention: Mr. M. P. Levy

April 4, 1969

2. Draft page 4 EXTRA MATERIALS AND DELETED MATERIALS:
The unit price schedule in Section B implies that the total price of 19,999 units is $653,967.30 whereas the total price of 20,000 units is $622,000.00. A schedule of unit prices for the deleted units would remedy this situation.

3. Draft pages 9, 10, 11, 12:
The dates for the delivery of the components and for the delivery of the damping units must be corrected.

4. Draft page 18 GUARANTEE BY THE VENDOR:
The number of units in Section C must be made consistent with the number given in Draft page 3.

5. Draft page A-5 Items to be Excluded from this Contract:
Section 2 should read, "Field bolts in the webs of tees and field bolts in the ends of 4" x ½" nominal bars."

6. Draft page A-9, Section 3.1.4:
Change S for Shear Stress to lower case s.

7. Draft page A-10:
   a. Delete the equation for Fatigue Loss in accordance with the proposed revisions of Section 4.0.
   b. Change s for standard deviation to upper case S in order to agree with Eq. 1.

8. Draft page A-11:
   a. In the first equation for S, X should be $\bar{X}$.

We would like to recommend the following revisions of Section 4.0, Requirements and Section 5.0, Quality Assurance. The aims of these provisions are: (1) to control the dispersion of the Stiffness and of the Ultimate Strength of the damping units and (2) to include in the Fatigue Test those parameters which are most pertinent to the system performance of the damping units in the building.

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

Port of New York Authority
Attention: Mr. M. P. Levy

April 4, 1969

1. Draft page A-11:
   a. Two paragraphs following Eq. 2 shall read as follows:
   "The Manufacturing Control Limit for the Loss Factor of an Acceptance Lot or of a Guarantee Lot shall be calculated by substituting the value of S from Eq. 2 and the appropriate value of the $t/\sqrt{n}$ from Table I, in Eq. 1."

2. Draft page A-11:
   4.1.3 Fatigue Test: The requirements of Loss Factor and Stiffness in 4.1.1 and 4.1.2 shall also be met for the 100th cycle.
   4.1.4 Ultimate Strength: The Ultimate Strength shall be at least 45,000 pounds at 75°F.

3. Draft page A-12:
   4.2.2 Stiffness: The average Stiffness at 75°F shall be greater than $(6{,}000 + 2.0S)$ but less than $(20{,}000 - 2.0S)$ pounds per 0.020" damper deflection, where S is the standard deviation of the sample calculated from Eq. 2.
   4.2.3 Fatigue Test: The requirements of Loss Factor and Stiffness in 4.2.1 and 4.2.2 shall also be met for the 100th cycle.
   4.2.4 Ultimate Strength: The average Ultimate Strength at 75°F shall be at least $(45{,}000 + 2.0S)$ pounds, where S is the standard deviation of the sample calculated from Eq. 2.
   4.3.1 Loss Factor: The average Loss Factor shall be at least 0.70.
   4.3.2 Stiffness: The average Stiffness at 75°F shall be greater

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Port of New York Authority
Attention: Mr. M. P. Levy

April 4, 1969

4. Draft pages A-13 and A-14:
   5.2.3 (1) Change "Fatigue Loss" to "Fatigue".
   (3) Change "Manufacturing Control Limit for that test" to "Acceptance Requirements in 4.2".
   (5) Change "Manufacturing Control Limit" to "Acceptance Requirements".
   (6) Change "Manufacturing Control Limit" to "Acceptance Requirements".
   (9) Change "Manufacturing Control Limit" to "Acceptance Requirements".

5. Draft page A-15:
   5.3.1 Delete the sentence, "Lots of dampers having average values of ..... more than one time in twenty after three samples." In the last paragraph of 5.3.1 change "destroyed" to "damaged".

6. Draft pages A-16 and A-17:
   5.3.3 (1) Change "at the rate of three for each 160 dampers" to "at the rate of one for each 50 dampers". Change "Fatigue Loss" to "Fatigue".
   (3), (5), (8), (9) Change "Manufacturing Control Limit" to "Guarantee Requirements".
   5.3.4 Change "prefix" to "suffix".

7. Draft page A-23:
   5.4.5.1 (11), (12) Change upper case S to lower case s.

8. Draft pages A-24 and A-25:
   5.4.5.2 Fatigue: Delete paragraphs (5) and (6). Add the following: "(5) Calculate Loss Factor and Stiffness for the 100th cycle by following the procedures given in 5.4.5.1."

9. Draft page A-25:
   5.4.5.3 Ultimate Strength: Revise paragraph (1) to read, "Follow 5.4.2".

10. Draft page A-26:
    5.4.5.3 (7) Use these values in calculating the mean and the standard deviation of the sample.

If you have any question concerning this review, we would be pleased to discuss the specification with you.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Leslie E. Robertson
pc/ls

10/6/69

SPECIFICATION

FOR

VISCOELASTIC DAMPING UNITS

CHAPTER ONE

GENERAL CONDITIONS

0.01 GENERAL

This Specification relates generally to the detailing, furnishing and application of Viscoelastic materials, bonding adhesive, protective aprons and 1/4" bolts, shims, spring lock nuts, and washers required to assemble the Components, furnished by others and machined by the Contractor, into Damping Units for the North Tower (Tower A) and the South Tower (Tower B) of the World Trade Center being constructed by the Authority in the City of New York.

This Specification requires the doing of all things necessary or proper for or incidental to manufacture of said Damping Units, as shown on the Contract Drawings in their present form. In addition, all things shown on the Contract Drawings even though not expressly mentioned in this Specification and all things mentioned in this Specification even though not shown on the Contract Drawings are required.

In the event that any requirements of the Specification appear to conflict with the requirements of the Contract Drawings or Contractor's Shop Drawings, the requirements of the Specification shall prevail.

0.02 WORKMANSHIP AND MATERIALS

Materials and workmanship shall in every respect be in accordance with the best modern practice and whenever the Contract Drawings, Specification or directions of the Engineer admit of a doubt as to what is permissible or fail to note the quality of any construction, the interpretation which calls for the best quality construction is to be followed. Materials shall be new materials and may be purchased from any qualified source, domestic or foreign, provided they meet the Contract requirements.

In case of discrepancy between a description or requirement in the Contract Drawings and Specification for any material or equipment and a catalog number or other designation for the same material or equipment (even though stated to be acceptable), the description or requirement shall control.

The right to use all patented material, compositions of matter, manufactures, apparatus, appliances, processes of manufacture or types of construction required in connection with this Contract shall be obtained by the Contractor without separate or additional compensation whether the same is patented before, during, or after the performance of the Contract.

0.03 APPROVALS BY ENGINEER

Any approval by the Engineer of any materials, workmanship, plant equipment, drawings, program, methods of procedure, or of any other act or thing done or furnished or proposed by the Contractor to be done or furnished in or in connection with the performance of the Contract shall be construed merely to mean that at that time the Engineer knows of no good reason for objecting thereto; and no such approval shall release the Contractor from his full responsibility for the accurate and complete performance of the Contract in accordance with all the terms thereof.

0.04 ERRORS AND DISCREPANCIES

If, in the performance of the Contract, the Contractor discovers any errors or omissions in the Contract Drawings or Specification, or in the work undertaken and executed by him, he shall immediately notify the Engineer and the Engineer shall promptly verify the same. If with the knowledge of such error or omission and prior to the correction thereof, the Contractor proceeds with any work affected thereby, he shall do so at his own risk and the work so done shall not be considered as work done under and in performance of this Contract unless and until approved and accepted.

0.05 PATENTS

The right to use all patented materials, composition of matter, manufactures, apparatus, appliances, processes of manufacture, or types

of construction as part of the sale shall be obtained by the Vendor without separate or additional compensation whether the same is patented before, during, or after the performance of this Contract.

0.06 INSPECTIONS

Testing and storage operations in connection with this Contract shall be at all times and places subject to the inspection of the Engineer, acting personally or through his Inspectors.

The Contractor, at his own expense, shall furnish such reasonable facilities and give such assistance for inspection as the Engineer may direct. The Contractor shall secure for the Engineer and his Inspectors free access to those parts of factories, plants or warehouses in which such testing and storage operations are conducted and shall give at least ten days' notice to the Engineer of his intention to commence initial acceptance and five year testing and recommencement after any suspension of testing of more than a week.

0.07 NO CONFIDENTIAL DISCLOSURES - PROPERTY OF AUTHORITY

The Contractor agrees that all information of any nature whatsoever, regardless of the form of the communication, received from the Contractor (including its officers, agents or employees) by the Authority, its Commissioners, officers, agents, employees, or consultants, and notwithstanding any statement therein to the contrary, has not been given in confidence and may be used or disclosed by or on behalf of the Authority without liability of any kind except as may arise under letters patent of the Contractor, if any.

All drawings, data, and other papers of any type whatsoever, whether in the form of writing, figures or delineations, which are the performance of this specifically prepared and required in

0.08 CONTRACT DRAWINGS

The Contract Drawings which accompany and form part of this Specification are separately numbered and entitled as follows:

DRAWING NUMBER	DRAWING TITLE	ORIGINAL DATE	REVISED DATE
DA-1	Damping Unit - Structural Tees	9-16-66	8-29-69
DA-2	Damping Unit - Structural Bars	9-16-66	8-29-69
DA-3	Viscoelastic Damping	10-27-67	5-20-69

2. Application of protective aprons to the visco-elastic material, bonding adhesive and visco-elastic material to the tee flange face and both sides of the nominal 4" x 1/2" bar to the thickness and lengths specified under this Contract.

3. The assembly of two tees and one bar into Damping Units after application of the Viscoelastic material using shims and 1/4" bolts, spring lock nuts, and washers to be furnished by the Vendor under this Contract.

4. The shipping and bundling of completed Damping Units on wood skids used for delivery of steel components segregated as to type of Damping Units. Each bundle to contain approximately 104 Type "A" or 104 Type "B" Damping Units and to be marked in accordance with detailed instructions

C. STRUCTURAL TEES - SPECIAL REQUIREMENTS

(a) No deviation from absolute flatness in excess of 1/32 inch over the entire flange surface.

(b) No deviation from absolute flatness in excess of 1/32 inch over the 4 inch extended area of the web.

(c) No deviation from perpendicularity of the 4 inch extended area of the web to the area to be machined in excess of 1/32".

(d) No deviation from perpendicularity of the entire area of the web to the area to be machined in excess of 1/16 inch.

(e) The 4 inch extended area of the web shall be parallel within 1/16 inch to the two center lines of the 1/2 inch diameter holes extending in the lengthwise (12 inch) direction of the area to be machined.


L REQUIREMENTS
TECHNICA

and Internally Threaded Standard Fasteners". ASTM A-307 bolts shall

3.1.1	FIXED CONDITIONS	NOMINAL VALUES
t =	temperature	75° ± 3°F.
l =	displacement amplitude	0.020"
T =	thickness of each viscoelastic slab	0.050"
f =	frequency	0.1 cycle per sec.
γ =	maximum shear strain	0.4 inches/inch
W =	width of each visco-elastic slab	4.0"
L =	bonded length of each viscoelastic slab	10.0"
$A_{v.e.}$ =	viscoelastic shear area	2WL = 80 sq. in.
V =	volume of viscoelastic material	2WLT = 4 cu. in.

3.1.3 MEASURED PARAMETERS

$$D = \text{Loss Factor} = \frac{G''}{G'}$$

3.2 REQUIREMENT AVERAGE

The Requirement Average is the limiting average value of the

The Requirement Average for all subsequent 5 Year lots shall be continuously and cumulatively adjusted by pooling the standard deviation of all Acceptance lots with the standard deviations of all accepted 5 Year lots by Equation 2.

4.0 REQUIREMENTS

4.1 ACCEPTANCE REQUIREMENTS

All requirements must be met

4.1.1 LOSS FACTOR

Requirement Average = $0.7 + 0.948\sigma_{\bar{x}}$ when n = 5
Requirement Average = $0.7 + 0.670\sigma_{\bar{x}}$ when n = 10
Requirement Average = $0.7 + 0.547\sigma_{\bar{x}}$ when n = 15

4.1.2 STIFFNESS

$6000 + 1.25\sigma_{\bar{x}} \leq$ Requirement Average $\leq 20{,}000 - 1.25\sigma_{\bar{x}}$ when n = 5
$6000 + 1.25\sigma_{\bar{x}} \leq$ " " $\leq$ " " $\sigma_{\bar{x}}$ when n = 10

4.2.2 **STIFFNESS**

$5400 + 1.25\sigma_i \leq$ Requirement Ave. $\leq 22{,}000 - 1.25\sigma_i$ when n = 10
$5400 + 1.25\sigma_i \leq$ " " $\leq$ " " σ_i when n = 20
$5400 + 1.25\sigma_i \leq$ " " $\leq$ " " σ_i when n = 30

(3) If the averages of the test results meet the Acceptance

(6) If the individual test results of the original and second group of samples do not meet the Acceptance Requirements, the lot is rejected.

5.1.4 IDENTIFICATION

All dampers shall be permanently imprinted with an identification code of the type shown below:

ALL DAMPERS			ACCEPTANCE TEST DAMPERS
DAMPER TYPE	PDTN. LOT #	YEAR	DAY	SUFFIXED

5.2.3 SELECTION OF SAMPLES

(2) Test one-half of these dampers for Ultimate Strength in accordance with Section 5.3.

(3) If the individual test results meet the 5 Year Requirements, the lot is accepted for this requirement.

(4) If the individual test results do not meet the 5 Year

FIGURE I

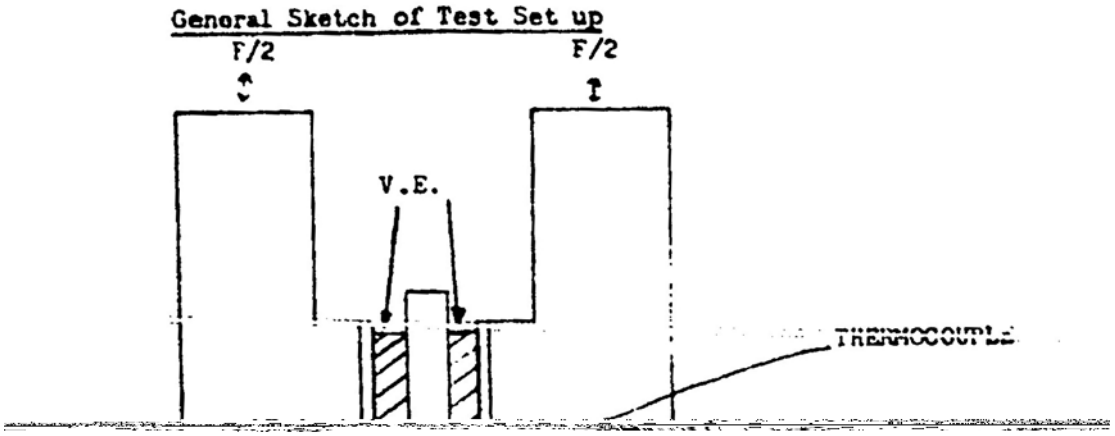
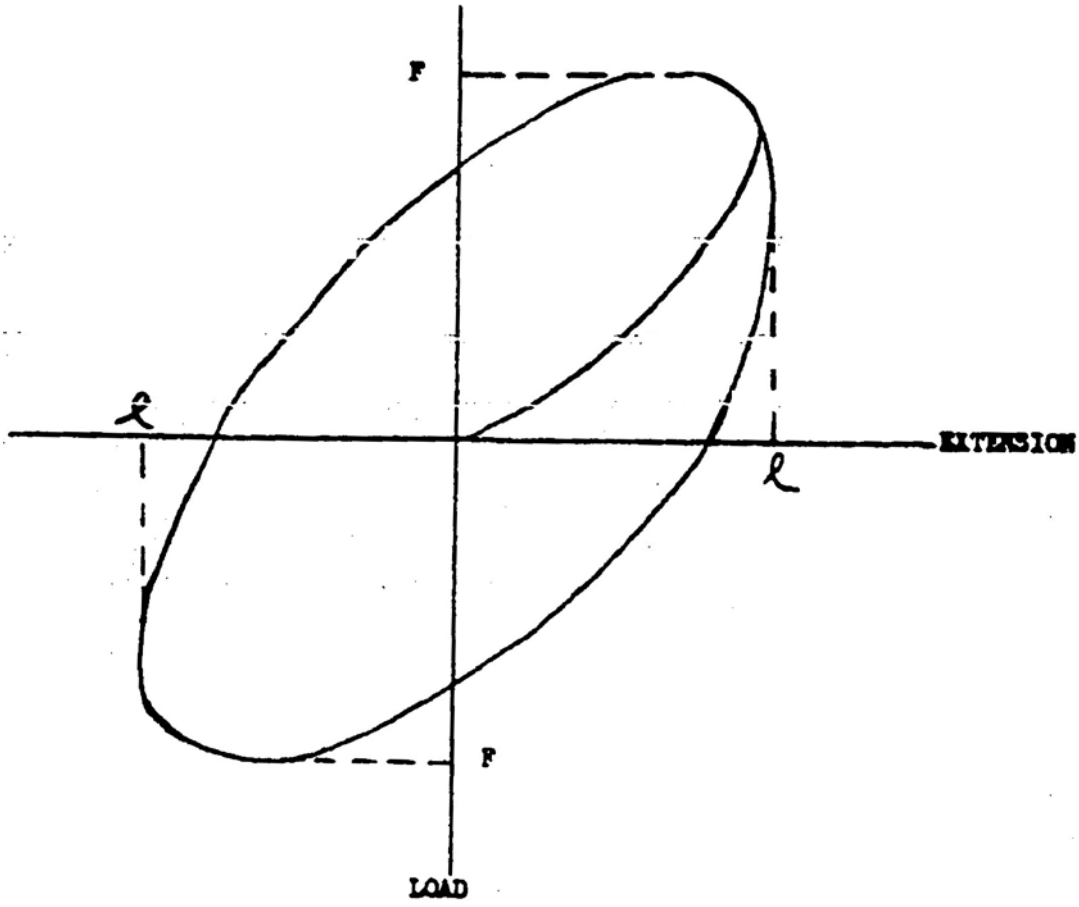


FIGURE II

A TYPICAL HYSTERESIS LOOP



p. 20

(5) Record the value of F from the X-Y chart recorder.

(6) Calculate results from Step (5) to a common viscoelastic width of 8" following the procedure given in 5.3.4 and record separately.

(7) Calculate results from Step (6) to a common temperature of 75°F. according to the procedure given in 5.3.5. Use these values in calculating the Requirement Average according to the procedure given in 3.2.

(8) Measure the bounded area of the hysteresis loop with a planimeter.

(9) Calculate the results from Step (8) for a common viscoelastic width of 8" following the procedure given in 5.3.4 and record separately.

(10) Calculate the Loss Shear Modulus, G", from

$$G'' = \frac{A_L C_1 C_2}{\pi \gamma^2 v}$$

using the values of A_L from Step (9).

(11) Calculate the shear stress, s, from

$$s = \frac{F}{A_{v.e.}}$$

using the values of F from Step (6).

(12) Calculate the complex shear modulus, G*, from

$$G^* = \frac{s}{\gamma}$$

(13) Calculate the Elastic Shear Modulus, G', from

$$G' = [\ (G^*)^2 - (G'')^2\ ]^{1/2}$$

(14) Calculate Loss Factor, D, from

$$D = \frac{G''}{G'}$$

Use these values in calculating the Requirement Average according to the procedure given in 3.2.

5.3.6.2 FATIGUE TEST

(1) Measure and record the temperature of the viscoelastic material immediately before starting the Fatigue Loss measurements.

(2) Following the detailed procedures given in Section 5.3.6.1 run 99 successive cycles of the hysteresis loop (Loss Factor and Stiffness) test.

(3) Return the damper to the temperature measured under (1) $\pm$ 1°F.

(4) Run the 100$^{th.}$ cycle as in (2).

(5) Following the procedures given in 5.3.6.1 calculate Stiffness for the 100$^{th.}$ cycle.

5.3.6.3 ULTIMATE STRENGTH

(1) Follow 5.3.3.

(2) Bolt an assembled damper in the special jaws attached to the test machine. Use new high tensile steel bolts for each test. Use 1" diameter ASTM A 490 bolts for attaching the tee end of the damper and 7/8" diameter A-490 bolts (Type A units) or 1 1/4" diameter A 490 bolts (Type B units) for the bar end. Tighten all nuts until all four jaws and the specimen are firmly together, then tighten each nut an extra 1/2 turn.

Remove the four assembly packaging bolts. Do not remove shims.

(3) Set the test machine on lineal deformation control at a speed of 0.5"/min. and apply a compressive load axially to the ends of the damper until shear failure of the viscoelastic bonded area occurs.

(4) Use the X-Y chart recorder to make a continuous permanent record of the load-deflection relationship.

(5) Record the maximum load shown on the chart.

(6) Calculate results from Step (5) for a common viscoelastic width of 8" following the procedure given in 5.3.4. This is the Ultimate Strength.

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Appendix E
SUPPORTING DOCUMENTS FOR CHAPTER 6

This appendix contains the supporting documents that are referenced in Chapter 6 of this report. All of the documents contained in this appendix are reproduced with permission of The Port Authority of New York and New Jersey. Table E–1 contains a summary of supporting documents and their location within this appendix. The footnote numbers given in the table correspond to those in Chapter 6. Documents in the table without footnote numbers are referenced in the main body of Chapter 6.

Table E–1. Supporting documents for Chapter 6.

Footnote Number	Document Title	Page(s)
	Section 6.3.1 – Floor Trusses	
–	Fabrication and inspection requirements from the contract between the Port Authority and Laclede Steel Company for the floor trusses used in WTC 1 and WTC 2 (WTCI-71-I)	276
	Section 6.3.2 – Box Core Columns and Built-up Beams	
–	Fabrication and inspection requirements from the contract between the Port Authority and Stanray Pacific Corporation for the box core columns and built-up beams used in WTC 1 and WTC 2 (WTCI-244-L)	299
1	Letter dated June 5, 1967 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-491-L)	309
2	Draft contract between United States Testing Company and PONYA dated August 25, 1967 (WTCI-493-L; first page of the contract and Appendix I of this document]	319
3	Letter dated April 5, 1967 from Leslie E. Robertson of SHCR to Malcolm P. Levy of PONYA (WTCI-489-L)	325
4	Letter dated September 21, 1967 from R. M. Monti of PONYA to R. E. Morris of the Stanray Pacific Corporation (WTCI-490-L)	330
5	Letter dated November 13, 1967 from R. M. Monti of PONYA to R. E. Morris of Stanray Pacific Corp. (WTCI-498-L)	332
	Section 6.3.3 – Exterior Wall from Elevation 363 ft to the 9th Floor Splice	
6	Letter dated October 21, 1966 from PDM to James R. Endler of Tishman Realty and Construction Company Inc. (part of WTCI-745-L; second page and enclosure appears to be missing)	335
–	Amendments made to initial quality control program submitted to PONYA by PDM (parts of WTCI-744-L)	336
7	PDM specifications for welding procedures (parts of WTCI-741-L)	347
8	Letter dated October 4, 1967 from R. M. Monti of PONYA to H. M. Fish of PDM (WTCI-745-L)	364
	Section 6.3.4 – Exterior Wall Above 9th Floor Splice	
–	Fabrication and inspection requirements from the contract between the Port Authority and Pacific Car and Foundry Co. for the exterior walls used in WTC 1 and WTC 2 (WTCI-242-L)	366
9	Letter dated July 8, 1967 from R. C. Symes of Pacific Car and Foundry to R. M. Monti of PONYA (part of WTCI-748-L)	372
10	Letter dated July 13, 167 from James White of SHCR to R. M. Monti of PONYA (part of WTCI-748-L)	373
	Section 6.3.5 – Rolled Columns and Beams	
–	Fabrication and inspection requirements from the contract between the Port Authority and Montague-Betts Company, Inc. for the rolled columns and beams used in WTC 1 and WTC 2 (WTCI-243-L)	379

CHAPTER THREE

FABRICATION OF STRUCTURAL STEEL

01 GENERAL

301.100 Structural steel shall be fabricated complete as shown in the Drawings and in approved details shown in the shop drawings.

301.200 The steel furnished for each location shall have a minimum yield point equal to that scheduled in the Drawings, and shall be selected from the applicable steel specifications listed in Chapter Two, MATERIALS.

301.300 All steel shall be ASTM A36 for locations where a specific strength requirement is not stated in the Drawings.

02 IDENTIFICATION

302.100 The Contractor shall identify all steel which will be used in the work beginning at the mill and shall maintain identification at all times thereafter including during fabrication. The method used shall make both the grade and yield point of the steel readily identifiable. Identification shall be maintained after fabrication.

302.200 The Contractor shall identify each member or assembly with a system

SPECIFIC REQUIREMENTS

303.100 Flame cutting by hand shall not be performed without the Engineer's approval. Handcut surfaces shall be made smooth by chipping, planing or grinding.

303.200 Fabricated material containing sharp kinks or bends shall be rejected. Material straightened prior to fabrication shall be carefully examined for signs of distress or other defects before being placed in fabrication. Distressed or otherwise defective material shall not be used in the work.

303.300 Where required by the Contract Documents, surfaces shall be milled, or finished by other approved means. All finishing shall be clearly shown in the shop drawings.

303.400 Bolt holes and similar holes shall be punched, drilled, sub-punched or sub-drilled and reamed, and shall not be made or enlarged by gas cutting.

303.500 Holes required by the Erector and shown on the Drawings prior to approval of Shop Drawings shall be furnished without cost.

4 FABRICATION TOLERANCES

304.100 Fabrication tolerances shall conform to the requirements of the AISC Specification and AWS D1.0, as supplemented by specific requirements contained in the Drawings and Specifications. In no case shall tolerances exceed those obtainable by the best modern shop practice.

SPECIAL REQUIREMENTS

Floor trusses shall be fabricated to fall within the tolerances listed below:

1.	Camber at midspan	± 3/8 inch
2.	Deviation from design depth	± 1/4 inch
3.	Longitudinal deviation of panel point along chord	± 1/4 inch
4.	Vertical deviation of panel point from longitudinal axis	± 1/4 inch
5.	Deviation in over-all length	± 3/8 inch
6.	Maximum sweep (in inches)	$\frac{\text{over-all length (in feet)}}{40}$

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05 QUALITY CONTROL AND INSPECTION:

105.100 Supervision and Inspection

All fabrication and welding of floor trusses shall be

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All production line panel point welds will undergo "on-line" non-destructive testing by hydraulic wedge action testers which apply pre-determined, accurately measured test forces. The force applied by the wedge action tester will subject the welds tested to a minimum force across the welds of 2.25 times the calculated design force carried by the highest loaded member at the subject joint. The wedge action testing device is arranged so that the test force is applied to the two welds on one side of each panel point, resulting in mechanical inspection of 50% of all production line welds.

In addition, production line panel point welds on completed trusses will be spot-checked by vertical double shear tests. These spot-check tests will include the first completed truss in each run of a given style and a

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Full scale load tests will be performed on completely fabricated truss components. A minimum of one load test will be made for each identified truss style designated on Design Data Sheets D105-T1 through D105-ET10, inclusive (see Pages 0-11 and 0-12). Test loads will be applied by hydraulic loading in a test frame designed for this purpose. Load will be measured by electric load cells and center span deflection will be checked by dial gages. Deflection and recovery data will be measured and recorded for each increment of load application or removal for at least one load test of each style referred to above. Deflection at design load and maximum applied load will be recorded for all load tests. One copy of the report of each load test, whether successful or unsuccessful, will be forwarded to The Authority.

105.103 Physical Tension Tests

Tension tests on truss components, chord angles, and webs will be performed at random on selected sample members included in the normal truss fabrication. Reports of these tests will be forwarded to the Engineer and to S-H-C-R.

105.104 Marking

All trusses will be subjected to final inspection by The Contractor's Quality Control personnel. Trusses which conform to the requirements of the foregoing Quality Control and Inspection program and to the Specifications will be marked by a painted erection mark for each type of truss. Identification tags will be affixed to each truss or each bundle of trusses of the same style and erection mark

105.105 Access to Plant

Free access to the plant of the truss manufacturer and

the available inspection and test facilities will be offered the qualified inspectors representing the Authority for observation of the test and inspection procedures outlined herein.

105.106 Additional or Extra Tests

Any testing requested beyond that identified herein shall be for the account of the Authority.

CHAPTER FOUR

WELDING OF STRUCTURAL STEEL

401 GENERAL REQUIREMENTS

401.100 Welding of structural steel shall conform to the requirements of the AISC Specification and AWS D1.0, except where the AISC Specification of AWS D1.0 is specifically modified or supplemented by information included in the Drawings or Specifications.

402 QUALIFICATION AND CERTIFICATION OF WELDERS

402.100 Welders and welding operators (except resistance welding machine operators) shall have passed the applicable AWS qualification tests prescribed in AWS D1.0, Appendix D, Parts II and III. AWS qualification tests shall be supervised and witnessed by an agency approved by the Engineer. The approved agency shall issue certified test reports which describe the tests performed and indicate the results of the tests. Certification papers issued by the approved agency shall clearly state the types of work the certified welder or welding operator is qualified to perform. Certification is to be achieved in the 12 months preceding the date the subject welder begins work under the Contract. AWS qualification tests and certification shall be paid for by the Authority and witnessed by the Engineer's designated representative.

403 WELDING PROCEDURE SPECIFICATIONS AND JOINT QUALIFICATIONS

403.100 Joints conforming to the details specified in AWS D1.0, Articles 209, 210, 211, 212, 213 and 214 and welded in accordance with the

requirements of Sections 3 and 4 of AWS D1.0 are designated prequalified with the following exceptions:

403.101 Partial penetration butt welds

403.102 Welds in steels with yield points exceeding 50 ksi.

403.200 The Contractor shall develop welding procedure specifications for all welded joints. No joint shall be welded until the welding procedure specification for that joint has been approved by the Engineer.

403.300 For steels with specified yield points exceeding 50 ksi, welding procedure specifications shall be qualified in accordance with Article 502, AWS D1.0. No work containing a joint requiring qualification shall be fabricated before welding procedure specifications for that joint are qualified by the Contractor and approved by the Engineer. Records of procedure tests shall be maintained by the Contractor. Test reports shall be certified by the Contractor and submitted to the Engineer for examination.

404 PREHEAT AND INTERPASS TEMPERATURES

404.100 Preheat and interpass temperatures shall be those specified in the welding procedure specifications prepared by the Contractor and approved by the Engineer.

405 WELDING ELECTRODES AND FLUX

405.100 Manual welding electrodes shall be those scheduled in the Drawings and shall in all cases be those specified in the approved welding procedure specifications.

405.200 Welding electrodes and flux for submerged arc welding shall conform to Section 202, MATERIALS.

405.300 Gas metal-arc welding materials, where approved for use in the work, shall conform to Section 202, MATERIALS, and to the requirements of the approved welding procedure specification.

405.400 Electronically controlled resistance welding of truss panel points shall be approved provided the submitted quality control provisions for weld strength and consistency are satisfied.

Resistance welds shall consist of four point scale free welds developed by pressure contact of beaded chord angles and round web sections. Where fillers and single web intersections occur, two point welds shall be developed by pressure contact.

Welding cycle, welding pressure and current applications shall be electronically controlled to assure uniform scale free resistance welds in all cases to develop the strength required in single or double shear.

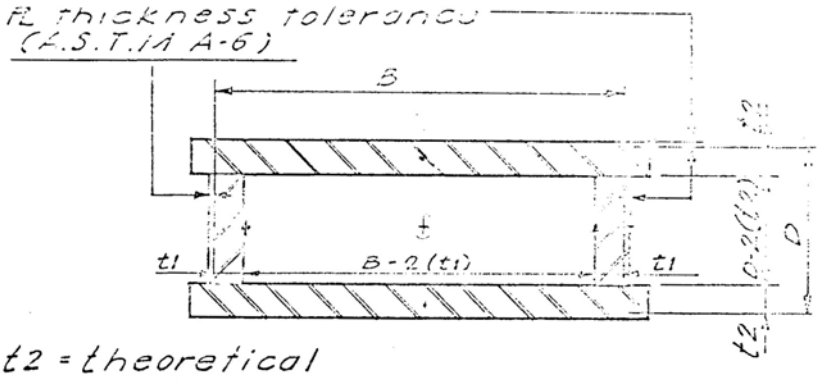
Certification as to the weld strength as required by the submitted quality control program shall be made available to the Engineer.

303.600 The Contractor may substite tees cut from rolled shapes in lieu of tees built up from plates at the beam and girder seat connections in the drawings. Tees cut from rolled shapes shall be of a thickness and grade equal to or greater than the thickness and grade of plates presently shown in the drawings.

303.700 Where box beams in this Contract connect to columns by means of a beam seat and top flange connection plate, the top flange connection plate may at the Contractor's option be shipped loose with the box beam. No shims for "loose" top flange connection plates are required.

303.800 The Contractor may elect to shop splice box core columns at each floor, at a point 3' -0" above the floor line. The edge preparation and welding at these shop splices shall conform to the edge preparation and welding shown for field splices at box core columns in Drawing Book #3. Each individual section shall be milled, welded up, and then the completed column shaft shall be milled to final length.

303.900 The Contractor may substitute a type 300 column, using plates of the same grade, equivalent area and section modulus, for the type 400 box columns with a middle web. In this case, the Contractor shall provide any transitional section required to suit the type 400 or type 500 columns below the 9th story splice. All fillet welds shall be in accordance with Drawing Book #3.



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t1 & t2 = theoretical thickness.

DETAILING DIMENSIONS

requirements of Sections 3 and 4 of AWS D1.0 are designated as prequalified.

403.200 The Contractor shall develop welding procedure specifications for all types of welds such as: manual, semi-automatic and automatic procedures for fillet, butt and groove welds. No welding shall be done until the welding procedure specification for that type of weld has been approved by the Engineer.

404 PREHEAT AND INTERPASS TEMPERATURES

404.100 Preheat and interpass temperatures shall be those specified in the welding procedure specifications prepared by the Contractor and approved by the Engineer.

405 WELDING ELECTRODES AND FLUX

405.100 Manual welding electrodes shall be those scheduled in the Drawings and shall in all cases be those specified in the approved welding procedure specifications.

405.200 Welding electrodes and flux for submerged arc welding shall

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105 INSPECTION, QUALITY CONTROL AND TESTS

105.100 Quality Control and Tests (see Contractor's letter of 6/2/67 attached hereto)

105.101 The Contractor shall comply with the quality control and testing program annexed hereto and forming a part hereof during the course of the work to assure that all work conforms to the Contract Documents.

105.102 Materials Control

All steel plates and shapes are subject to visual inspection on receipt into the material receiving yard.

Unsatisfactory material is identified at this point and referred to the Engineering Department for disposition.

Copies of mill test reports are received by the Quality Control Department. Heat numbers on all steel items are identified and compared to mill test reports to verify use of proper material.

Heat numbers are transferred to each main component by paint stick prior to cutting.

If Authority requires welders to be re-certified, Authority will pay the cost of re-certification.

Each welding operator is assigned a steel stencil identification symbol. Each welding operator shall stamp for identification purposes each weld as it is completed.

Preheat temperatures shall be checked by appropriate "tempsticks" prior to performing welds.

105.105 Testing by Contractor

Non-destructive testing of welds shall be accomplished by either magnetic particle and/or dye penetrant methods. The method selected shall be at the discretion of the quality control supervisor of the Contractor.

Time of such testing and selection of welds to be tested shall be the responsibility of the quality control supervisor. However, these functions will be carried out in a manner so as to provide a minimum of delays to

105.107 Built-up Members

On completion of fit-up and prior to welding, inspect for material size, thickness and dimensional conformance with applicable shop drawings and tolerances in accordance with the specifications.

Inspect for layout of mill line for shop splice.

Inspect welding of built-up members per 105.106.

Perform non-destructive testing per 105.105.

Perform final inspection of built-up members for full compliance with Contract documents. Final acceptance to be signified on record shop drawing for each member.

Final acceptance to be signified on record shop drawing for each member inspected.

105.109 The Contractor shall submit mill test reports to the Engineer for all material used in the work.

The Contractor shall report the location and quality of all corrective work.

The Authority's inspection will be provided at no cost to the

Building Components (Columns and Beams)

STANRAY PACIFIC CORPORATION
subsidiary of STANRAY CORPORATION

11633 SOUTH ALAMEDA STREET · LOS ANGELES, CALIFORNIA 90002 · (213) 566-2111

June 2, 1967

Mr. Lester Feld
The Port of New York Authority
111 Eighth Avenue at Fifteenth Street
New York, New York

Subject: World Trade Center
Contract No. WTC 217.00 - Revised Quality Control Program

Dear Lester:

Enclosed you will find two copies of the Welding Procedures to be incorporated into our Quality Control Program which is outlined in section 105 of Contract No. WTC 217.00. This constitutes our entire Quality Control and Testing Program.

The Inspection Requirements referred to as item 2 C in your letter of May 25, is now completed and will be mailed to you on Monday, June 5.

Yours very truly,

STANRAY PACIFIC CORPORATION

F. E. Allen
Controller

dh
Encl.

June 2, 1967

WELDING PROCEDURES

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Fillet Welds - Semi Automatic Innershield Wire

Weld Type: IS-1

Material:	A36
Electrodes:	NS-3M Flux Core
Weld Position:	1F and 2F
Electrode Size:	0.120"
Amperage:	425 to 550
Voltage:	28 to 36
Preheat:	To 3/4" T - Nominal Temperature Over 3/4" T - 100° F per inch thickness to 250° F maximum
Current:	D.C. reverse polarity

Fillet Welds - Tandem Wire Submerged Arc

Weld Type: SA-1

Material:	A36
Electrodes & Flux:	A.S.T.M. - A558
Weld Position:	Flat
Electrode Size:	7/32" and 3/16"
Amperage:	7/32" - 750 to 950 3/16" - 700 to 850
Voltage:	7/32" - 35 to 40 3/16" - 35 to 40
Preheat:	To 3/4" T - Norminal Temperature Over 3/4" T - 100° F per inch thickness to 250° F maximum
Current:	7/32" - D.C. straight polarity 3/16" - A.C.

Fillet Welds - Triple Wire Submerged Arc

Weld Type: SA-2

Material:	A-36
Electrodes & Flux:	A.S.T.M. - A558
Weld Position:	Flat
Electrode Size:	3/16", 3/16" and 5/32"
Amperage:	3/16" Lead Wire, 1000 to 1200 3/16" No. 2 Wire, 850 to 1000 5/32" No. 3 Wire, 750 to 900
Voltage:	3/16" Lead Wire, 35 to 40 3/16" No. 2 Wire, 38 to 43 5/32" No. 3 Wire, 40 to 46
Preheat:	To 3/4" T - Nominal Temperature Over 3/4" T - 100° F per inch thickness to 250° F maximum
Current:	Lead Wire: D.C. straight polarity No. 2 Wire: A.C. No. 3 Wire: A.C.

WELDING PROCEDURES

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Complete Penetration Welds, Manual Electrodes
Partial Penetration Welds, Manual Electrodes

Weld Type: MB-1

Joint Specification: A.W.S. D1.0, Appendix E2 and E4

Material:	A36
Electrodes:	E7018
Weld Position:	1G; 2G; 3G
Electrode Size:	5/32" and 3/16"
Amperage:	5/32" - 150 to 200 3/16" - 180 to 260
Voltage:	5/32" - 20 to 26 3/16" - 22 to 27
Preheat:	To 3/4" T - Nominal Temperature Over 3/4" T - 100° F per inch thickness to 250° F Maximum
Current:	D.C. reverse polarity or A.C.

Complete Penetration Welds, Semi Automatic Innershield
Partial Penetration Welds, Semi Automatic Innershield

Weld Type: IS-2

Joint Specification: A.W.S. D1.0, Appendix E2 and E4

Material:	A36
Electrodes:	NS-3M
Weld Position:	1G and 2G
Electrode Size:	0.120"
Amperage:	425 to 500
Voltage:	26 to 30
Preheat:	To 3/4" T - 70° F Over 3/4" T - 100° F per inch thickness to 250° F maximum
Current:	D.C. reverse polarity

WELDING PROCEDURES

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Complete Penetration Welds, Manual and Semi Automatic
Partial Penetration Welds, Manual and Semi Automatic

Weld Type: CB-1

Joint Specification: A.W.S. D1.0, Appendix E2 and E4

Material:	A36
Electrodes:	Manual - E7018 root passes Semi Automatic - NS3M Innershield
Weld Position:	1G and 2G
Electrode Size:	E7018 - 5/32" NS3M - 0.120"
Amperage:	5/32" E7018 - 150 to 220 NS3M - 475 to 500
Voltage:	E7018 - 22 to 25 NS3M - 28 to 32
Preheat:	To 3/4" T - 70° F Over 3/4" T - 100° F per inch thickness to 250° F maximum
Current:	D.C. reverse polarity

Manual Fillet Welds - Low Hydrogen Electrodes

Weld Type: MF-S1

Material:	A572, Grade 50
Electrodes:	E7018
Weld Position	1F, 2F, 3F
Electrode Size:	5/32" and 3/16"
Amperage:	5/32" - 150 to 200 3/16" - 200 to 250
Voltage:	5/32" - 20 to 24 3/16" - 21 to 25
Current:	D.C. reverse polarity or A.C.
Preheat:	To 3/4" T - 70° F

WELDING PROCEDURES

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Weld Type: MF-S2

Material:	A572, Grade 50
Electrodes:	E7028
Weld Position:	1F and 2F
Electrode Size:	3/16" and 7/32"
Amperage:	3/16" - 220 to 300
	7/32" - 250 to 350
Voltage:	3/16" - 23 to 27
	7/32" - 23 to 28
Current:	D.C. reverse polarity or A.C.
Preheat:	To 3/4" T - 70° F
	Over 3/4" T - 100° F per inch thickness to 250° F maximum. 300° F maximum interpass temperat
Temperature Control:	"Tempil-Stik" Crayons or equal

Semi Automatic Fillet Welds - Innershield Electrodes

Weld Type: IF-S1

Material:	A572, Grade 50
Electrodes:	NS3M Flux Core
Weld Position:	1F and 2F
Electrode Size:	0.120"
Amperage:	425 to 500
Voltage:	28 to 36
Preheat:	To 3/4" T - 70° F
	Over 3/4" T - 100° F per inch thickness to 250° F maximum. 300° F maximum interpass temperatu
Temperature Control:	"Tempil-Stik" Crayons or equal

Submerged Arc Fillet Welds - Dual Tandem Wire

Weld Type: SA-S1

Material:	A572, Grade 50
Electrodes & Flux:	A.S.T.M. - A558
Weld Position:	Flat
Electrode Size:	7/32" and 3/16"
Amperage:	7/32" - 850 to 950
	3/16" - 800 to 900
Voltage:	7/32" - 35 to 40
	3/16" - 35 to 40
Current:	7/32" - D.C. straight polarity
	3/16" A.C.
Travel Speed:	30 to 36 inches per minute
Preheat:	To 3/4" T - 70° F
	Over 3/4" T - 100° F per inch thickness to 250° F maximum. 300° F maximum interpass temperat
Temperature Control:	"Tempil-Stik" Crayons or equal

WELDING PROCEDURES

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Submerged Arc Fillet Welds - Triple Tandem Wire

Weld Type: SA-2S

Material:	A-572, Grade 50
Electrodes & Flux:	A.S.T.M. - A558
Weld Position:	Flat
Electrode Size:	3/16", 3/16" and 5/32"
Amperage:	3/16" lead wire - 1100 to 1200
	3/16" No. 2 wire - 900 to 1000
	5/32" No. 3 wire - 850 to 900
Voltage:	3/16" lead wire - 40
	3/16" No. 2 wire - 43
	5/32" No. 3 wire - 46
Current:	Lead wire - D.C. straight polarity
	No. 2 wire - A.C.
	No. 3 wire - A.C.
Travel Speed:	45" per minute
Preheat:	To 3/4" T - 70° F
	Over 3/4" T - 100° F per inch thickness to 250° F maximum. 300° F maximum interpass temperature
Temperature Control:	"Tempil-Stik" Crayons or equal

Complete Penetration Welds - Manual, Low Hydrogen Electrodes
Partial Penetration Welds - Manual, Low Hydrogen Electrodes

Weld Type: MB-S1

Material:	A572, Grade 50
Electrodes:	E7018
Weld Position:	1G, 2G, 3G
Electrode Size:	5/32" and 3/16"
Amperage:	5/32" - 150 to 200
	3/16" - 175 to 260
Voltage:	5/32" - 20 to 26
	3/16" - 22 to 27
Current:	D.C. reverse polarity, or A.C.
Preheat:	To 3/4" T - 70° F
	Over 3/4" T - 100° F per inch thickness to 250° F maximum. 300° F maximum interpass temperature
Temperature Control:	"Tempil-Stik" Crayons or equal

WELDING PROCEDURES

Page - 7 -

Complete Penetration Welds - Semi Automatic Innershield
Partial Penetration Welds - Semi Automatic Innershield

Weld Type: IB-S2

Material:	A572, Grade 50
Electrodes:	NS3M Flux Core
Weld Position:	1G and 2G
Electrode Size:	0.120"
Amperage:	425 to 500
Voltage:	30 to 34
Current:	D.C. reverse polarity
Preheat:	To 3/4" T - 70° F
	Over 3/4" T - 100° F per inch thickness to 250° F maximum. 300° F maximum interpass temperature
Temperature Control:	"Tempil-Stik" Crayons or equal

Complete Penetration Welds - Manual Electrode and Semi Automatic ...

WELDING PROCEDURES

PAGE-8-

CRITERIA FOR ADJUSTING PERCENTAGE OF NON-DESTRUCTIVE TESTING

Non-destructive testing of welds will be performed using either the dye penetrant and/or the magnetic particle process. Welds will be checked for performance with applicable ASTM specification. Non-destructive testing of welds will be performed on 10% of all members.

100% of the linear footage of each weld will be checked on the first 10 columns and on the first 10 beams fabricated. Provided that all

The Port of New York Authority
111 Eighth Avenue
New York, New York 10011

The World Trade Center

FABRICATED STEEL

Contract WTC-217.00

June 6, 1967

ADDENDUM #D2

This addendum should be physically annexed to the Form of Proposal, but the Form of Proposal will in any case be construed as though this addendum had been so physically annexed and all addenda issued will be considered incorporated in the Form of Proposal.

In Drawing Book #3, Page 56, dated 9/12/66, revise the last two items in the table to read as follows:

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

Consulting Structural and Civil Engineers • 230 Park Avenue, New York, N. Y. 10017 • Mu. 9-8874

John B. Skilling *Helge J. Helle* • *John. V. Christiansen* • *Leslie E. Robertson*

Consultants
Harold L. Worthington
Joseph F. Jackson

June 5, 1967

Mr. Malcolm P. Levy
Port of New York Authority
World Trade Center Planning
111 Eighth Avenue
New York, New York 10011

Reference: The World Trade Center
Contract WTC-217.00, Stanray Pacific
Inspection, Testing, Coordination and
Supervision at Fabricating Plant

Gentlemen:

Contract WTC-217.00 contains provisions stipulating that irrevocable title to "built-up members" and to "building components" passes to PNYA after the completion of detailed inspection and acceptance by PNYA. The contract also states that PNYA assumes all risk for loss or damage of fabricated units after they are placed in the hands of the shipper. These contract provisions, coupled with the major use of steel produced in Japan and England, make it necessary for PNYA to implement a comprehensive program of supervision, coordination, inspection and testing of the work performed by Stanray Pacific Corporation. The coordination function assumes particular importance because of the large quantities of steel to be supplied from abroad. Stanray Pacific must receive delivery of this steel in time to meet the approved progress schedule which, in turn, forms an integral part of the overall progress schedule for The World Trade Center.

Accompanying this letter is a comprehensive program for supervision, coordination,

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

The Resident Engineer will be in a position to work closely with the mill, the detailer, the fabricator and the shipper. His responsibility will be limited to that of reviewing and reporting on the work and to directing the activities of the testing and inspection agency. He will establish full-time residence at the fabricating plant, beginning approximately 5 weeks prior to the beginning of fabrication and will remain in residence until such time as PNYA and SECR determine that weekly visits are sufficient.

The program proposed herein will provide PNYA with [illegible]

COORDINATION, SUPERVISION, INSPECTION AND TESTING

OF FABRICATED STRUCTURAL STEEL

Stanray Pacific, Contract WTC-217.00

A. Scope

1. Supervision, coordination, inspection and testing services shall be performed during the course of the work in order to ensure proper interpretation of the technical provisions of the contract, to provide PNYA assurance through adequate documentation that fabricated steel conforms to the Contract Documents, and to assure on-time delivery of fabricated steel to PNYA by identifying potential sources of delay at the earliest possible moment.
2. Detailed inspection by check list and by non-destructive testing must be performed prior to final acceptance of:
   a) each "built-up member" and
   b) each "building component"

   to enable PNYA and SHCR to identify unacceptable fabricated items prior to final acceptance, such acceptance being irrevocable under the terms of the contract.

B. Personnel

1. Supervision, coordination, inspection and testing activities shall be managed by a Resident Engineer (a professional engineer employed full time by SHCR).
2. Inspection and testing activities shall be performed by qualified and experienced technicians in the full time employ of an independent testing agency retained and paid by PNYA. The testing agency shall submit to PNYA and SHCR detailed resumes of the qualifications and experience of each man proposed for assignment to the work.

C. Records and Drawings

1. The fabricator shall provide the Resident Engineer with one copy of each of the following:
   a) Each advance bill for mill order
   b) Each bill of lading for shipment of steel plate

SKILLING-HELLE-CHRISTIANSEN-ROBERTSON

c) Each certified mill test report
d) Each typical detail sheet
e) Each approved erection plan
f) Each approved steel detail drawing as corrected to reflect any and all approval notations.
g) Each shop bill of material
h) Each fastener and welding material list
i) Each shipping bill or bill of lading or both for completely fabricated and accepted components
j) The fabricator's Quality Control Program for the work.
k) Test documents certifying qualification in accordance with the provisions of AWS D1.0-66 for each
   (1) welder,
   (2) welding machine operator, and
   (3) welding procedure specification applicable to the work.

2. PNYA and SHCR will provide the Resident Engineer with the following:
   a) A complete set of contract documents including all revisions to the contract documents
   b) One print of each approved or corrected shop drawing
   c) One copy of the current approved fabrication schedule
   d) One copy of each mill inspection report
3. The Resident Engineer will:
   a) Prepare a daily report of his activities, and will submit these reports weekly, or more often where special conditions warrant
   b) Maintain a complete up-to-date file of all welding certification documents
   c) Maintain a complete file of test and inspection reports prepared by the independent testing agency.
   d) Maintain complete and orderly files of all other data provided to the Resident Engineer by the fabricator, PNYA and SHCR.
4. The independent testing agency will prepare test and inspection reports on a daily basis. Test reports shall record the results of each test or related group of tests and shall clearly identify each member or component tested, type of test made, and results of each test. Individual inspection reports shall be made for each inspector's work and shall specifically note each member or component inspected, specific items included in the inspection, and results of the inspection

D. Supervision

1. Supervision shall be performed by the Resident Engineer.
2. Supervision shall include:
   a) A complete study of the fabricator's quality control procedures, proposed fabrication procedures, provisions for storage of incoming material, for completed "built-up members" and for "building components," and provisions for loading and shipping of completed "building components". This study will be made by the Resident Engineer prior to the beginning of fabrication. The Resident Engineer will submit a complete report and analysis of his findings to SHCR and PNYA prior to the beginning of fabrication.
   b) Liaison between PNYA and SHCR on the one hand, and Dovell Engineering Company on the other, regarding the preparation and approval of shop drawings.
   c) Ensure proper interpretation of the Drawings and Specifications by assistance to the fabricator. Where the Resident Engineer determines that a ruling from the Engineer is in order, he will expedite receipt of the Engineer's ruling by immediately reporting all pertinent data for SHCR and PNYA.
   d) Direction of the work performed by the independent testing agency and its inspectors. The scope of inspection and testing is defined in Part C of this outline. Should conditions occur during the course of the work which, in the judgment of the Resident Engineer, warrant additional inspection or tests, the Resident Engineer shall have the authority to order such additional inspection or tests as he deems necessary. The Resident Engineer shall report to SHCR and PNYA immediately all such instances.
   e) Continual surveillance of the quality of the work including
      (1) Checking material as received and stored in the receiving and storage yard for
         (a) Grade, heat number and marking
         (b) Condition
         (c) Dimensions
         (d) Method of storage
      (2) Cross-checking of certified mill test reports against material received at the receiving and storage yard. Items (a) and (b)

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shall be performed immediately upon receipt of material at the receiving and storage yard.

(3) Random checking during fabrication of width, length and thickness of plate, layout work, edge preparation, jigs and templates, welding of main members, preparation of detail material, welding of detail material, distortion control, milling of columns, and other items as required.

(4) Surveillance of the fabricator's quality control program as actually implemented by the fabricator, including review of any reports prepared by the fabricator for submission to SHCR and PNYA.

(5) Continual direction of inspection and testing work performed to ensure adherence to the amounts of inspection and testing outlined in Parts 6F and 7G herein.

E. Coordination

1. Coordination shall be performed by the Resident Engineer with the assistance of inspectors from the independent testing agency.

2. Coordination shall include

a) Continual scrutiny of the approved progress schedule.

b) Organization of advance bills of material into groups based on dates material must be delivered to conform to progress schedule.

c) Review of bills of lading for shipment of material against advance bills of material and approved progress schedule.

d) Check of material actually on hand in receiving and storage yard against a), b), and c) above. The Resident Engineer shall notify the fa. cator, SHCR and PNYA immediately upon discovery of any discre ncy or omission.

e) Check : each unit from the beginning of fabrication until loaded for pment. The date and time shall be clearly recorded on the Res nt Engineer's copy of the applicable shop drawing and erection dr ng for

(beginning of fabrication

, final acceptance of "built-up member"

(3) final acceptance of "building component"

(4) completion of loading for shipment.

The Resident Engineer shall notify the fabricator, SHCR and PNYA immediately should any unit fall behind schedule, and shall notify

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SHCR and PNYA promptly of the date fabricated components actually leave the fabricator's yard.

F. Inspection

1. Inspection shall be performed by qualified and experienced structural steel inspectors in the full time employ of the independent testing agency.
2. Only inspectors approved by PNYA and SHCR shall be assigned to the work. Approval will be based on review of detailed résumés of each inspector's qualifications, experience and ability to perform the required work.
3. Generally, one full time inspector shall be assigned to each work shift. The Resident Engineer shall have the authority to increase the number of inspectors working in a given shift in accordance with amount of inspection work to be performed, or to reduce or increase the hours worked by any inspector as work load varies.
4. Duties of inspectors will be as follows:
   a) Assisting the Resident Engineer as required in analyzing and cross-checking advance bills of material, bills of lading for material and certified mill test reports
   b) Checking each plate upon arrival at the receiving and storage yard for
      (1) Heat number and specification conformance
      (2) Condition
         (a) Edge defects (laminations, slag inclusions)
         (b) Surface defects
         (c) Damage (bends, kinks)
   c) Checking of "built-up members" during fabrication
      (1) Plates
         (a) Heat number and yield point.
         (b) Length, width and thickness
         (c) Tolerance conformance
         (d) Edge and surface defects
      (2) Jigs, templates and positioners
         (a) Suitability
         (b) Dimensional accuracy
         (c) Alignment
      (3) Welding
         (a) Edge preparation
         (b) Fit-up (proper use of tack welds. diaphragm plates, jigs)

(c) Position for welding
(d) Flux, electrode, preheat, type of welding equipment, voltage and amperage for conformance to welding procedure specification
(e) Visual check of 100% of completed welds
(f) Select lengths of weld for non-destructive testing to be performed after member cools

(4) Fully welded members shall be checked after cooling for conformance to the required tolerances (camber, sweep, out-of-square)

(5) Finishing
(a) Theoretical centerline
(b) Milling of first end for perpendicularity to theoretical centerline
c) Check layout of length for milling second end including corrections to theoretical length for temperature and shortening under load
(d) Check of perpendicularity to theoretical centerline of second end
(e) Final check of actual length after milling is complete

d) Checking of "building components" during fabrication
(1) Heat number and yield point of detail material
(2) Proper size and weight of steel sections or thickness of plate
(3) Layout of detail material for proper location of holes, copes and cuts
(4) Fit-up of detail material
(a) Proper fit-up for welding
(b) Proper location off theoretical column centerline
(5) Visual check of 100% of detail welding
(6) Select lengths of detail welds for non-destructive testing

e) Final check
(1) Check main material for dimensions
(a) Length
(b) Width
(c) Thickness
(2) Check main material for conformance to steel spec. A36, etc.

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(3) Check basic dimensions
   (a) Overall length
   (b) Sweep, camber, out-of-square
   (c) Theoretical centerline
   (d) Finished surfaces for 90° angle to centerline

(4) Check detail material
   (a) Length, width, thickness, copes
   (b) Hole patterns, edge preparation, etc.
   (c) Conformance to steel specifications
   (d) Location in relation to theoretical centerline
   (e) Location longitudinally
   (f) Freedom of edges from burr, lamination, slag inclusion, etc.
   (g) Cleaning of steel
   (h) Protection of milled surfaces
   (i) Accurate and clear marking

5) Checking will be against structural drawings wherever possible. Results of inspection will be recorded on the Resident Engineer's record set of shop drawings.

Testing

1. Testing activities will be performed by personnel in the full time employ of the testing laboratory. Non-destructive testing will be performed by persons fully qualified, experienced and capable in the non-destructive testing technique used.
2. Testing activities fall into two categories:
   a) Non-destructive testing performed at the material receiving and stor yard and in the fabricating works
   b) Testing performed at the testing laboratory
3. Non-destructive testing may be divided into five categories
   a) Visual inspection (including measurements)
   b) Dye penetrant inspection
   c) Magnetic particle inspection
   d) Ultrasonic inspection
   e) Radiographic inspection
4. Visual inspection will ascertain the locations where other types o: testing will be employed.

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5. Dye penetrant inspection will be used as a random spot check of welds where such inspection is judged desirable by either the inspector or the Resident Engineer.
6. Magnetic particle inspection will be used to inspect a minimum of 5 percent of all member and detail welds.
7 Ultrasonic inspection will be used where the Resident Engineer determines special conditions warrant this type of inspection.
8. Radiographic inspection will not be required for the subject work.
9. Testing performed at the testing laboratory falls into three categories:
   a) Testing of specimens for welder and welding machine operator qualification tests
   b) Mechanical tests of steel plate or weld metal
   c) Chemical (check) analysis of steel plate or weld metal

   It is anticipated that only a) above will be required. However, should special conditions warrant, the Resident Engineer shall have the authority to call for tests listed under b) and c) in the number judged necessary by the Resident Engineer.

SKILLING-HELLE-CHRISTIANSEN-ROBERTSON

D R A F T 8/25/67

United States Testing Company
1514 Park Avenue
Hoboken, New Jersey

Gentlemen:

The undersigned, The Port of New York Authority, hereinafter referred to as the "Authority", hereby offers to retain The United States Testing Company, hereinafter referred to as 'U. S. Testing" to furnish to the Authority for such periods of time as the Construction Manager or Assistant Construction Manager of the World Trade Center of the Authority, hereinafter called the 'Manager" may require, the services of such number of experienced and qualified steel inspectors and field and laboratory technicians who are qualified to perform the services listed In Appendix 1 attached hereto and forming a part hereof in connection with such quantities of steel to be incorporated in the World Trade Center being constructed by the Authority in the City of New York as may be fabricated by the Stanray Pacific Corporation at their facilities located in Los Angeles, California and at the direction of the Manager to perform physical and chemical tests on foreign steel samples which will be forwarded to the U. S. Testing Laboratories in Hoboken, New Jersey. U. S. Testing shall not, without its further consent, either express or implied, be obligated to furnish such services after December 31, 1970.

The Authority will obtain entrance for U. S. Testing to fabrication shops where U. S. Testing is required to perform its services and will furnish to U. S. Testing necessary technical specifications, drawings, shipment dates, and other information required for it to perform its services hereunder.

APPENDIX NO. I

SCOPE OF DUTIES

F. Inspection

1. Inspection shall be performed by qualified and experienced structural steel inspectors in the full time employ of the independent testing agency.

2. Only inspectors approved by PNYA shall be assigned to the work. Approval will be based on review of detailed resumes of each inspector's qualifications, experience and ability to perform the required work.

3. Generally, one full time inspector shall be assigned to each work shift. The Supervising Engineer to be supplied by the Authority shall have the authority to increase the number of inspectors working in a given shift in accordance with amount of inspection work to be performed, or to reduce or increase the hours worked by any inspector as work load varies.

4. Duties of inspectors will be as follows:

   a) Assisting the Supervising Engineer as required in analyzing and cross-checking advance bills of material, bills of lading for material and certified mill test reports

   b) Checking each plate upon arrival at the receiving and storage yard for

      (1) Heat number and specification conformance

      (2) Condition

         (a) Edge defects (laminations, slag inclusions)

         (b) Surface defects

         (c) Damage (bends, kinks)

   c) Checking of "built-up members" during fabrication

      (1) Plates

         (a) Heat number and yield point

         (b) Length, width and thickness

         (c) Tolerance conformance

         (d) Edge and surface defects

(2) Jigs, templates and positioners

(a) Suitability

(b) Dimensional accuracy

(c) Alignment

(3) Welding

(a) Edge preparation

(b) Fit-up (proper use of tack welds, diaphragm plates, jigs)

(c) Position for welding

(d) Flux, electrode, preheat, type of welding equipment, voltage and amperage for conformance to welding procedure specification

(e) Visual check of 100% of completed welds

(f) Select lengths of weld for non-destructive testing to be performed after member cools

(4) Fully welded members shall be checked after cooling for conformance to the required tolerances (camber, sweep, out-of-square)

(5) Finishing

(a) Theoretical centerline

(b) Milling of first end for perpendicularity to theoretical centerline

(c) Check layout of length for milling second end including

(5) Visual check of 100% of detail welding

(6) Select lengths of detail welds for non-destructive testing

e) Final check

(1) Check main material for dimensions

(a) Length

(b) Width

(c) Thickness

(2) Check main material for conformance to steel spec. A36, etc.

(3) Check basic dimensions

(a) Overall length

(b) Sweep, camber, out-of-space

(c) Theoretical centerline

(d) Finishes surfaces for 90^{o} angle to centerline

(4) Check detail material

(a) Length, width, thickness, copes

f) Witness and certify qualification of Welders

g) Check Contractor's invoices for quantities of acceptable material

G. Testing

1. Testing activities will be performed by personnel in the full time employ of the testing laboratory. Non-destructive testing will be performed by persons fully qualified, experienced and capable in the non-destructive testing technique used.

2. Testing activities fall into two categories:

a) Non-destructive testing performed on the material receiving end

5. Radiographic inspection will not be required for the subject work.

specimens for welder and welding machine operator a) Testing of

on tests qualificati

tests of steel plate or weld metal b) Mechanical

heck) analysis of steel plate or weld metal c) Chemical (c

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o call for tests listed under b) and c) in the number the authority t

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SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

Consulting Structural and Civil Engineers • 230 Park Avenue, New York, N. Y. 10017 • Mu. 9-5874

John B. Skilling • Helge J. Helle • John. V. Christiansen • Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

April 5, 1967

Port of New York Authority
World Trade Center Planning
111 Eighth Avenue
New York 11, New York

Attention: Mr. Malcolm P. Levy

Reference: The World Trade Center
Mill Inspection of Japanese Steel

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

under which the signature of the Chief Metallurgist or other authorized agent of the mill appears. The correctness of the mill test report may be further attested by the signature of a notary public. The purchaser may have finished material representing each heat checked for chemical composition by check analysis. While this is rarely done in commercial building construction, it is occasionally required in bridge and governmental work. Check analysis is normally performed at the mill, at additional cost, and is sometimes witnessed by an independent testing laboratory. ASTM specification requirements are broader for check analysis than for ladle analysis.

Second, SHCR must, as structural engineers for The World Trade Center, review the documentation of all certified mill test reports to assure that steel conforms to the requirements of the Specifications. The procedure is not involved, consisting of a careful cross-check of all documentation to assure that all material used in the work has been tested and that the results of the tests conform to the requirements of the Specifications

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b. Witness 25 percent of the check analysis tests performed by the mill to assure conformance with ASTM A6 and the requirements of the steel specification. Steel to be subjected to check analysis shall be selected by the independent testing laboratory and should represent about one out of each six heats from which steel is supplied for use in the work.

2. Physical Properties

a. Witness 10 percent of tensile tests performed by the mill to assure conformance to the requirements of the steel specification, ASTM A6, and the applicable portions of ASTM A370.

b. Witness 10 percent of bend tests performed by the mill to assure conformance to the requirements of the steel specification, ASTM A6, and the applicable portions of ASTM A370.

3. Conditioning

a. Should the manufacturer elect to deposit plates in accordance with ASTM A6, the witness shall witness [illegible] 100 percent

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2. Physical Properties

   a. Witness 15 percent of the tensile tests performed by the mill to assure conformance to the steel specification, ASTM A6 or ASTM A20, as applicable, and to the applicable portions of ASTM A370.

   b. Witness 15 percent of the bend tests performed by the mill to assure conformance to the steel specification, ASTM A6 or ASTM A20, as applicable, and to the applicable portions of ASTM A370.

   c. Witness 20 percent of the Charpy impact tests performed by the mill, where required by the steel specification.

   d. Witness 10 percent of the Brinell Hardness tests, where required by the steel specification.

   e. Witness 10 percent of the grain size tests, where required by the steel specification.

   f. Witness all retests, where allowed by the steel specification.

3. Conditioning

   a. Should the manufacturer elect to repair plates in accordance with ASTM A6 or ASTM A20, as applicable, and the provisions of the steel specification, the testing laboratory should witness all conditioning work to assure conformance to the applicable specification requirements.

4. Marking

   a. The testing laboratory should check the marking of steel plate for conformance to ASTM A6 or ASTM A20 and the Specifications, and for proper representation on a certified mill test report

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Last, but of prime importance, the structural steel fabricator must assure himself that all steel conforms to the requirements of the Specifications. The fabricator should do this through the review of mill test reports, checking of material against the mill test reports, and the performance of additional tests where the fabricator deems necessary. In addition, the fabricator must check all plate for correct dimensions, satisfactory finish and freedom from unacceptable laminations.

Very truly yours,

SKILLING-HELLE-CHRISTIANSEN-ROBERTSON

Leslie E. Robertson

LER:e

THE PORT OF NEW YORK AUTHORITY

Stanray Pacific Corporation September 21, 1967

Attention: Mr. R. E. Morris

under the subject contract. However, we will continue as above to offer any assistance we can.

Sincerely,

R. M. Monti

THE PORT OF NEW YORK AUTHORITY

World Trade Department
Guy F. Tozzoli, Director

Malcolm P. Levy, Chief, Planning & Construction Division
R. M. Monti, Construction Manager Telephone (212) 267-7600 Office of the Construction Manager 77 Church St., New York, N.Y. 10007

November 13, 1967

Stanray Pacific Corp.
11633 South Alameda Street
Los Angeles, California 90002

Attention: Mr. R.E. Morris

Subject: WORLD TRADE CENTER - CONTRACT WTC 217.00 - MILL INSPECTION

Gentlemen:

As you know, the Port Authority as part of its overall quality control program on fabricated steel for the World Trade Center, has established a policy of providing mill inspection at all sources, whether foreign or domestic. The scope of this inspection includes independent checking of chemical and physical properties on a random basis. In order to implement this program, each fabricator has been requested to have their suppliers make available to our inspection agency, extra samples. Our inspectors will collect a representative percentage of these samples for independent testing. Some of the testing will be performed by the agency inspecting at the mill, and in the case of foreign sources, some of the samples will be forwarded to the United States for testing.

The independent testing portion of the mill inspection program will be performed as follows:

A. Domestic Sources

1. Steel with yield points less than 50,000 psi - One tension test and one check analysis on samples selected at random from 1 out of 10 heats.

2. Steel with yield points of 50,000 psi and higher - One tensile, one bend test and a check analysis on samples selected at random from 1 out of 10 heats.

Stanray Pacific Corp. November 13, 1967

B. Foreign Sources

1. Steel with yield points less than 50,000 psi - One tension test and one check analysis on samples selected at random from 1 out of 10 heats to be performed abroad.

Stanray Pacific Corp. November 13, 1967

Kindly implement the above procedure immediately on all present and future mill orders and please keep the undersigned advised on any problems that you may experience.

Very truly yours,

for R.M. Monti
Construction Manager
The World Trade Center

CC: J. Endler (TRCC), L. Robertson (SCHR), M. Levy

CABLE PITTDEMOIN
TELEX 086 734

Pittsburgh-Des Moines Steel Company

Engineers
Fabricators
Constructors

NEVILLE ISLAND · PITTSBURGH, PENNSYLVANIA 15225 · AREA CODE 412
PHONE 3..-3000

October 21, 1966

Tishman Realty and Construction Co., Inc.
666 Fifth Avenue
New York, New York 10019

Attention: Mr. James R. Endler,
Assistant Vice President

Reference: The World Trade Center
Quality Control and Testing Program
Structural Steel - Packages I, III & IV

Gentlemen:

We are pleased to transmit herewith our proposed Quality Control and Testing Program for Packages I, III and IV of the Project. We will appreciate early review and comment on this Program so that any adjustments which may be desired can be incorporated into our proposals.

We have had to make important assumptions as to the amount of radiographic or ultrasonic testing of welds which will be required to maintain acceptable quality throughout the work. Therefore, the amount of such testing specified in the enclosed Program is not an expression of judgment on our part as to whether said amount of testing will guarantee a quality level consistent with the service required. Responsibility for this judgment rests with the Owner.

Generally, our weld quality control program is based on the "spot-examination" principle. The quality of welding produced to meet spot-examination requirements will approach that which would be produced for 100 percent inspection. However, spot examination will not insure work of predetermined quality level throughout, and work accepted under spot-examination requirements may still contain defects which might be disclosed under further examination. If all unacceptable weld defects which would be revealed by radiographic or ultrasonic inspection must be eliminated from the structure or specific portions thereof, then 100 percent inspection must be employed, and must be included as a factor in the cost of production.

CABLE: PITTDEMOIN
TELEX: 086-734

PDM Pittsburgh-Des Moines Steel Company

Modern Fabricators Constructors

NEVILLE ISLAND • PITTSBURGH, PENNSYLVANIA 15225 • AREA CODE 412
PHONE 331-1000

November 28, 1966

Tishman Realty and Construction Company, Inc.
666 Fifth Avenue
New York, New York 10019

Attention: Mr. James R. Endler, Ass't. Vice President

Reference: The World Trade Center
Quality Control and Testing Program
Steel - Packages I, III & IV
Amendment No. 1, dated November 25, 1966

Gentlemen:

Amendment No. 1 to our proposed
Testing Program for Packages I, III &
This Amendment is submitted in response
Skilling, Helle and Jackson letter dated
th reference to the comments listed
ction in each case has been as follows:

Enclosed is
Quality Control and T
IV of the Project.
to the Worthington, S
October 27, 1966. Wi
in that letter, our a

mation contained in the first
nt has been incorporated into

1. Infor
comme

Pittsburgh-Des Moines Steel Company

6. Description of production methods, jigs, templates and other means of dimension control have been added as Appendixes B, C and D, and paragraph SP-6.03 has been added referring to these appendixes.

7. Paragraph SP-4.02 has been revised to provide for material delivery in accordance with ASTM A6 and A20 both.

8. A statement regarding life of the proposed painting system has been added as paragraph SP-8.05.

9. Procedures for cutting, de-burring and edge preparations for welding have been outlined by revision of paragraph SP-4.05 and addition of paragraph SP-4.06.

10. Paragraph SP-5.10 has been added to describe the use of welding procedure specifications and joint welding procedure qualification tests in quality control work.

This Amendment No. 1 also incorporates a revised section on Radiographic Inspection into the body of the PDM Quality Control Program. This revision was completed shortly after our original submittal of the Program.

We hope this Amendment will be considered satisfactory response to the comments on our Program, and that the Program may therefore have final approval. We will be pleased to discuss the matter further; however, and will make any additional changes which may be deemed necessary.

Yours very truly,

PITTSBURGH-DES MOINES STEEL COMPANY

James C Dods

James C. Dods,
Special Products Department

JCD/k

Atts.

CABLE: PITTDEMOIN
TELEX: 066-734

Pittsburgh-Des Moines Steel Company

Engineers
Fabricators
Constructors

NEVILLE ISLAND • PITTSBURGH, PENNSYLVANIA 15225 • AREA CODE 412
PHONE 331-3000

December 23, 1966

Tishman Realty & Construction Company, Inc.
666 Fifth Avenue
New York, New York 10019

Attention: Mr. James R. Endler

Reference: The World Trade Center
Quality Control and Testing Program
Amendment No. 2

Gentlemen:

We acknowledge receipt of the Worthington, Skilling, Helle & Jackson letter dated December 20, 1966 regarding our Quality Control Program for the World Trade Center. In accordance with the statement therein that the text of the Program "should be changed", and in compliance with your request by letter dated December 21, 1966, we submit herewith Amendment No. 2, revising our Program to incorporate the items called for by the Engineers, and we will proceed to evaluate our earlier proposals to determine what influence this change may have on them.

Yours very truly,

PITTSBURGH-DES MOINES STEEL CO.

James C. Dods
Special Products Dept.

JCD/k/lsb

Atts.

HAMMOND PRODUCTS

PITTSBURGH-DES MOINES STEEL COMPANY
QUALITY CONTROL AND TESTING PROGRAM

THE WORLD TRADE CENTER

AMENDMENT No. 2 December 23, 1966

The Pittsburgh-Des Moines Steel Company Quality Control and Testing Program for the World Trade Center, dated October 19, 1966 with Amendment No. 1, dated November 25, 1966 is revised as described hereinafter in response to letter dated December 20, 1966 from Worthington, Skilling, Helle & Jackson to Tishman Realty and Construction Company. This Amendment also includes correction of a typographical error in the original Program.

1. Under Section SP-5 WELDING, delete paragraph SP-5.05 on page S-5, and substitute therefor the following:

   SP-5.05 Fillet welds will be inspected as follows:

   a. At least fifty percent (50%) of all fillet welds on quenched and tempered steels will be subjected to magnetic particle inspection 48 hours or more after welding.

   b. At least ten percent (10%) of all fillet welds in steels other than quenched and tempered steels will be subjected to magnetic particle inspection.

2. In Amendment No. 1, Paragraph SP-5.04, Change the first sentence to read as follows: "Inspection of welding by PDM Quality Control Personnel will conform to the requirements of Section 6, AWS D1.0-66".

3. Under Section SP-5, WELDING, in Paragraph SP-5.07b, ninth line, Change "twenty percent (20%)" to "ten percent (10%)".

CABLE PITTDEMOIN
TELEX 0B6 734

PDM Pittsburgh-Des Moines Steel Company

Engineers
Fabricators
Constructors

NEVILLE ISLAND · PITTSBURGH, PENNSYLVANIA 15225 · AREA CODE 412
PHONE 331-3000

June 2, 1967

Tishman Realty and Construction Co., Inc.
666 Fifth Avenue
New York, New York 10017

Attention: Mr. Herbert Weinstein

Reference: The World Trade Center
Contract WTC-213.00
Quality Control and Testing Program

Gentlemen:

In response to the letter dated May 16, 1961, from Mr. James White of Skilling-Helle-Christiansen-Robertson, we submit herewith Amendment No. 3 to the PDM Quality Control and Testing Program.

Some explanatory comment is in order concerning the dimensional control and checking procedures and the revision to Paragraph SP-6.03 in this Amendment No. 3. Mr. White and myself discussed this matter by telephone on May 16, 1967 and due to that conversation it is my understanding now that the information desired here should describe PDM Quality Control Department inspection procedures rather than actual work procedures as covered by Appendix C. Therefore, we have omitted reference to the Appendix and have revised Paragraph 6.03 so that it now concerns inspection procedures. Since approved shop drawings are used for developing these procedures, they cannot be described at this time.

We hope you will find this submittal satisfactory, and that our Quality Control and Testing Program may now be considered an acceptable reference for use with the executed Contract and Technical Specifications.

Yours very truly,

PITTSBURGH-DES MOINES STEEL COMPANY

J. C. Dodz,
Special Products Department

Atts.

cc: Mr. James White
Skilling-Helle-Christiansen-Robertson

HAMMOND PRODUCTS

PITTSBURGH-DES MOINES STEEL COMPANY

QUALITY CONTROL AND TESTING PROGRAM

THE WORLD TRADE CENTER

AMENDMENT NO. 3 JUNE 1, 1967

The Pittsburgh-Des Moines Steel Company Quality Control Program for The World Trade Center, dated October 19, 1966, with Amendment No. 1 dated November 25, 1966 and Amendment No. 2 dated December 23, 1966, is revised as described hereinafter in response to letter dated May 16, 1967 from Skilling-Helle-Christiansen-Robertson.

1. In Paragraph SP-5.03 on page 5 of Amendment No. 1, delete the entire last sentence: "The complete penetration butt welds.... bridge quality welds." and substitute therefore: "The complete penetration butt welds at the tops of the ninth story spandrels will conform to AWS D2.0-66, Article 409."

2. In Paragraph SP-5.11 on page 6 of Amendment No. 1, delete the entire first sentence: "Ultrasonic inspection .... of weldments." and substitute therefore: "Ultrasonic inspection of weldments will be governed by ASTM Standard E164-65, Standard Method for Ultrasonic Contact Inspection of Weldments, and by the PDM Quality Control Manual Section entitled Ultrasonic Inspection. Where there are conflicting requirements, the provisions of ASTM Standard E164-65 will govern".

   Also in paragraph SP-5.11, delete the entire last sentence: "(The PDM Quality Control..... added when complete)".

3. In Amendment No. 1, page 7, delete Paragraph SP-6.03 entirely and substitute therefor:

SP-6.03 PDM Quality Control Personnel will perform such inspections and dimensional checks as they consider necessary to maintain proper control of dimensions and to insure production of column panels which comply with the Specifications and meet the tolerances described therein. Procedures governing control and inspection will be developed to meet the requirements of this Contract, based on approved shop drawings.

4. In Paragraph SP-1.03 on page S-1 of the original Program, delete the entire sentence: "This Program.... of the Project". and substitute therefor: "This Program will govern Structural Steel Fabrication for Contract WTC-213.00, Fabricated Steel, Exterior Wall from Elevation 363 to the ninth story splice, North and South Towers".

5. In Paragraph SP-4.06 on page 4 of Amendment No. 1, in the eleventh and twelfth lines, delete the words ".... to the satisfaction of PDM Quality Control Personnel".

6. Attached is PDM Quality Control Manual Section entitled Ultrasonic Inspection dated 12-15-66, which is hereby made a part of this Quality Control and Testing Program.

12-15-66

1-D-e
Page 1

PITTSBURGH-DES MOINES STEEL COMPANY

QUALITY CONTROL MANUAL

NON-DESTRUCTIVE TESTING

ULTRASONIC INSPECTION

U - 1 GENERAL

U.1.1 - This is a procedure for ultrasonically testing and inspecting welds for internal discontinuities by the reflection method using pulsed waves introduced by direct contact of a search unit with the weldment.

U - 2 METHODS

U.2.1 - Shear Wave Testing

Shear wave inspection shall be performed to a 3% notch sensitivity. The test is conducted using angle projection transducers 45° to 85°; the selection of the angle being dependent on either or both the thickness and the geometry of the weldment.

U.2.2 - Longitudinal Wave Testing

Longitudinal wave inspection can be performed to a near 100% sensitivity with a #4 micro-inch surface finish and at 2½ mc, otherwise satisfactory results depend to a large extent upon the condition of the test surface.

U - 3 EQUIPMENT

U.3.1 - Electronic apparatus capable of producing, receiving and displaying high frequency electrical pulses at frequencies of 1 to 2.25 mc is normally satisfactory for most welds.

U.3.2 - The search units shall be capable of reversibly transforming electrical vibrations to sound vibrations within themselves as well as transmitting and receiving vibrations in the material being tested.

U.3.3 - The couplant between the transducer and the test surface shall have good wetting properties and shall be selected, if conditions permit, from the following list:

Oil	Glycerin	Silicones
Water	Grease	White Lead

U.3.4 - Reference plates will be provided for determining and checking instrument sensitivity, for instrument calibration and for comparison with defect indication. Each plate shall have artificial defects and all defects permanently marked.

ULTRASONIC INSPECTION

U - 4 SURFACE PREPARATION

U.4.1 - Hot rolled surfaces require removal of any loose adherent scale or other foreign matter. Conditioning of the surface can be accomplished by sandblasting, grinding or belt sanding to provide at least a 250 RMS surface finish.

U.4.2 - The base material surfaces to be used for inspection shall also be cleaned of weld spatter and roughness on each side of the weld for a minimum distance of six (6) inches. Weld surface irregularities which are beyond the normal patterns, shall be removed from both the inside and outside surfaces. The deposited weld metal shall merge smoothly into the base metal without undercuts, sharp ridges, or valleys.

U - 5 ULTRASONIC INDICATIONS OF WELD DISCONTINUITIES

U.5.1 - The maximum magnitude of a signal indicating a weld discontinuity shall be recorded as a percentage of the height of the signal from the hole in the reference weldment. The height of the signal is some indication of the size of the discontinuity. This method of estimating the size of the discontinuity shall be used when flaw dimension is smaller than one-half of the dimension of the crystal.

U.5.2 - A reflection that is always visible with movement of the transducer transversely to the discontinuity indicates depth which may be measured. Likewise a reflection that is always visible with movement of the transducer longitudinally to the discontinuity indicates length which can also be measured. This method of estimating the size of the flaw shall be used when the discontinuity dimension is larger than one-half of the dimension of the crystal.

U.5.3 - Locations of the flaw with respect to the surface of the plate are determined by the position of the signal on the tube and the location of the transducer with respect to the weld.

U.5.4 - Flaws in base metal are possible sources of misinterpreted indications. These areas will be searched with normal incident longitudinal wave test methods to determine the presence of such imperfections.

U.5.5 - Small reflections from the weld area are generally apparent to indicate that the sound is penetrating the weld.

U - 6 PROCEDURE FOR CHECKING BUTT WELD DISCONTINUITIES

U.6.1 - Discontinuities longitudinal to the weld, move the transducer slowly to and from the weld with mainly a transverse (with respect to weld) movement and at such a rate that the operator can clearly see and identify the signals. The transducer should be rotated slightly in the plane of the metal surface in both directions to obtain maximum signals.

ULTRASONIC INSPECTION

Use just enough longitudinal movement to advance the transducer parallel to the weld no more than one transducer width per transverse cycle. The total minimum transverse movement should be sufficient to fully cover the entire cross-section of the weld. Normally check both sides of the weld from one surface only, but in special cases a more complete investigation from both surfaces is required.

U.6.2 - Discontinuities Transverse to the Weld

If the weld is smooth, and satisfactory contact can be made, move transducer slowly along top of weld with the ultrasonic beam parallel to the weld. If satisfactory contact cannot be made on the weld, place the transducer on the base metal surface at the edge of the weld, and angle the transducer slightly to obtain the same effect, move the transducer at such a rate that the operator can clearly see and identify the reflection.

U - 7 PROCEDURE FOR CHECKING MISCELLANEOUS WELDS

U.7.1 - Branch or nozzle, flange to shell, corner and other full penetration welds can be inspected with an angle beam using procedure in U.6.1 or U.6.2 above, when the methods are adaptable to the geometry of the weldment.

U.7.2 - Inspection of fillet welds, attachment welds, and other welds not requiring full penetration can be generally inspected with an angle beam by procedures in U.6.1 or U.6.2. The signal must be carefully distinguished to avoid interpreting reflections from the geometry of the part as being indications of discontinuities. In all scanning, if a defect indication is obtained approaching in amplitude that of the reference plate, the adjacent area shall be scanned sufficiently to establish the size and location of the discontiniuty.

U - 8 STANDARDS FOR ULTRASONIC INSPECTION

U.8.1 - Any crack, lack of fusion, incomplete penetration, inclusion, or cavity which is indicated by a reflection equal to or greater than 80 per cent of the applicable reference hole and which has a linear dimension as indicated by the transducer movement exceeding:

1/4 inch for thickness up to 3/4 inch.
1/3 of the thickness for plate 3/4 inch to 2-1/4 inch.
3/4 inch for thicknesses over 2-1/4 inch.

is unacceptable.

U - 9 REPORTS OF INSPECTION

U.9.1 - The report of ultrasonic inspection shall be made after re-inspection of any areas requiring weld removal or weld repairs. The reports contain the following information:

12-15-66

1-D-8
Page 4

ULTRASONIC INSPECTION

1. Inspection date.
2. Instrument settings.
3. Height of general signals from parent metal and deposited metal.
4. Purchaser's order number and drawing number.
5. Sketch containing physical outline of weldment with location of repaired areas.
6. A table of the inspection results coordinated with a sketch estimating size, length, depth and location of flaws.

THE PORT OF NEW YORK AUTHORITY

World Trade Department
Guy F. Tozzoli, Director

Malcolm P. Levy, Chief, Planning & Construction Division
R. M. Monti, Construction Manager Telephone (212) 267-7600 Office of the Construction Manager 30 Church St., New York, N.Y. 10007

March 11, 1968

Pittsburgh-Des Moines Steel Company
Neville Island
Pittsburgh, Pennsylvania 15225

Attention: Mr. H. M. Fish

Re: The World Trade Center - Contract WTC 213.00
Welding Procedure Specifications

Gentlemen:

This will confirm approval of your submitted "Welding Procedure Specification DB 119-172 (WPS-1)", revised February, 1968, and Joint Qualification Sheets SA-3, 56-30, 58-36, 58-42, 60-35, 62-2 and 62-80, as noted on SHCR letter dated February 28, 1968.

R. M. Monti
Construction Manager
The World Trade Center

cc: J. Graner (RWH)
J. White (SHCR)

CABLE: PITTDEMOIN
TELEX: 099-734

PDM Pittsburgh-Des Moines Steel Company

Engineers
Fabricators
Constructors

NEVILLE ISLAND · PITTSBURGH, PENNSYLVANIA 15225 · AREA CODE 412
PHONE 331-3000

February 15, 1968

Mr. R. M. Monti
Construction Manager
Room 1119
The Port of New York Authority
30 Church Street
New York, New York 10007

Re: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17138

Gentlemen:

Enclosed herewith please find two (2) copies of Welding Procedure Specification DB119-172, WPS1 revised in accordance with Mr. James White's comments in his letter of December 19,1967 to Mr. R. M. Monti; and, our Mr. A. C. Hogan's telephone conversation with Mr. Jostein Nes on February 12, 1968.

In response to comment No. 13 of Mr. Whites letter, joint M4 is noted to weld in the flat position and is prequalified

Pittsburgh-Des Moines Steel Company
-2-

Mr. R. M. Monti
The World Trade Center February 15, 1968

Welding on this phase will start shortly so your early consideration of the above items will be appreciated.

Very truly yours,

PITTSBURGH-DES MOINES STEEL COMPANY

H. M. Fish, Project Manager

rw

cc: Mr. H. A. Tessler

Mr. Al Guttentag
w/one copy of DB119-172

Skilling-Helle-Christiansen-Robertson
Attn: Mr. James White
w/one copy of DB119-172

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · MU. 9-8574

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

February 28, 1968

Port of New York Authority
Office of the Construction
Manager - Room 1119
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti, Construction Manager

Reference: The World Trade Center
Contract WTC-213.00, Pittsburgh-Des Moines
Welding Procedure Specification DB 119-172 (WPS-1)
and Joint Qualifications

Gentlemen:

We have reviewed the PDM letter dated February 15, 1968 and approve Welding Procedure Specification DB 119-172 (WPS-1), revised February, 1968 in its present form, and also approve joint qualification sheets SA-3, 56-30, 58-36, 58-42, 60-35, 62-2 and 62-80.

We understand that PDM is not going to employ either joint M4 or M5 described in the joint welding procedure sheets included with their

CABLE: PITTDEMOI...
TELEX: ONO-734

PDM Pittsburgh-Des Moines Steel Company

Engineers
Fabricators
Constructors

NEVILLE ISLAND • PITTSBURGH, PENNSYLVANIA 15225 • AREA CODE 412
PHONE 331-3000

March 6, 1968

Mr. R. M. Monti
Construction Manager
Room - 1119
The Port of New York Authority
30 Church Street
New York, New York 10007

Re: The World Trade Center
Contract WTC-213.00

PITTSBURGH-DES MOINES STEEL COMPANY

Rev. 3-6-68

PDM

ENGINEERS / FABRICATORS / CONSTRUCTORS

PITTSBURGH-DES MOINES STEEL COMPANY

August 23, 1968

Mr. R. M. Monti
Construction Manager
Room - 1119

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

3. Page 1, paragraph 4.1.1, fourth sub-paragraph should have an additional sentence added stating, "Electrodes which come in contact with water, grease or dirt shall be scrapped".

4. Page 2, paragraph 4.2, Submerged Arc Process, should have a

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

September 23, 1968

*Thickness	Manual Shielded Metal-Arc & MIG	Submerged Arc Carbon Steel Wire & Alloy Flux
To 1/2" Incl.	**50 ° F. Min.	**50 ° F. Min.
Over 1/2" to 1" Inc.	**50 ° F. Min.	200 ° F. Min.
Over 1" to 2" Incl.	150 ° F. Min.	300 ° F. Min.
Over 2"	200 ° F. Min.	400 ° F. Min.

Maximum Preheat and Interpass Temperature 425° F.

*Thickness of thickest part at point of weld.
** Welding at plate temperature below 100° F. requires assurance that moisture is not present in vicinity of joint.


SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

Page 6 September. 23, 1968

III Welding Procedure Specification, DB119-172, WPS-1

Through our review of procedures WPS-3 and WPS-2, we have the following additional comments on Procedure WPS-1 approved by SHCR letter of February 28, 1968, as well as PDM's revisions to page 5


SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

STANRAY PACIFIC CORPORATION
subsidiary of STANRAY CORPORATION

11633 SOUTH ALAMEDA STREET · LOS ANGELES, CALIFORNIA 90002 · (213) 566-2111

June 2, 1967

Mr. Lester Feld
The Port of New York Authority
111 Eighth Avenue at Fifteenth Street
New York, New York

Subject: World Trade Center
Contract No. WTC 217.00 - Revised Quality Control Program

Dear Lester:

Enclosed you will find two copies of the Welding Procedures to be incorporated into our Quality Control Program which is outlined in section 105 of Contract No. WTC 217.00. This constitutes our entire Quality Control and Testing Program.

The Inspection Requirements referred to as item 2 C in your letter of May 25, is now completed and will be mailed to you on Monday, June 5.

Yours very truly,

STANRAY PACIFIC CORPORATION

F. E. Allen
Controller

dh
Encl.

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

September 13, 1968

Port of New York Authority
Office of the Construction
Manager - Room 1119
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

SUMMARY OF PDM

WELDING PROCEDURE SPECIFICATION SHEETS

AND

PROCEDURE QUALIFICATION SHEETS

PDM Joint Designation ... SHCR Approval ... Remarks

Office of the Construction Manager
30 Church Street, New York City

October 4, 1967

Pittsburgh-Des Moines Steel Company
Neville Island
Pittsburgh, Pennsylvania 15225

Attention: H.M. Fish

Reference: WORLD TRADE CENTER - WTC 213.00 - Inspection and Scheduling

Gentlemen:

This will confirm my telegram of October 4th wherein you were advised

Pittsburgh-Des Moines Steel Company October 4, 1967

Your proposed form for conveying mill order and fabrication information as requested by Mr. Endler of the Tishman Realty and Construction Company appears to contain all of the information requested by Mr. Endler. However, we would suggest that it might be more reasonable to list more than one column on each sheet so as to reduce the total number of sheets. Such a format would remain preliminary information for the Authority

CHAPTER THREE

FABRICATION OF STRUCTURAL STEEL

301 GENERAL

301.100 Structural steel shall be fabricated complete as shown in the Drawings and in approved details shown in the shop drawings.

301.200 The steel furnished for each location shall have a minimum yield point equal to that scheduled in the Drawings, and shall be selected from the applicable steel specifications listed in Chapter Two, MATERIALS.

301.300 All steel shall be ASTM A36 for locations where a specific strength requirement is not stated in the Drawings.

302 IDENTIFICATION

302.100 The Contractor shall identify all steel which will be used in the work beginning at the mill and shall maintain identification at all times thereafter including during fabrication. The method used shall make both the grade and yield point of the steel readily identifiable.

303 SPECIFIC REQUIREMENTS

303.100 Flame cutting by hand shall not be performed without the Engineer's approval. Handcut surfaces shall be made smooth by chipping, planing or grinding.

303.200 Fabricated material containing sharp kinks or bends shall be rejected. Material straightened prior to fabrication shall be carefully examined for signs of distress or other defects before being placed in fabrication. Distressed or otherwise defective material shall not be used in the work.

303.300 Where required by the Contract Documents, surfaces shall be milled, or finished by other approved means. All finishing shall be clearly shown in the shop drawings.

303.400 Bolt holes and similar holes shall be punched, drilled, sub-punched or sub-drilled and reamed, and shall not be made or enlarged by gas cutting.

303.500 Holes required by the Erector and shown on the Drawings prior

304 FABRICATION TOLERANCES

304.100 Fabrication tolerances shall conform to the requirements of the AISC Specification and AWS D1.0, as supplemented by specific requirements contained in the Drawings and Specifications. In no case shall tolerances exceed those obtainable by the best modern shop practice.

305 SPECIAL REQUIREMENTS

305.100 Fabrication tolerances shall conform to the tolerances shown on Sheets 3-04 through 3-17 inclusive. Where specific tolerances are not shown on Sheets 3-04 through 3-17 tolerances shall conform to the requirements of the Specifications.

305.200 Cut edges of steel shall be free of burrs, overhangs, gross laminations, excessive slag inclusions and similar defects. Where necessary, cut edges shall be repaired be means described in the Contractor's quality control and testing program. Where required to maintain weld quality, corners of plates shall be eased and cut edges shall be ground. Work of this nature shall be outlined in the Contractor's quality control and testing program and shall be described in detail in the Contractor's welding procedure specifications.

305.300 In certain locations in the Drawings, slotted or oversize holes are specifically required. Where the Contractor elects to use slotted or oversize holes not shown in the Drawings, the use of slotted or oversize holes shall be subject to the Engineer's approval.

305.400 The Engineer will provide for the Contractor's use a table of correction factors which the Contractor shall use to determine the correct as-fabricated dimensions of structural steel members. The correction factor for columns will be the sum of the correction for temperature at time of fabrication and the correction due to shortening under load. Correction factors will be based on a standard temperature of 70 degrees Fahrenheit.

105 INSPECTION, QUALITY CONTROL AND TESTS

105.100 Quality Control and Tests

105.101 The Contractor shall comply with the quality control and testing program annexed hereto and forming a part hereof during the course of the work to assure that all work conforms to the Contract Documents.

105.102 The Contractor shall continually review his quality control and testing program against experience gained

measurements, and certification that equipment, materials and methods conform to the Specifications or to procedure specifications approved by the Engineer. The Contractor shall state in writing his certification regarding the completeness and authenticity of each quality control and testing document. The Contractor's certification shall be attested by the full written legible signature of the party in responsible charge of the work for the Contractor and the technician actually performing the work.

105.104 The Contractor shall submit mill test reports to the Engineer for all material used in the work.

105.105 The Contractor shall report the location and quality of all corrective work.

105.106 The Contractor shall furnish all testing machines, testing machine operators and testing materials required for the Contractor's quality control and testing program.

105.200 Inspection

105.201 Inspection is intended to assure that the Contractor's quality control and testing program maintains conformance to the Contract Documents.

105.202 Inspection will consist of a random sampling of the work and will, to the degree possible, follow immediately the performance of the work. Inspection is intended, for the most

part, to consist of surveillance and evaluation of the Contractor's quality control and testing program.

105.203 The Contractor shall furnish the Engineer free access to the work. The Contractor shall cooperate with the Engineer to allow Inspection.

105.204 The Contractor shall furnish, free of charge, all electrical power, turning or moving of members, hoisting, staging and other facilities required for Inspection. The Authority will provide testing machines, testing machine operators and testing materials used for Inspection.

105.205 The Contractor shall notify the Engineer a minimum of six (6) working days in advance of the beginning of work subject to Inspection. This requirement applies to each location at which work is performed, and to each resumption of work after any interruption or suspension of work. The Contractor shall pay the actual cost of salaries and travel expenses, in reasonable amounts, incurred because work is not ready for Inspection at the time stated by the Contractor.

105.206 The Contractor shall not in any manner construe Inspection to relieve the Contractor of any of his responsibilities under the Contract.

Pacific Car and Foundry Company
80 SOUTH HUDSON · SEATTLE, WASHINGTON 98134 · RO 2-7440

July 8, 1967 PCF #666-14

THE PORT OF NEW YORK AUTHORITY
Room 300
111 Eighth Avenue
New York, New York

Attention: Mr. R. M. Monti
Construction Manager

Reference: World Trade Center
Contract WTC-214.00
Project D-666

Gentlemen:

Please find enclosed two (2) copies of each of the following documents:
1. Quality Control Procedures - Revision 1, July 7th, 1967.
2. Welding Procedure - Revision 1, July 7th, 1967.

These procedures have been revised to suit your comments and those of Messrs. Skilling, Helle, Christiansen, Robertson. In the welding procedure we have also included Appendix B, Welder Certification form, as requested in your letter of June 14, 1967. In the quality control procedure we have added a section (part II, page five) which more fully defines the extent and methods of inspection which we propose for this contract.

We now request your formal approval of these documents. A copy of this letter and procedures has been forwarded directly to Mr. L. Robertson of Skilling, Helle, Christiansen, Robertson.

Yours very truly,

PACIFIC CAR AND FOUNDRY COMPANY

R. C. Symes, Project Engineer
Structural Steel Division

RCS/ap
encl.
cc: L. Robertson (SHCR)
J. Endler (Tishman)
J. Pigott
A. Philippy
D. Erickson

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John. V. Christiansen · Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

July 13, 1967

Port of New York Authority
World Trade Center Planning
111 Eighth Avenue
New York, New York 10011

Attention: Mr. R. M. Monti, Construction

Reference: The World Trade Center
Contract WTC-214.00, Pacific Car & Foundry
Quality Control and Testing Program

Gentlemen:

We have reviewed the documents: 1) Quality Control Procedures, Revision 1, July 7, 1967, and 2) Welding Procedures, Revision 1, July 7, 1967, forwarded with the PCF letter of July 8, 1967.

Based upon our review, we approve the PCF Quality Control and Testing Program contingent upon the incorporation into the program of the attached charts prepared by SHCR titled "Weld Inspection Rates" and subject to the specific conditions listed hereafter:

1. The weld numbers and designations used in the charts "Weld Inspection Rates" (Sheets No. 1-4 inclusive attached hereto) are those numbers and designations appearing in Drawing [illegible] in its current form as of July 15, 1967.

2. The first three full penetration spandrel butt welds (Weld #10) performed by each new welding machine operator or welder will be subjected to ultrasonic testing.

3. Where a spandrel butt weld is rejected, all welds made by the same welder or welding machine in the subject panel, the panel produced immediately previous to the subject panel, and the panel produced immediately after the subject panel, will be tested by the ultrasonic testing technique.

SEATTLE OFFICE: 1340 WASHINGTON BUILDING, SEATTLE, WASHINGTON 98101

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

4. Approval of the PCF Quality Control and Testing Program does not include approval of any welding process or procedure subject to AWS qualification tests (see Sheet WS-11A), and does not include approval of Drawings WS-11B and WS-11C.

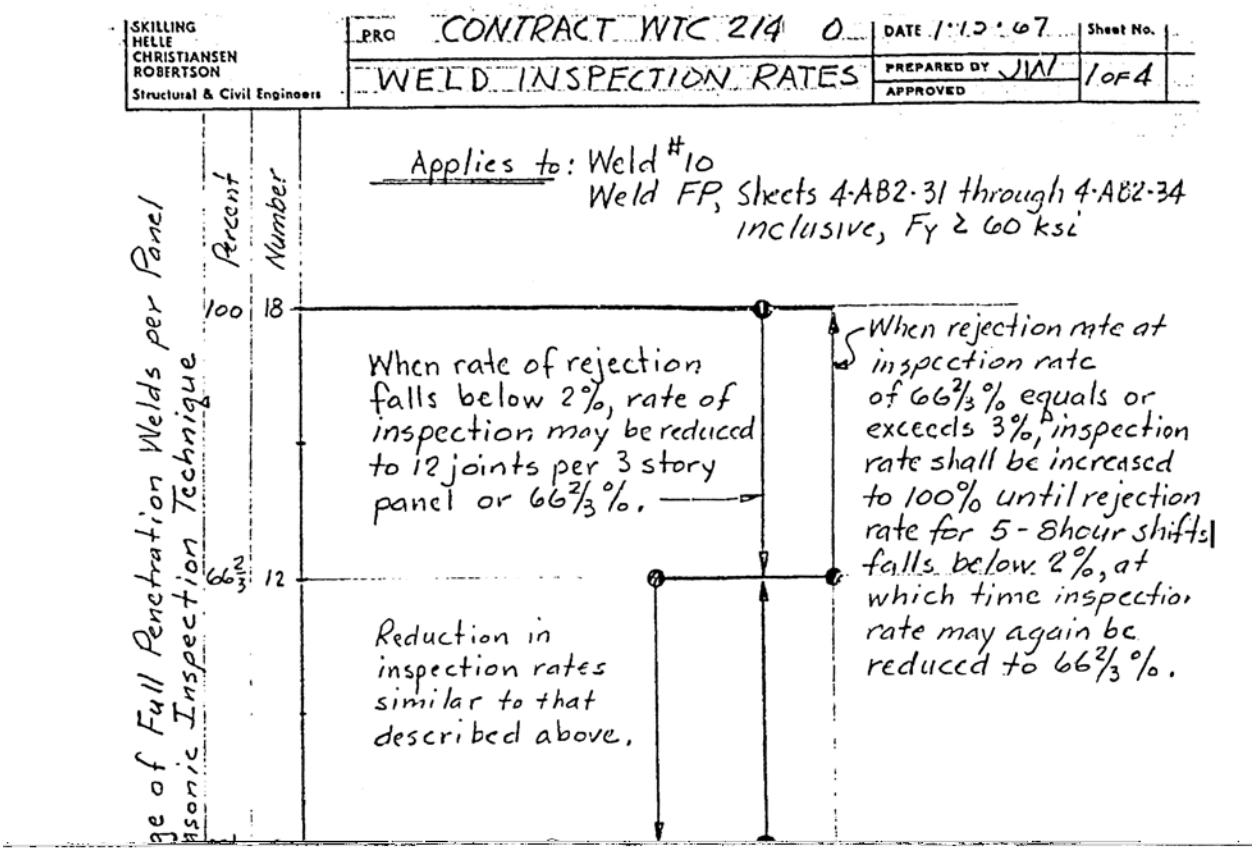
5. Visual inspection shall be carried out by certified PCF inspection personnel on 100% of all types of welds included in the work.

Very truly yours,

SKILLING-HELLE-CHRISTIANSEN-ROBERTSON

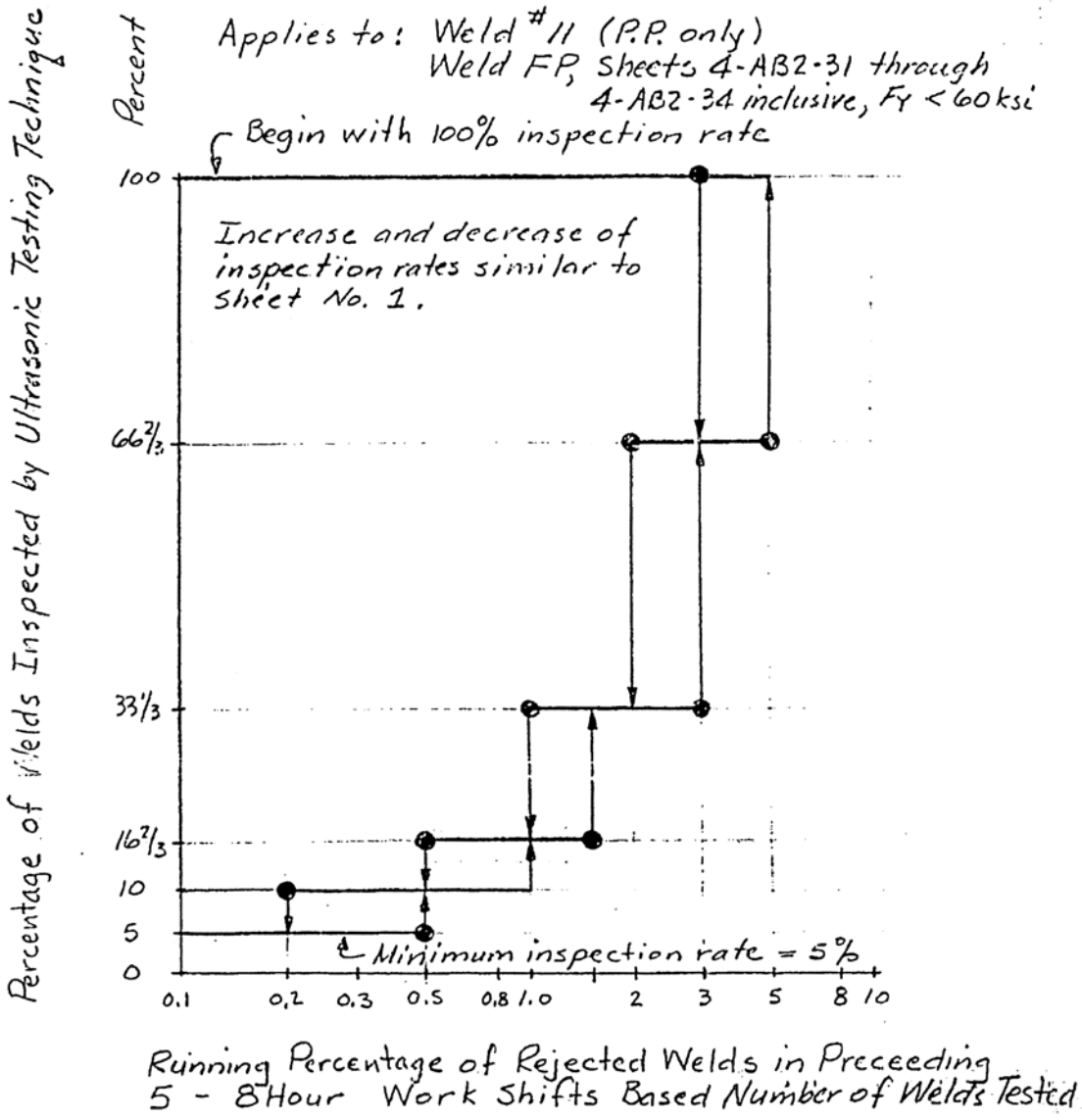
James White

JW:e
cc: Mr. M. Levy
Mr. L. Feld
Mr. W. Cosinuke
Mr. M. Springer


SKILLING HELLE CHRISTIANSEN ROBERTSON
Structural & Civil Engineers
PRO CONTRACT WTC 214 0
WELD INSPECTION RATES
DATE 1·12·07
PREPARED BY JW
APPROVED
Sheet No.
1 OF 4
Applies to: Weld #10
Weld FP, Sheets 4-AB2-31 through 4-AB2-34 inclusive, Fy ≥ 60 ksi
Percent
Number
100
18
66⅔
12
When rate of rejection falls below 2%, rate of inspection may be reduced to 12 joints per 3 story panel or 66⅔%.
When rejection rate at inspection rate of 66⅔% equals or exceeds 3%, inspection rate shall be increased to 100% until rejection rate for 5-8hour shifts falls below 2%, at which time inspection rate may again be reduced to 66⅔%.
Reduction in inspection rates similar to that described above.
ge of Full Penetration Welds per Panel
Ultrasonic Inspection Technique

SKILLING HELLE CHRISTIANSEN ROBERTSON
Structural & Civil Engineers

PR CONTRACT WTC 2 .00 | DATE 7-13-67 | Sheet No.
WELD INSPECTION RATES | PREPARED BY JW | APPROVED | 2 OF 4

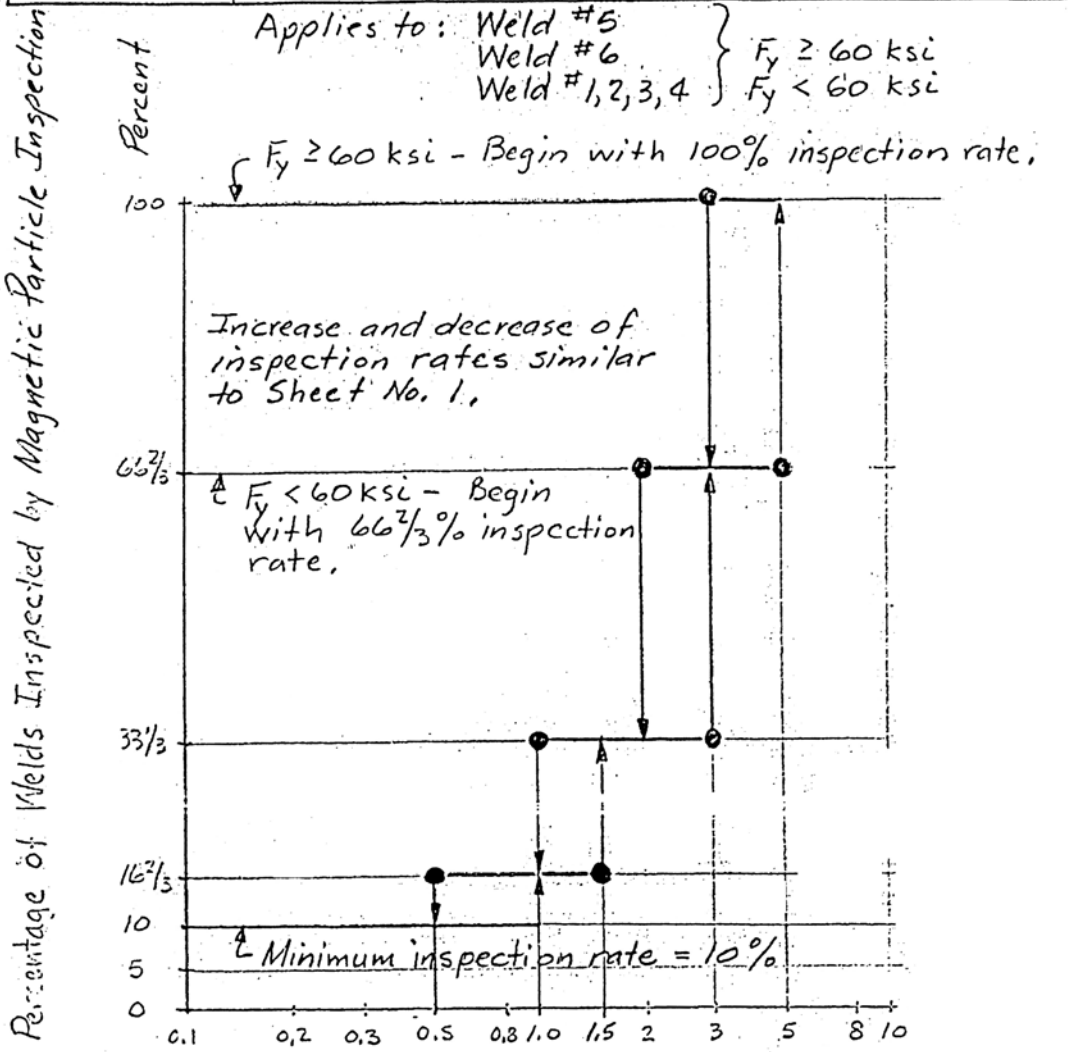


REV. 7-15-67

SKILLING HELLE CHRISTIANSEN ROBERTSON
Structural & Civil Engineers

JOB CONTRACT WTC 2 .00 | DATE 7-13-67 | Sheet No.
WELD INSPECTION RATES | PREPARED BY | APPROVED | 3 of 4

Applies to: Weld #5, Weld #6 — $F_y \geq 60$ ksi
Weld #1, 2, 3, 4 — $F_y < 60$ ksi



Note: Welds #1, #2, #3, #4 shall be inspected for 1'-0" length beginning at column ends.

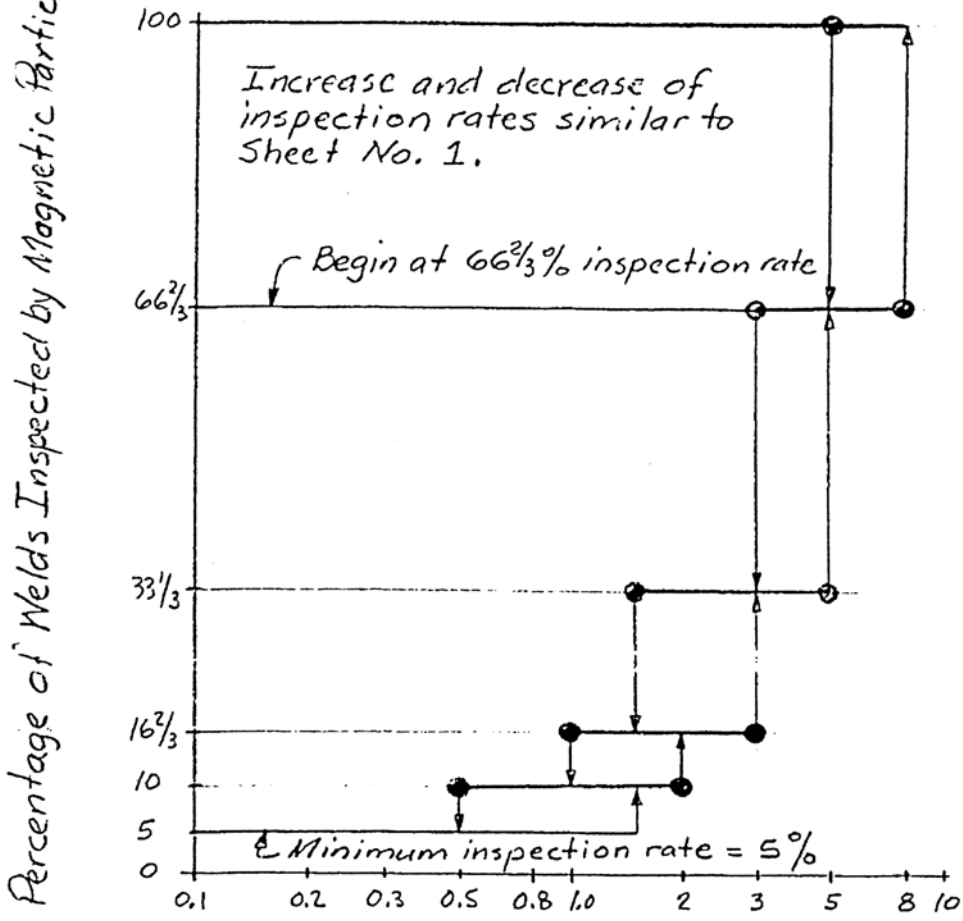
REV. 7-15-67

KILLING HELLE CHRISTIANSEN ROBERTSON
Structural & Civil Engineers

PRC WTC CONTRACT 214 0 | DATE 7-13-67 | Sheet No. 4 OF 4

WELD INSPECTION RATE | PREPARED BY | APPROVED

Applies to: Welds #1, 2, 3, 4 F_y < 60 ksi
Weld #11 (fillet weld only)
Fillet welds not specifically identified elsewhere.



Note: Welds #1, 2, 3, 4 shall be inspected for 1'-0" length beginning at column ends.

CHAPTER THREE

FABRICATION OF STRUCTURAL STEEL

301 GENERAL

301.100 Structural steel shall be fabricated complete as shown in the Drawings and in approved details shown in the shop drawings.

301.200 The steel furnished for each location shall have a minimum yield point equal to that scheduled in the Drawings, and shall be selected from the applicable steel specifications listed in Chapter Two, MATERIALS.

301.300 All steel shall be ASTM A36 for locations where a specific strength requirement is not stated in the Drawings.

302 IDENTIFICATION

302.100 The Contractor shall identify all steel, other than A.S.T.M. A36, which will be used in the the work beginning at the mill and shall maintain identification at all times thereafter including during fabrication. The method used shall make both the grade and yield point of the steel readily identifiable. Identification shall be maintained after fabrication.

302.200 The Contractor shall identify each member or assembly with a system of marks. Each mark shall be clearly indicated in the shop drawings. The system of identification marks for fabricated structural steel shall be a permanent system approved by the Engineer. In addition, the Contractor shall paint erection

304 FABRICATION TOLERANCES

304.100 Fabrication tolerances shall conform to the requirements of the AISC Specification and AWS D1.0, as supplemented by specific requirements contained in the Drawings and Specifications. In no case shall tolerances exceed those obtainable by the best modern shop practice.

305 SPECIAL REQUIREMENTS

305.100 Cut edges of steel shall be free of burrs, overhangs, gross laminations, excessive slag inclusions and similar defects. Where necessary, cut edges shall be repaired by means described in the Contractor's quality control and testing program. Where required to maintain weld quality, corners of plates shall be eased and cut edges shall be ground. Work of this nature shall be outlined in the Contractor's quality control and testing program and shall be described in detail in the Contractor's welding procedure specifications.

305.200 In certain locations in the Drawings, slotted or oversize holes are specifically required. Where the Contractor elects to use slotted or oversize holes not shown in the Drawings, the use of slotted or oversize holes shall be subject to the Engineer's approval.

305.300 The Engineer will provide for the Detailer's use a table of correction factors which the Detailer will use to determine the correct as-fabricated dimensions of columns. This correction factor for column shortening under load is to be included in the dimensions shown on the Shop Drawings. A separate correction for temperature at time of fabrication is to be made by the Contractor based on a standard temperature of 70 degrees Fahrenheit for steel members.

CHAPTER FOUR

WELDING OF STRUCTURAL STEEL

401 GENERAL REQUIREMENTS

401.100 Welding of structural steel shall conform to the requirement of the AISC Specification and AWS D1.0, except where the AISC Specification or AWS D1.0 is specifically modified or supplemented by information included in the Drawings or Specifications.

402 QUALIFICATION AND CERTIFICATION OF WELDERS

402.100 Welders and welding operators shall have passed the applicable A qualification tests prescribed in AWS D1.0, Appendix D, Parts II and III. AWS qualification tests shall be supervised and witnessed by an agency approved by the Engineer. The approved agency shall issue certified test reports which describe the tests performed and indicate the results of the tests. Certification papers issued by the approved agency shall clearly state the types of work the welder or welding operator is qualified to perform. Certification shall be achieved immediately preceding the date the subject welder begins work under the Contract. AWS qualification tests and certification shall be paid for by The Authority and witnessed by the Engineer's Representative.

403 WELDING PROCEDURE SPECIFICATIONS AND JOINT QUALIFICATIONS

403.100 Joints conforming to the details specified in AWS D1.0, Articles 209, 210, 211, 212, 213 and 214 and welded in accordance with the

405.200 Welding electrodes and flux for submerged arc welding shall conform to Section 202, MATERIALS.

405.300 Gas metal-arc welding materials, where approved for use in the work, shall conform to Section 202, MATERIALS, and to the requirements of the approved welding procedure specification.

WORLD TRADE CENTER

105 INSPECTION, QUALITY CONTROL AND TESTS

105.100 Quality Control and Tests

105.101 The Contractor shall comply with the quality control and testing program of Montague-Betts Company, Inc., dated June 9, 1967, as such program is revised in the respects indicated in the letter from Skilling-Helle-Christiansen-Robertson dated June 23, 1967, to the extent necessary to obtain the approval of the Engineer. The aforesaid program and letter are annexed hereto and form a part hereof.

105.102 The Contractor shall continually review his quality control and testing program against experience gained during the course of the work. Where the Contractor desires revisions to his quality control and testing program, he shall submit the proposed revisions to the Engineer for approval. The Contractor shall not make changes in the approved quality control and testing program without the Engineer's approval. The Cnntractor may,at his option, perform quality control and testing in addition to that required by the approved quality control and testing program.

105.103 The Contractor shall maintain complete records of all quality control and testing performed by the Contractor. Records shall be kept in report form, and shall include the results of all visual control of the work, the results of all tests and

part, to consist of surveillance and evaluation of the Contractor's quality control and testing program.

105.203 The Contractor shall furnish the Engineer free access to the work. The Contractor shall cooperate with the Engineer to allow Inspection.

105.204 The Contractor shall furnish, free of charge, all electrical power, turning or moving of members, hoisting, staging and other facilities required for Inspection. The Authority will provide testing machines, testing machine operators and testing materials used for Inspection.

105.205 The Contractor shall notify the Engineer a minimum of six (6) working days in advance of the beginning of work subject to Inspection. This requirement applies to each location at which work is performed, and to each resumption of work after any interruption or suspension of work. The Contractor shall pay the actual cost of salaries and travel expenses, in reasonable amounts, incurred because work is not ready for Inspection at the time stated by the Contractor.

105.206 The Contractor shall not in any manner construe Inspection to relieve the Contractor of any of his responsibilities under the Contract.

QUALITY CONTROL PROGRAM

THE WORLD TRADE CENTER
CONTRACT WTC-226.00
FABRICATED STEEL
ROLLED CORE COLUMNS, INTERIOR COLUMNS
LOUVER WALL STRUTS AND ROLLED BEAMS
NORTH & SOUTH TOWERS

THE PORT OF NEW YORK AUTHORITY
NEW YORK, NEW YORK

SUBMITTED BY
MONTAGUE-BETTS COMPANY, INC.
JUNE 9, 1967

RECEIVING (under the direct supervision of Yard Foreman)

a. Materials will be checked as unloaded for conformance with mill order and shipping papers.

b. Materials will be stacked on blocks off of the ground in predetermined storage areas.

c. Bay numbers will be recorded for future reference in locating materials as needed.

d. Remarking size, length and grade will be done as necessary.

e. Each piece or bundle will be marked with the letters PONYA.

f. Discrepancies in quantity, length or grade will be reported immediately for replacement.

PREPARATION (under the direct supervision of Yard Foreman)

a. Cutting to size will be by sawing, shearing or machine flame burning.

New pieces will be marked to maintain proper identity.

c. lumn ends will be milled as required and protected against normal weathering with a mixture of one part white lead, one part linseed oil and two parts lard.

FABRICATION (under the direct supervision of Shop Foreman)

a. Layout and fitting will be performed by Fitters working with necessary Helper(s).

b. Detail parts will be tack welded for location.

c. Holes will be punched, drilled or subpunched and reamed.

d. Copes, blocks, notches, etc., will be accomplished by hand burning and grinding smooth.

e. Overhangs, gross laminations, excessive slag inclusions and similar defects will be corrected by grinding or Arcair gouging and built up as necessary with weld metal.

f. Material will be cleaned of oil, grease, dirt and foreign matter only.

g. Pieces will be marked as shown on shop drawings using DuPont #65-3010 white metal primer on a background of Tnemec #99 red metal primer; marks will be between 3" to 4" high and background 4" larger than complete mark.

6-9-67

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

Welding procedure specifications must be prepared and qualification tests performed by the fabricator, where applicable. One copy of each welding procedure specification and report of qualification tests should be forwarded to PNYA and to SHCR for approval.

Preheat and interpass temperatures must conform to the welding procedure specification where specific preheat and interpass temperature requirements are included in the welding procedure specification.

All welds should receive 100 percent visual inspection.

Non-destructive testing of welds has not been described, and may be divided into three classes:

1. Fillet welds
2. Partial penetration welds
3. Full penetration welds

Appendix F
SUPPORTING DOCUMENTS FOR CHAPTER 7

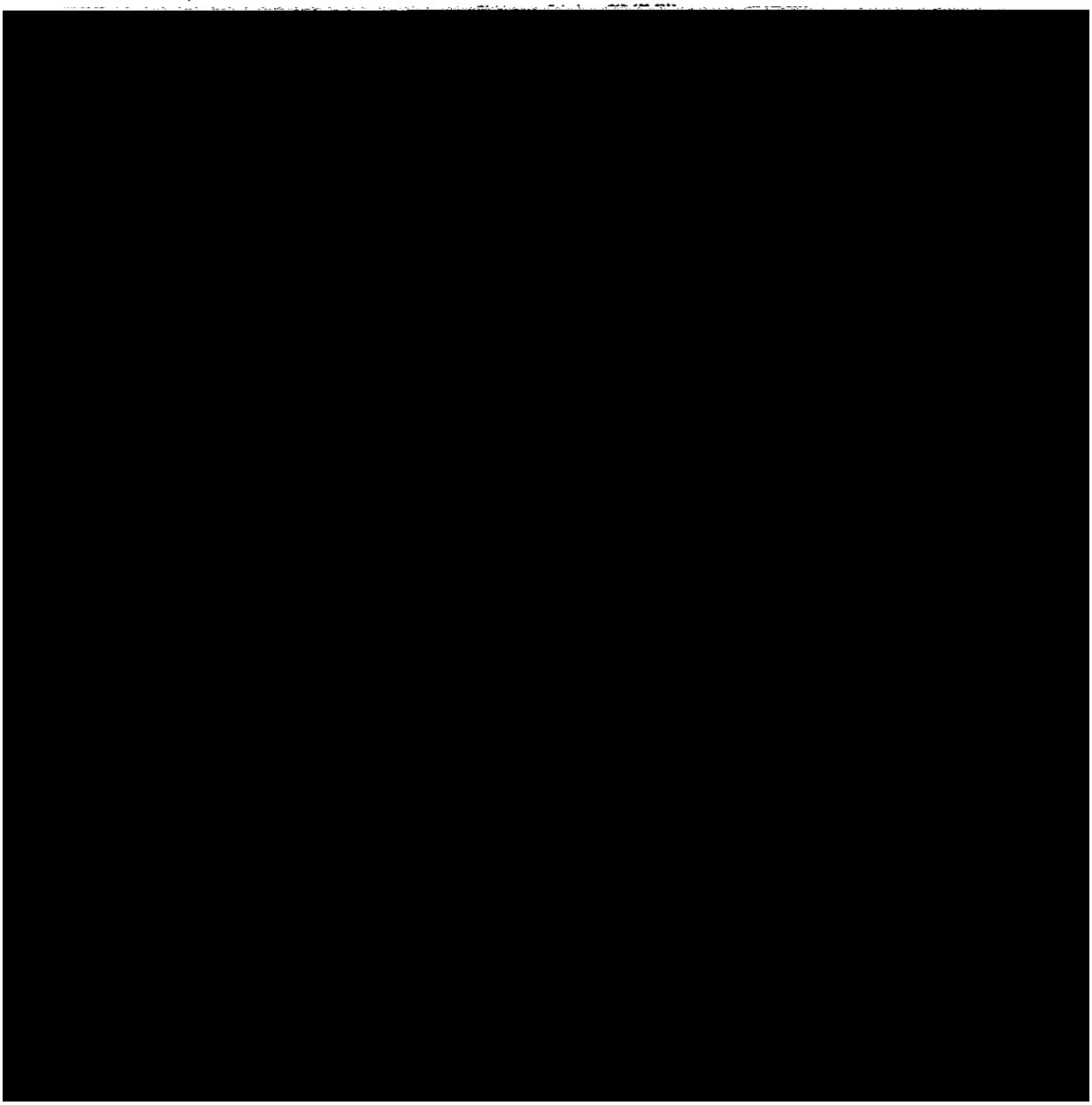
This appendix contains the supporting documents that are referenced in Chapter 7 of this report. All of the documents contained in this report are reproduced with permission of The Port Authority of New York and New Jersey. Table F–1 contains a summary of supporting documents and their location within this appendix. The footnote numbers given in the table correspond to those in Chapter 7.

Table F–1. Supporting documents for Chapter 7.

Footnote Number	Document Title	Page(s)
	Section 7.1 - Overview	
1	General instructions from Malcolm P. Levy of PONYA to prime contractors for WTC contracts (WTCI-239-P)	390
	Section 7.2 – Erection Marks and Marking System	
2	General instructions on erection marks and marking system for structural steel from the Port Authority to steel fabricators/suppliers for WTC 1 and WTC 2 (WTCI-495-L)	395
	Section 7.3 – Quality Control and Inspection Program	
3	Memo dated July 26, 1968 from David L. Brown of PONYA to James White of SHCR (WTCI-515-L)	400

THE PORT OF NEW YORK AUTHORITY
111 Eighth Avenue - at 15th Street, New York, N.Y. 10011

World Trade Department
Guy F. Tozzoli, Director
Richard C. Sullivan, Director, The World Trade Center



THE PORT OF NEW YORK AUTHORITY

Subject Matter	Addressee	Copies
Shop drawings and catalog cuts.	To: Mr. Marvin Altman, Architectural Coor., Tishman Realty & Construction Co., Inc. 11th Floor, 30 Church Street, New York, N.Y. 10007	For information on number of copies of shop drawings, size required, etc., see Contract Specification clause entitled, "Working Drawings and Catalog Cuts." Submit original drawings to Mr. Altman, one copy of each transmittal letter to Mr. Monti, and one copy to Mr. H.A. Tessler, Manager, Project Planning, Room 300, The Port of New York Authority, 111 Eighth Avenue, New York, N.Y., 10011.
Approval of equipment and material including samples, purchase orders, lists of materials and equipment proposed to be furnished under the contract and proposals for substitutions for specified material or equipment.	To: Mr. Monti	Direct original copy of all correspondence to Mr. Monti, one copy to Mr. Tessler, and one copy to Mr. Endler. For further instructions on inspection of material see clauses of specifications entitled "Inspec-

THE PORT OF NEW YORK AUTHORITY

- 4 -

C. An accurate description of the work involved.

D. Three references on work of similar nature previously performed by subcontractor.

Malcolm P. Levy, Chief
Planning & Construction Division
The World Trade Center

November 7, 1967

Mr. Herman Winters
Dreier Structural Steel Co., Inc.
32-50 Vernon Blvd.
Long Island City, New York 11106

Re: The World Trade Center - Contract WTC-211.00 -
Shop Drawing Procedures and Marking Systems

Dear Mr. Winters:

Enclosed for your information and use are letters and procedures previously sent to other fabricators on the WTC Towers. These procedures were developed jointly with Nassau Bridge Detailers starting in April 1967.

Sincerely,

Lester S. Feld
Planning Engineer

Enclosures:
1. Erection marks and marking system for structural steel in the WTC Towers - Pages 1 - 10 inclusive dated 10/1/67
2. Letter of June 16, 1967 on Erector's Derrick Division
3. Drawings S-EA-1000 and S-EB-1000 dated 5/25/67
4. Index to Marks System - dated 10/15/67 (2 pages)

cc: Messrs. J. Endler (TRCC), J. White (BMCR) - w/encl. #1

bcc: Messrs. D. Brown, R. Copde, M. Levy, R. Monti, H. Tessler

LSF:jw

ERECTION MARKS AND MARKING
SYSTEM FOR STRUCTURAL STEEL
IN
THE WORLD TRADE CENTER
NORTH AND SOUTH TOWERS

Rev. 4/28/67
Rev. 10/1/67

1. Each mark shall be painted in accordance with the Specifications in the same position on each piece as the mark appears on the erection drawing. All marks shall be followed by the Erector's Derrick Division. See Item 20 below.

2. Exterior Wall Columns (Below the 1st Story Splice)

Use the column number shown on the design drawing suffixed with the column tier number. Examples:

(a) 301 (S5-S1) - Indicates - Col. 301 from Tier S5 (El. 242) to splice above Tier S1 (El. 294').

(b) 330 (S1-1) - Indicates - Col. 330 (On centerline of Tower) from splice in Tier S1 to splice above first floor.

Tier marks are in accordance with Architect designation wherein:

S - Service Level - El. 294'
S1 - Sub-Level 1 - El. 284'
S2 - Sub-Level 2 - El. 274'
S3 - Sub-Level 3 - El. 264'
S4 - Sub-Level 4 - El. 253'
S5 - Sub-Level 5 - El. 242'

3. Exterior Wall Columns - (Above 1st Story Splice)

Use the column number shown on the design drawing suffixed with the column tier: Examples:

(a) 330 (1-4) - Indicates - Column 330 (on centerline of Tower) from the 1st Story Splice to the splice above the 4th floor, that is, from El. 318' to El. 363'.

(b) 330 (4-9) - Indicates - Panel 330 (On center-

(c) 200 $^{(18\text{-}20)}$ - Indicates - Panel 200 - A corner panel at N.E. Corner of Tower from the 18th Story Splice to the 20th Story Splice. This is a corner column spandrel panel to be fabricated by PC&F, and here again the panel number used is the middle column number of the three columns comprising the column tree.

4. Core Columns

Use the column number shown on the design drawing suffi· with the column tier number. Examples:

(a) 501 $^{(S5\text{-}S2)}$ - Indicates - Corner core column 501 from Tier S5 (El. 242) up to the splice above tier S2 (El. 274').

(b) 605 $^{(S2\text{-}1)}$ - Indicates - Core column 605 from splice in Tier S2 (El. 274') up to splice in 1st story.

(c) 605 $^{(1\text{-}3)}$ - Indicates -Core column 605 from 1st story splice to 3rd story splice.

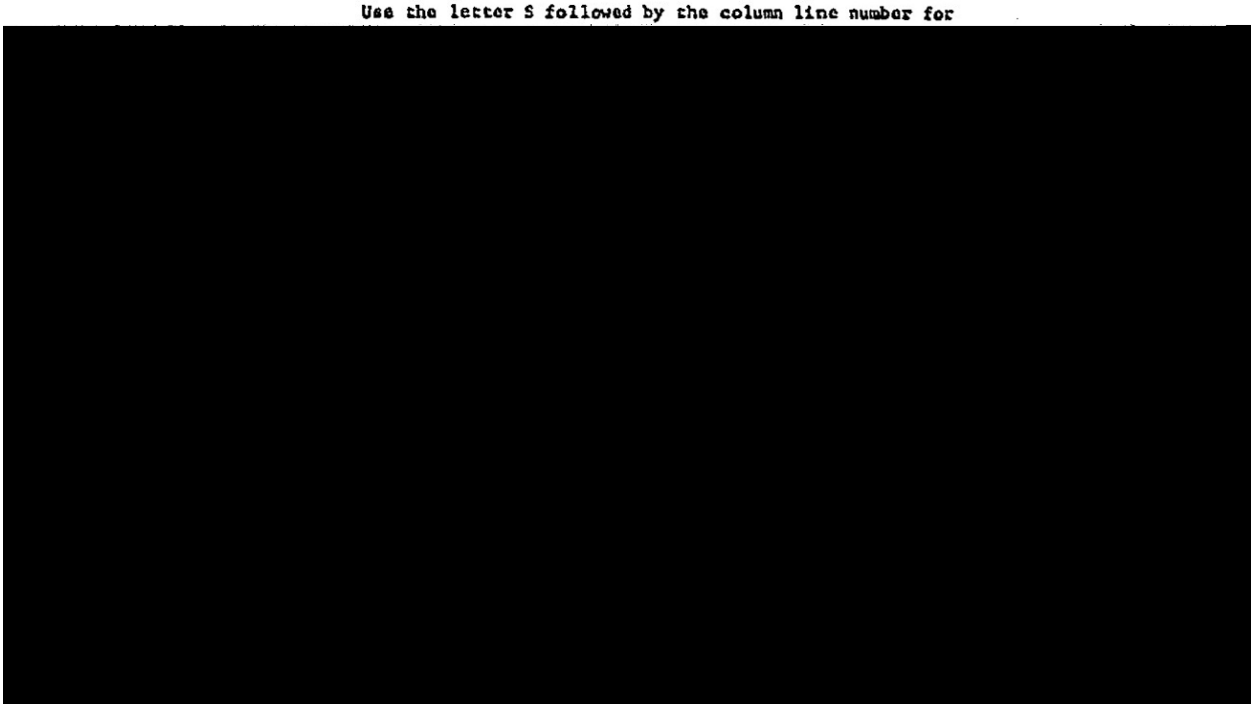
5. Interior Columns (Below the 1st floor - El. 310')

Use the column number shown on the design drawing suffixed with the column tier number.

(a) 1200 $^{(S5\text{-}S3)}$ - Indicates - Column 1200 from Tier S5 (El. 242) up to splice in Tier S3 (El. 264).

6. Louver Wall Struts

Use the letter S followed by the column line number for

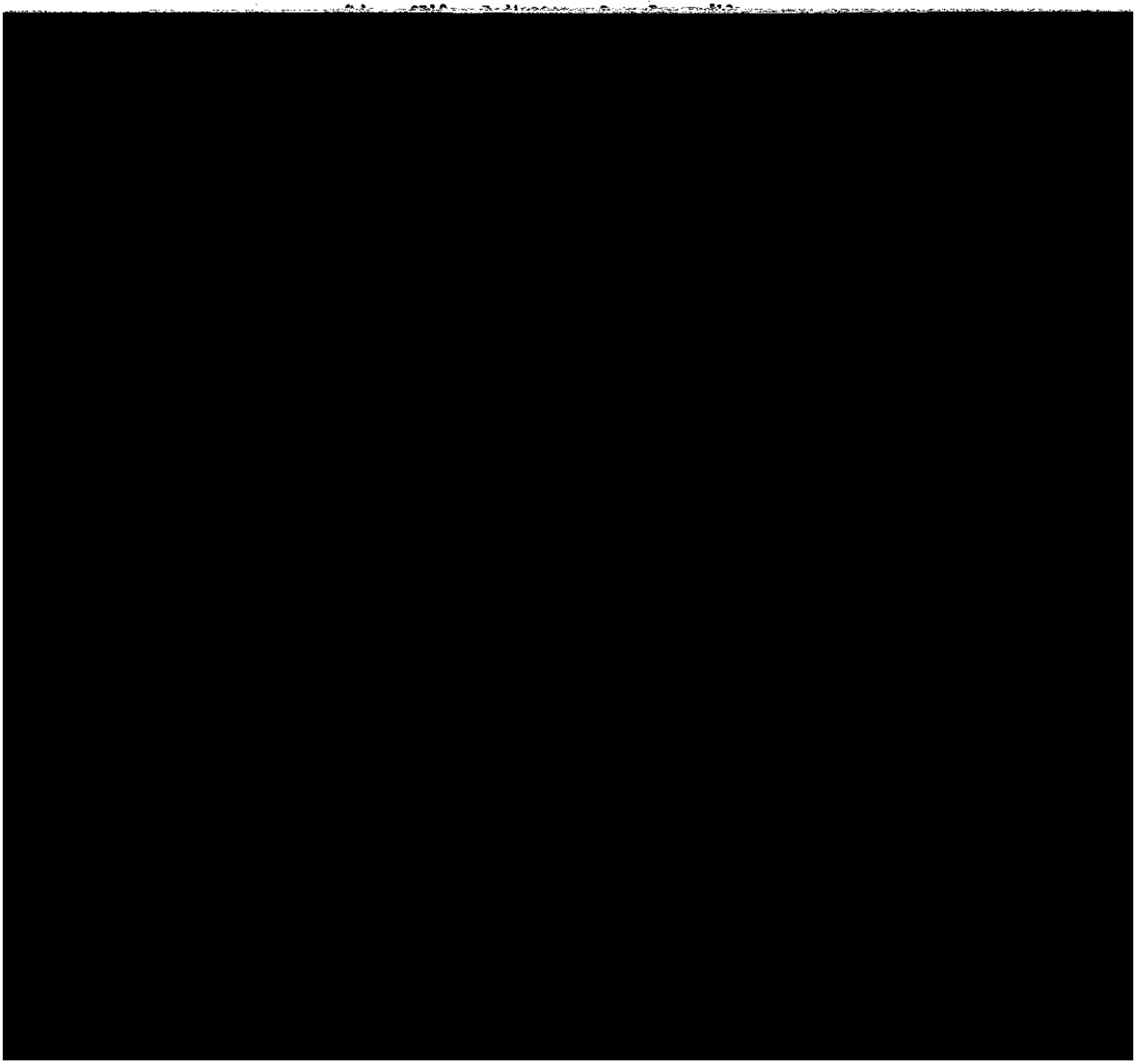


Please note that no tier marks are used as a suffix here. Marks shall appear on elevations of erection drawings only - not in plans.

8. Vertical Bracing at Core Columns

Use the letters CB followed by numerals 1, 2, etc. Example:

(a) CB1 - Indicates - Core Brace #1



11. Horizontal Bracing at Exterior Wall - At Beam Framed Floors

All diagonals and struts within the 10'-3" panel area adjacent to the exterior column reference line shall be prefixed with the letter H followed by a numeral and suffixed with the floor designation. Example:

H1 (7), H1 (9), H10 (41), H10 (43) would all be horizontal braces in Tower -, occuring at the 7, 9, 41 and 43rd floors.

12. Prefabricated Floor Units

All prefabricated panels shall be prefixed "F" followed by a numeral and suffixed with the floor designation. All panels to be numbered clockwise starting with "1" at the panel between core columns 501 and 502. Example:

(a) F1 (10), F2 (10), etc. - Indicates floor unit at 10th floor.

(b) F1 (15), F2 (15), etc. - Indicates floor unit at 15th floor.

With regard to components comprising prefabricated units, the following ground rules shall prevail:

A. All trusses, bridging, bracing and beams for prefabricated floor units supplied by Laclede to the assembler (Koch) shall be marked as agreed between the parties. Laclede shall furnish an assembly diagram to Koch showing components in each "F" panel.

B. All steel deck and power/telephone calls for prefabricated floor units supplied by Granco to the Assembler (Koch) shall be marked as agreed between the parties. Granco shall furnish an assembly diagram to Koch showing components of deck and P/T calls in each "F" panel.

C. The assembler (Koch) shall furnish a combined assembly diagram showing all components comprising each "F" panel.

13. Loose Deck and Loose Power/Telephone Calls for Beam-Framed Areas and Core Areas

All loose deck shall be prefixed SD followed by a numeral and floor designation such as:

SD1 (7), SD2 (7), etc.

Similarly all power/telephone calls shall be prefixed PT followed by a numeral and floor designation such as:

PT1 (9), PT2 (9), etc.

14. Anchor Bars and Anchor Plates (see drawing SAB-198)

Use prefix WX at exterior walls.

Use prefix WC at perimeter of core.

Examples: WX1, WX2, etc. - Indicate - Anchors at exterior wall

WC1, WC2, etc. - Indicate - Anchors at core perimeter.

Note - No tier designations are required. All anchors will be shown and located on erection plans and field welding sketches.

15. Shear Studs

Prefix "R" - followed by 3 digit numeral indicating diameter in eighths, length in inches and eighths such as:

R742 - Stud - 7/8" diameter x 4½"long, shall be painted on all kegs or containers.

16. Damping Units

Use Prefix "D" -

Example: D1, D2, D3, etc.

NOTE: No tier designations are required

16A. Grillages, Base Plates and Anchor Bolts

Use the following prefix letters:

G - Assembled Grillages

BP - Loose Base Plates

AB - Anchor Bolts

All the above prefix letters are to be preceeded by the Tower letter thus:

A-G1, A-G-2, etc. (Tower A Grillages)

B-G1, B-G2, etc. (Tower B Grillages)

A-BP-1, A-BP-2, etc. (Tower A Base Plates)

B-AB-1, B-AB-2, etc. (Tower B Anchor Bolts)

MEMORANDUM

PA 30-A
5-63

TO: James White - Skilling-Helle-Christiansen-Robertson
FROM: David L. Brown
DATE: July 26, 1968
SUBJECT: THE WORLD TRADE CENTER - CONTRACT WTC-230.00 - QUALITY CONTROL & SAFETY PROGRAM
REFERENCE

COPY TO: L.S. Feld (W/Att), R.M. Monti, F.H. Werneke; A. Guttentag (TRCC)

Please review the attached Koch Quality Control Program as soon as possible and let me have your comments on same.

David L. Brown
Supervising Engineer
The World Trade Center

DLB/DMD
Att.

April 25, 1968

Outline of Items to be Included in Quality Control Program by Karl Koch Erecting Company

A. Survey Control

1. Methods and Equipment
2. Qualification of survey personnel
3. Establishment of monuments and reference lines

B. Control of Construction and Erection Loads

1. Loads on work platforms and finished structure
   a. Weight of equipment
   b. Weight of stored materials
   c. Posting of load limitations
   d. Provision of planking where required
2. Cranes and derricks
   a. Boom angle vs. weight of pick
3. Bracing and erection sequences
   a. Column bracing in Plaza area
   b. Bracing of core columns for tower cranes
      (1) Sequence of jumping bracing
      (2) Sequence of jumping crane
      (3) General erection sequences

C. Field Welding

1. Control of field weld details vs. Fy of material.
2. Qualification and certification of welders
3. Qualification and certification of welding procedure specifications for joints not pre-qualified by AWS.

4. Preparation of welding procedure specifications for welds and joint designs designated pre-qualified by AWS.
5. Control of preheat and innerpass temperatures.
6. Control of welding electrodes, ~~welding~~ fluxes, ~~welding~~ shielding gases, and the like.
7. Storage of welding materials such as heating ovens for low hydrogen electrodes.

D. Bolting of Structural Steel

1. Control of type of bolts and washers used
2. Installation methods and procedures for bolted connections
3. Quality control and assurance that high tensile bolts are properly tightened.
4. Control of ASTM A307 bolts
5. Control of set-up of bolted joints
6. Cleaning of faying surfaces for bolted joints

E. Control of Stud Welding Operations

G. Erection procedures

1. Plumbing
2. Fit-up
3. Guying and bracing
4. Elimination of trapped water from box columns and similar members.
5. Allowance for temperature changes and related movements and deflections of structure.

H. Control of Workmanship

1. Flame-cutting
2. Reaming of holes
3. Drifting

I. Control of Erection Tolerances

1. Refer to tolerance diagrams included in the Specifications.
2. Surveying and other controls.

J. As-Built Drawings

1. Preparation of as-built drawings, procedures for.
2. Control and maintenance of as-built drawings and related procedures.

K. Safety Programs

1. Hoisting equipment
2. Guying materials.
3. Wind conditions
4. Provisions for bad weather

Note: KKE should relate their quality control program carefully to the provisions and requirements of the Specifications and Drawings. Possibly in some areas of the KKE quality control program, explanatory sketches should be prepared and included in the document.

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Appendix G
SUPPORTING DOCUMENTS FOR CHAPTER 8

This appendix contains the supporting documents that are referenced in Chapter 8 of this report. All of the documents contained in this appendix are reproduced with permission of The Port Authority of New York and New Jersey. Table G–1 contains a summary of supporting documents and their location within this appendix. The footnote numbers given in the table correspond to those in Chapter 8.

Table G–1. Supporting documents for Chapter 8.

Footnote Number	Document Title	Page(s)
	Section 8.2 – Variances Relating to Fabrication/Erection Tolerances	
1	Letter dated December 27, 1967 from Richard Chauner of SHCR to Robert Dempsey of United States Testing Company (WTCI-499-L)	407
2	Letter dated December 22, 1967 from James White of SHCR to R. Monti of PONYA (WTCI-499-L)	412
3	Letter dated June 20, 1969 from James White of SHCR to R. Bay from Laclede Steel Company (WTCI-506-L)	415
4	Letter dated November 17, 1969 from James McGuiness of SHCR to R. Monti of PONYA (WTCI-506-L)	418
5	Letter dated October 16, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L)	424
6	Letter dated October 20, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L)	426
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12	Letter dated March 31, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-506-L)	445
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15	Letter dated May 5, 1969 from R. Monti of PONYA to H. Fish of PDM (WTCI-735-L)	462

Footnote Number	Document Title	Page(s)
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17	Letter dated June 6, 1969 from James White of SHCR to R. Monti of PONYA (WTCI-736-L)	464
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34	Letter dated May 3, 1968 from James White of SHCR to R. Monti of PONYA (WTCI-742-L)	515
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PROJECT MEMORANDUM

FROM: SKILLING-HELLE-CHRISTIANSEN-ROBERTSON
1840 Washington Building
Seattle, Washington 98101

DATE: December 27, 1967

TO: United States Testing Company
5521 Telegraph Road
Los Angeles, California 90022

ATT'N: Robert Dempsey

SUBJECT: The World Trade Center- New York
Contract WTC 217.00 Stanray Pacific Steel Inspectic

RE:

Transmitted to you on 12-21-67 was a copy of a telegram fro James White, SHCR-New York concerning dimensional tolerance on the box columns. Included with this telegram was Stanra interoffice memorandum showing their interpretations of thi telegram. The following comments are to be added to these sketches.

1. This applies only to clip angles on the flange and web plates.

2. These minimum edge distances apply only away from the end of the column. Tolerances at the end sha be 1½ inches ± 5/32 inch.

3. Minimum AISC weld shall be increased by the gap dimension.

In addition to the above, other items were transmitted verb

1. The detail of welding certain clip angles call for fillet welds on three sides leaving the heel of th angle free for beam clearance. The AWS Code requires a return of the fillet weld on this side. This is not required...

2. Variance of the end tolerance on column 604-9 has been approved by the supervising engineer. This permitts one flange to be offset 3/16 inch in plac of 1/8 inch as specified on Page 3-04 of the contra document.

PROJECT MEMORANDUM Page 2

FROM: SKILLING-HELLE-CHRISTIANSEN-ROBERTSON
1840 Washington Building
Seattle, Washington 98101

DATE: December 27, 1967

TO:

ATT'N:

SUBJECT:

RE:

3. All hold dimensions on the detail drawings shall be ± 1/16 inch except as modified by the enclosed telegram.

4. Slotted holes shall not be hand flame cut.

5. The tolerance on the dimension between flanges of the column shall be plus 1/8 inch and minus 1/4 inch.

Very truly yours,

SKILLING-HELLE-CHRISTIANSEN-ROBERTSON

Richard W. Chauner

cc: SHCR-New York Jim White

W. P. MARSHALL, Chairman of The Board — TELEGRAM — R. W. McFALL, President

The filing time shown in the date line on domestic telegrams is LOCAL TIME at point of origin. Time of receipt is LOCAL TIME at point of destination

1137A PST DEC 20 67 LA102
SSD189 L NA092 RX PDB NEW YORK NY 20 145P EST
J N TARKAN, STANRAY PACIFIC CORP
11633 SOUTH ALAMEDA ST LOSA
THESE RULINGS APPLY TO BOX COLUMNS FABRICATED UNDER CONTRACT WTC-217.00. ITEM ONE REFER TO DRAWING 6-AB1-41 6-AB7-2. ANGLE IRON CLIPS THESE AND EQUIVALENT DETAILS MAY HAVE ELONGATED HOLES. LONG DIMENSION PERPENDICULAR TO COLUMN FACE SHALL BE BOLT DIAMETER PLUS 1/4 INCH, SHORT DIMENSION STANDARD 1/16 INCH OVERSIZE. THIS PROVIDES 1/8 INCH PLUS OR MINUS TOLERANCE FROM KEEP DIMENSION TOLERANCE FOR ROUND HOLES SHALL BE 1/16 INCH PLUS OR MINUS KEEP DIMENSION. ITEM TWO NO WEB PLATE IN COMPLETED MEMBERS SHALL MEASURE LESS THAN ONE INCH FROM FACE OF WEB TO INSIDE CORNER OF FLANGE PLATE. THIS ALLOWS WEB PLATE TO RUN STRAIGHT END TO END OF COLUMN AND ACCOMMODATED MAXIMUM ALLOWED SWEEP OF 3/8 INCH IN THE FLANGE PLATE. ITEM THREE FOR

Class of Service: This is a fast message unless its deferred character is indicated by the proper symbol.

WESTERN UNION

W. P. MARSHALL, Chairman of The Board — TELEGRAM — R. W. McFALL, President

SYMBOLS: DL=Day Letter; NL=Night Letter; LT=International Letter Telegram

The filing time shown in the date line on domestic telegrams is LOCAL TIME at point of origin. Time of receipt is LOCAL TIME at point of destination

L NA092/2

COLUMNS FABRICATED ON OR BEFORE DECEMBER 16 1967 WHEN INSPTECTED AT MILLED ENDS. 1/16 INCH GAP AT ROOT OF LONGITUDINAL FILLET WELD PLUS 1/32 INCH FOR OUT OF SQUARE CUT WILL BE ALLOWED WHEN MEASURED AT INSIDE PLATE. ANY GAP EXCEEDING THIS ALLOWANCE SHALL RECEIVE AISC MINIMUM FILLET WELDS BEGINNING ONE INCH FROM THE MILLED COLUMN END AND PROVIDE FULL THROAT MINIMUM OF NINE INCHES IN LENGTH
JAMES WHITE

WTC-217.00 6-AB1-41 6-AB7-2 1/4 1/16 1/8 3/8 16 1967 1/16 1/32 (32).

NOTE DETAIL PLATE ON FACE OF COLUMN ANCHORING CAN HAVE HOLD ±1/16

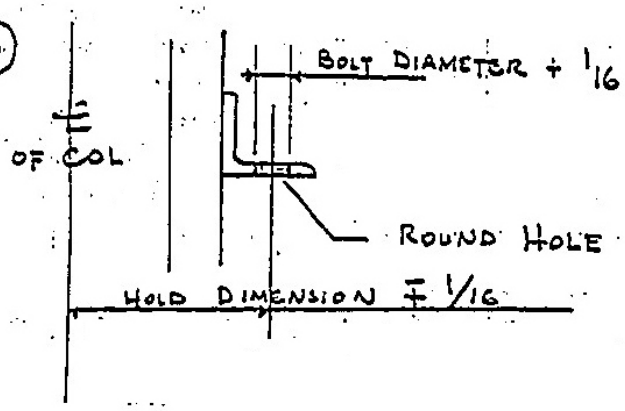
STANRAY PACIFIC CORPORATION
INTER-OFFICE MEMORANDUM

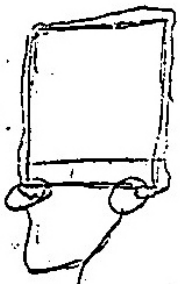
To: GENE WALTON Date: 12-21-1967

From: JOE TARKAN Subject: WORLD TRADE CENTER

ALL COLUMNS FABRICATED ON OR BEFORE DECEMBER 16TH SHALL BE COMPLETED WITHIN THE LIMITS OF FOLLOWING TOLARANCES

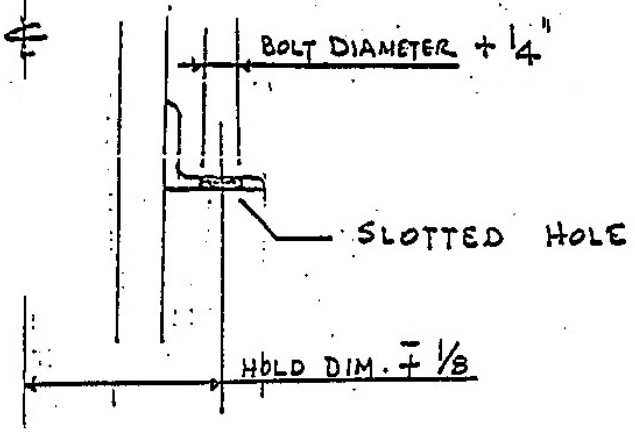
1.





TUBE CAN BE DRAWN

OR



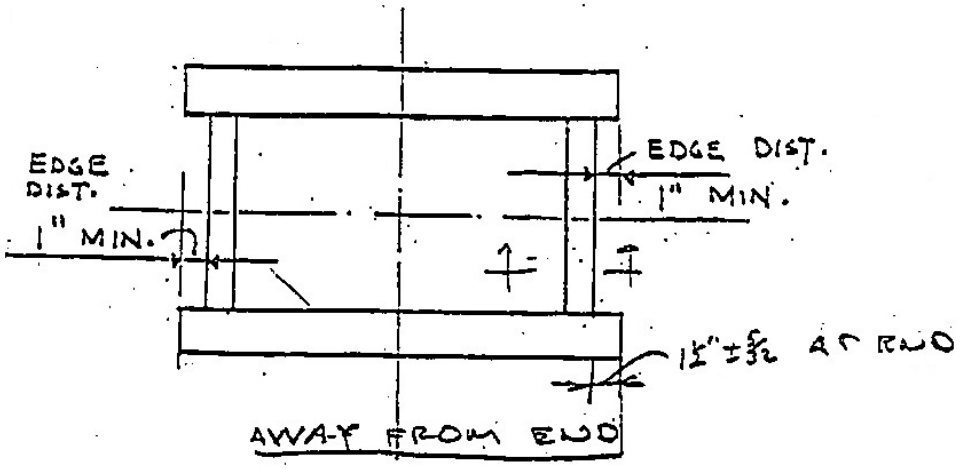
ALSO CLIP ANGLE ON FACE OF WEB.

STANRAY PACIFIC CORPORATION
INTER-OFFICE MEMORANDUM

To: Date:

From: Subject:

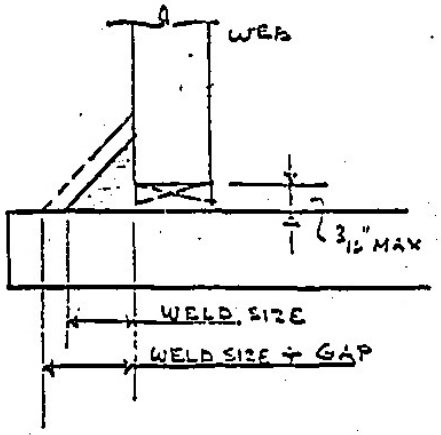
(2)



(3) THE GAP AT MIDDLE OF COLUMN SHALL NOT BE MORE THAN 3/16"

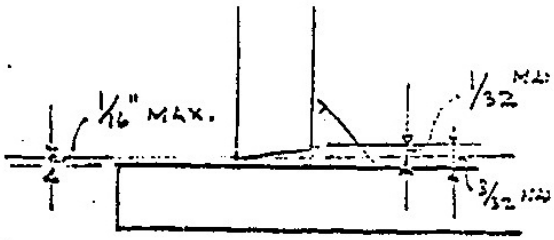
WELD SIZE AT GAP SHALL BE INCREASED ACCORDINGLY

GAPS OF 1/16" OR LESS SHALL BE IGNORED



GAPS AT THE END OF COLS SHALL BE 3/32 MAX. AS SHOWN

IF GAP IS MORE THAN THESE LIMITS PUT 9" LONG FILLET WELD AT INSIDE OF COLUMN STARTING 1" BEYOND MILLED END ACCORDING AISC MIN. WELD SCHEDULE



SKILLING – HELLE – CHRISTIANSEN – ROBERTSON

Consulting Structural and Civil Engineers • 230 Park Avenue, New York, N. Y. 10017 • Mu. 9-8874

John B. Skilling • Helge J. Helle • John. V. Christiansen • Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

December 22, 1967

Port of New York Authority
Office of the Construction
Manager - Room 1119
30 Church Street
New York, New York 10007

Attention: Mr. R. n. Monti, Construction Manager

Reference: The World Trade Center
Contract WTC-215.00, Moshe
Tolerances for Box Beams

Gentlemen:

Enclosed please find a copy of a letter received by SHCR from Mosher Steel Company dated December 14, 1967 requesting approval of tolerances shown on the 8-1/2" x 11" sketch prepared by Mosher and attached to their letter.

We approve the tolerances as shown on the Mosher sketch. All tolerance figures shown are 1/16 or 1/8 inch (see sketch).

We approve a maximum twist in box columns as fabricated of 1/4 inch when measured at one end in relationship to the other end.

Very truly yours,

SKILLING-HELLE-CHRISTIANSEN-ROBERTSON

James White

James White

JW:s
cc: Mr. W. C. Bradford, Mosher
Mr. L. Feld, PNYA
Mr. R. Fensch, SIS
Mr. J. Clulo, SHCR-SE

Enclosure

MOSHER STEEL COMPANY

ENGINEERS - FABRICATORS - ERECTORS

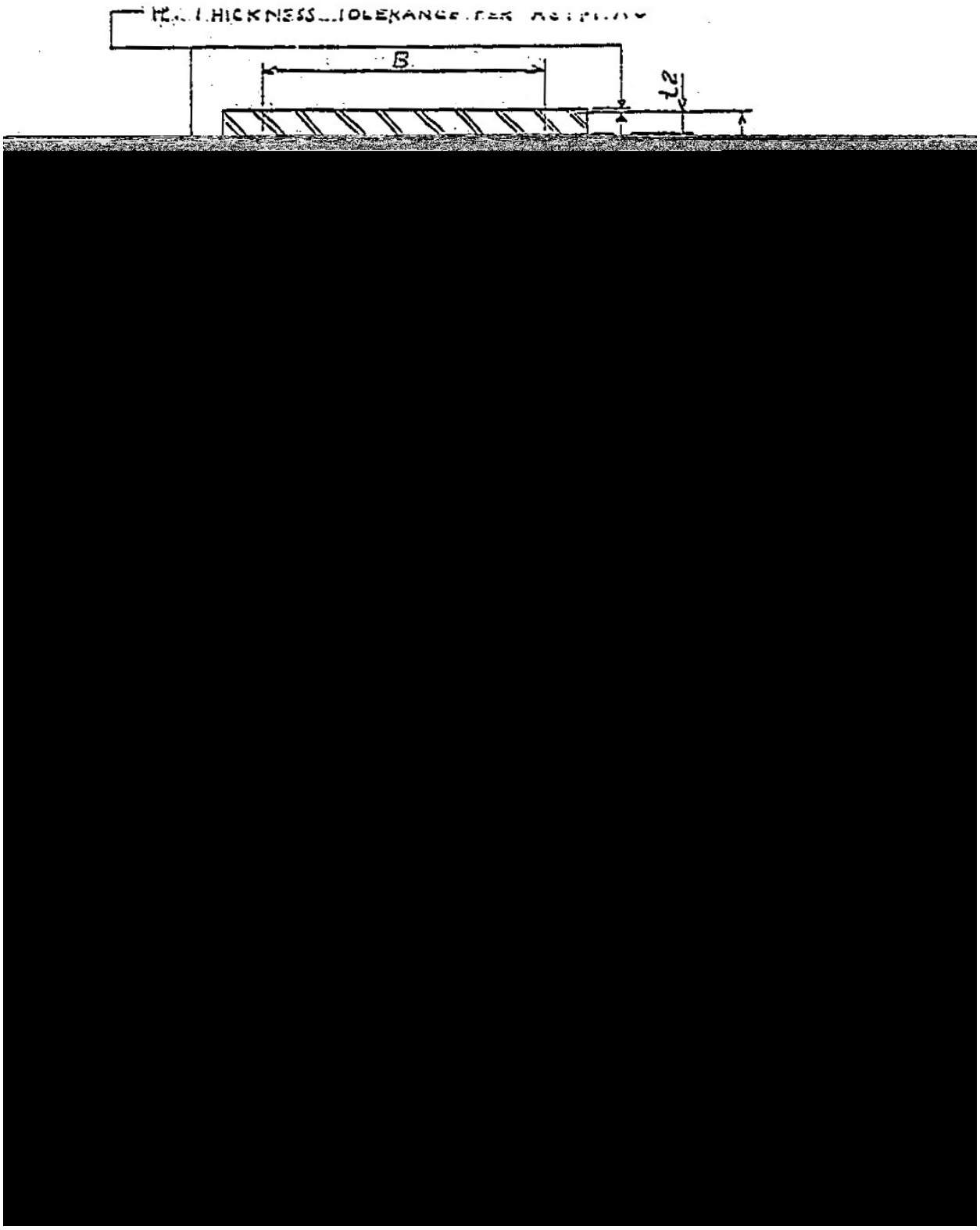
Mail office box 1220 HOUSTON, TEXAS 77001

Over 80 Years

December 14, 1967

Skilling - Helle - Christiansen - Robertson

[redacted]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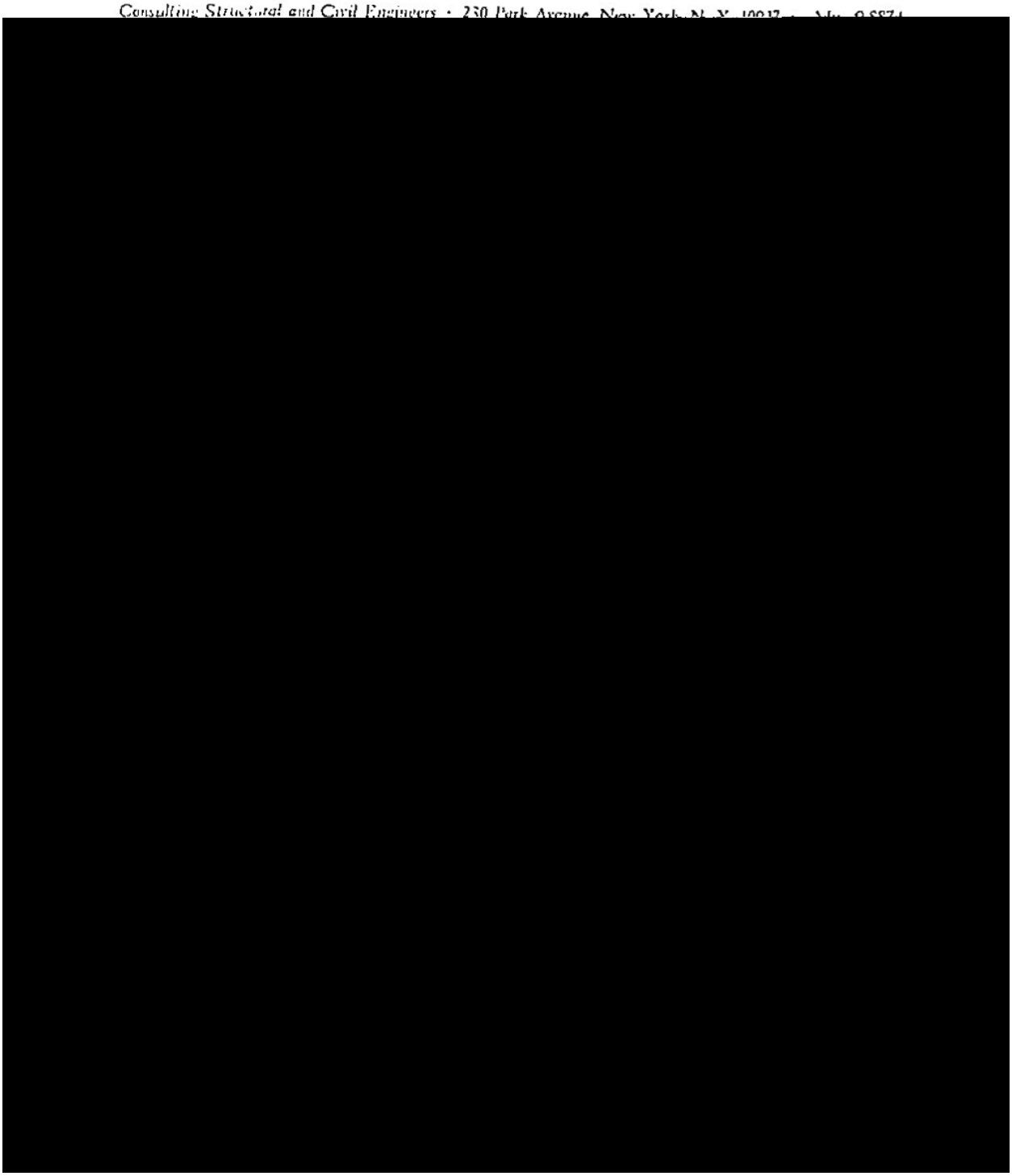
SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · [redacted]



Pacific Steel Company

[illegible]

[illegible] March 13, 1969

Mr. Wayne Brewer
Skilling-Helle-Christiansen- Robertson
230 Park Avenue
New York, New York

Dear Wayne:

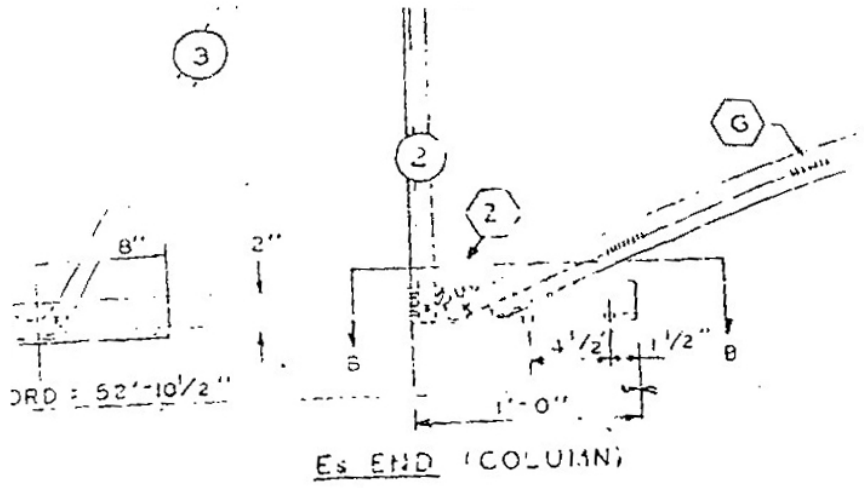
Request for Acceptance of
32" Trusses not Fabricated
According to Approved Drawing

The purpose of this letter is to formally request approval of the twenty (20) trusses listed below that were verbally approved by Mr. Gene Chorny at our Madison Plant on March 11, 1969.

4 - C32T35
8 - C32T34
8 - C32T33

These trusses were fabricated with the "hold exact" dimension at the core end as being 4" instead of 4-1/2" as shown on the approved drawings.

[redacted]



2'-10 1/4"

[redacted]

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N Y 10017 · MU 9-8874

John B Skilling · Helge J Helle · John V Christiansen · Leslie E Robertson

Manager
Wayne A Brewer

Consultants
Harold L Worthington
Joseph F Jackson

November 17, 1969
File WTC-221C-WTC-223C

Port of New York Authority
Office of the Construction Manager
30 Church Street-10th Floor
New York, New York 1007

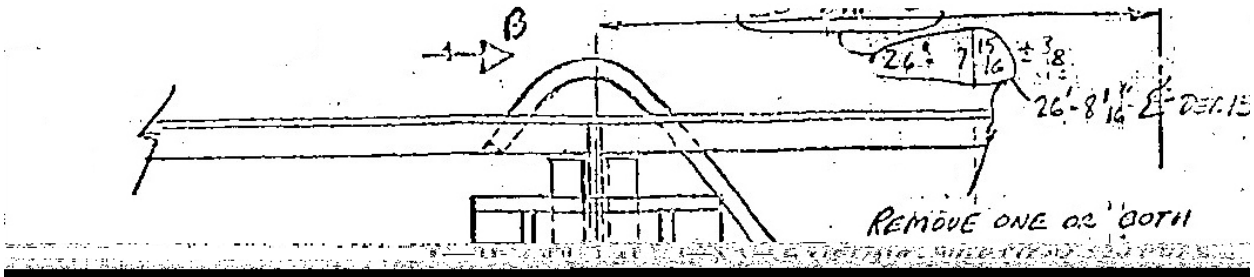
Attention: Mr. S. M. Honti

Reference: The World Trade Center
Contract WTC-221.00, LeClede
Contract WTC-223.00, EKE (Carteret)
Tolerances and Repair Procedures
Letter of November 7, 1969, EKE to TWCC

Gentlemen:

We have reviewed the EKE letter of November 7, 1969

[redacted]



[redacted]

KARL KOCH ERECTING CO., INC.
[illegible] AVE. CARTERET, N. J. 07008 · 201/969-1700 · Cable ERECTING

WORLD TRADE CENTER PROJECT
130 LIBERTY ST. · NEW YORK, N.Y. 10006
TEL. 212/233-0810

November 7, 1969

Tishman Realty and Construction Co., Inc.
30 Church Street
New York, New York

Attention: Mr. Al Guttentag
Project Manager

Re: Letters from R. Piasecki to A. Guttentag
dated April 11, 1969 and July 8, 1969

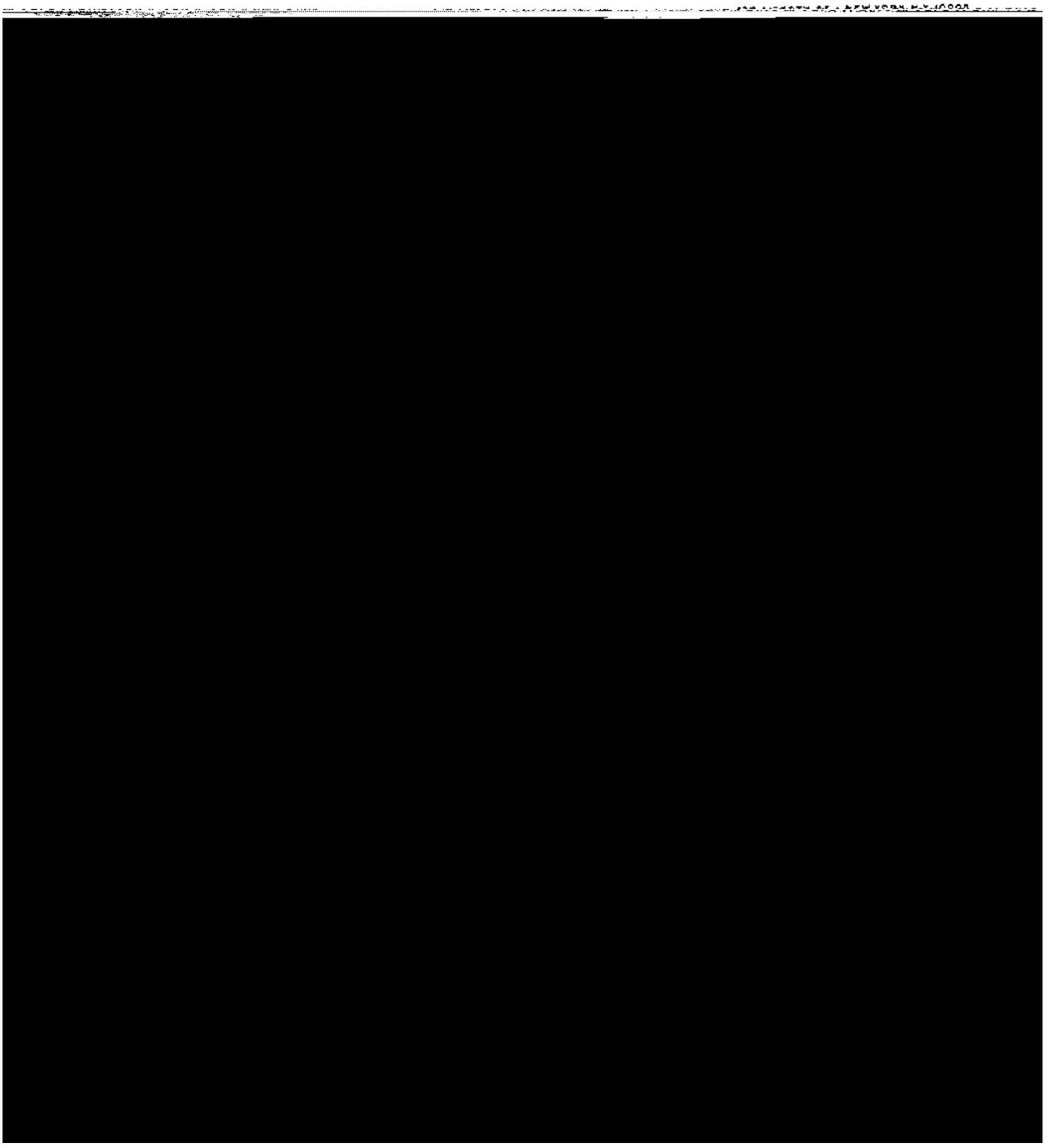
Dear Sirs:

As stated in the above referenced letters the assembly of truss

[redacted]

KARL KOCH ERECTING CO., INC.
400 ROOSEVELT AVE. · CARTERET, N. J. 07008 · 201/969-1700 · Cable ERECTING

WORLD TRADE CENTER PROJECT



SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Brewer

Consultants
Harold L. Worthington
Joseph F. Jackson

October 16, 1969
File: WTC-221C

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-221.00, Laclede
Fabrication Tolerance

Gentlemen:

Please refer to Laclede's letter to SBCR dated September 18, 1969. A copy

[redacted]

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Brewer
Consultants
Harold L. Worthington
Joseph F. Jackson

October 20, 1969
File: WTC-221.00

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-221.00, Laclede
Fabrication tolerances

Gentlemen:

Please refer to the Laclede Steel Company to SECR dated October 6, 1969. A copy of the subject letter is attached to this letter for your reference.

We approve the tolerance of ±3/8" for the 2-7/8" or 1-3/4" dimension at the top chord intersection of the inclined strut (mark 2 in the shop drawings) as requested in the Laclede letter. Please note that this tolerance applies to inclined end struts on 24T trusses only. This relaxation of tolerance cannot be allowed to extend to other cases. One example is the vertical strut member ST (members 2 and 5) for truss C32T6 on Laclede sheet number ST206. It is essential that these members be installed as accurately as possible in all cases.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

cc: Messrs. L. Feld, PNYA
W. Borland, PNYA
R. Bay, Laclede
B. Jackson, PTL @ St. Louis

JW:1

Laclede Steel Company

General Offices · Laclede Building

St. Louis, Missouri 63101 October 6, 1959

Mr. Wayne Brewer
Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10017

Dear Wayne,

This letter is written to request a tolerance of ± 3/8" for the dimension of 2-7/8" or 1-3/4" that locates the upper end of the Inclined Strut (Mark 2) which is fabricated in one or both ends of the following 24" trusses.

24T9	24T11
24T9A	24T11A
24T10	24T11B
24T10A	24T11C
24T10B	24T12
24T10C	24T13
24T10D	24T13A
24T10E	24T13C
24T10F	24T13D
24T10H	BT216A
24T10J	BT216B
24T10K	BT216C
24T10L	

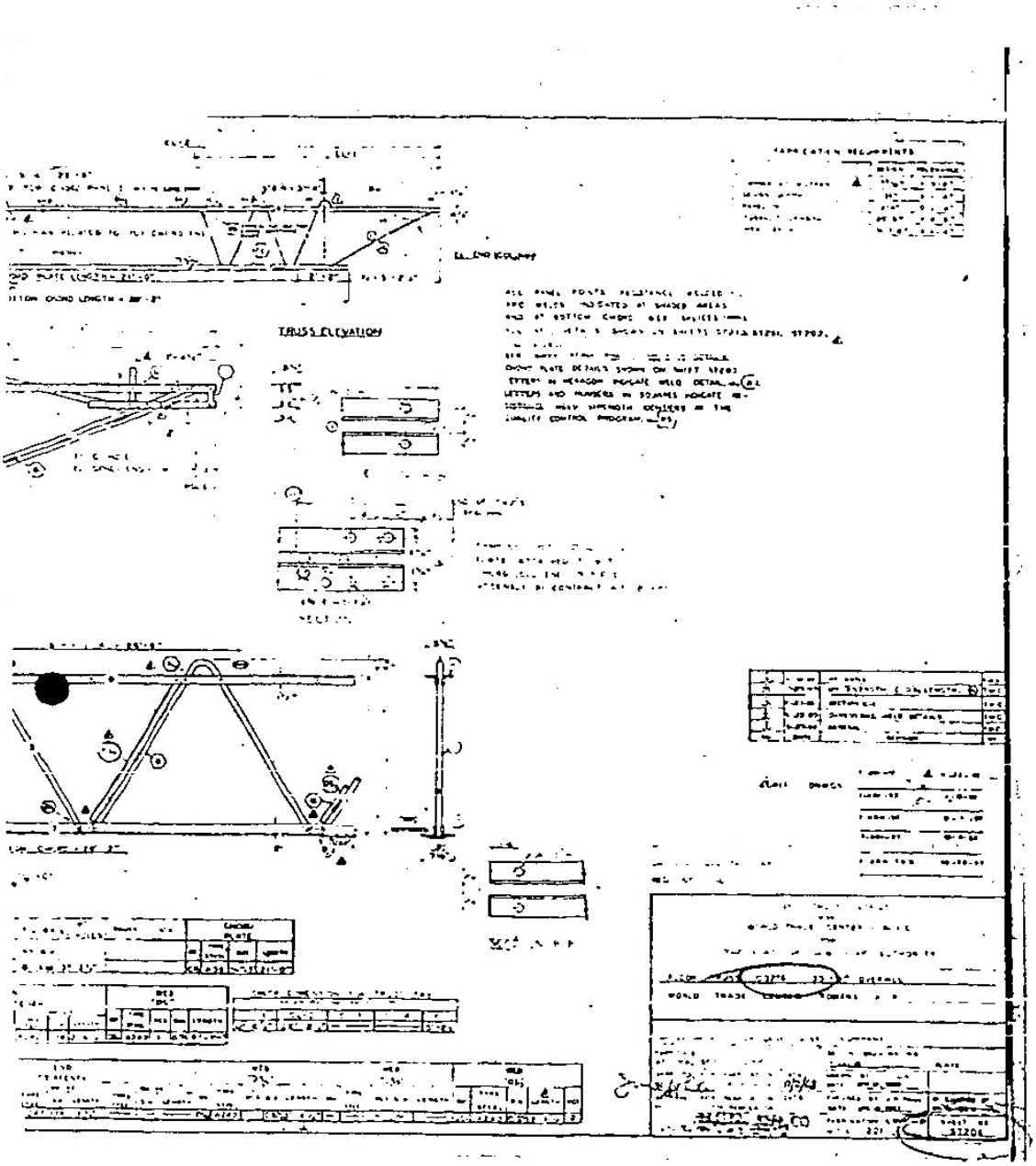
Because of the large number of these trusses that we plan to fabricate in the very near future, a prompt reply would be greatly appreciated.

Yours very truly,

LACLEDE STEEL COMPANY

Robert D. Bay
Director of Technical Services
Project Coordinator

kjj



THE PORT OF NEW YORK AUTHORITY
111 Eighth Avenue at 15th Street New York N.Y. 10011

World Trade Department
Guy F. Tozzoli Director
Richard C. Sullivan Director

June 16, 1969

Laclede Steel Company
Arcade Building
St. Louis, Missouri 63101

Attention: Mr. A. Carl Weber

Re: The World Trade Center - Contract WTC-221.00 -
Field Welded Connections for Bridging Trusses
and Bridging Angles at Panel Joints

Gentlemen:

A. After observing actual on-site difficulties encountered in Tower "A" (due to misalignment and accumulation of fabrication tolerances) in field welding the referenced connections, we directed the Erector to proceed as follows in order to expedite the work:

1. Use single butt plate, field welded option, shown on Drawings 7C/1, 8C/1, 9C/1, 10C/1 and 11C/1 which occur a total of 96 times on a typical floor. Butt plate thickness was determined by KKE from field measurement of actual gaps at the ends of bridging trusses in "as erected" position.

2. At connection 2C (which occurs 120 times on a typical floor) and connection 19C (which occurs 4 times on a typical floor) all field welding was eliminated by adding 4 extra #5 bars parallel to each row of bridging angles. Extra steel for a typical quadrant is shown on Drawing FP-1 (Revised 6-9-69).

3. At connections 7C thru 11C two extra #5 bars are added at all bridging truss panel joints to compensate for horizontal weld across top of top chord angles which was eliminated because of tight welding clearances.

4. Allowing 10% for laps, 7.8 tons of extra reinforcing is presently being added for floors 10-20± per floor.

5. Connections 13C thru 17C remain as originally designed with no change in field welding details occurring a total of 20 times on a typical floor.

B. To mitigate costs, Laclede is directed to proceed as follows on all future deliveries:

1. At connection 2C - delete connection plate, mark P-1, as shown on Laclede Drawing CD-201.

2. At connection 7C - delete connection plates, mark P-2 and P-3, and delete connection bar, mark CB-1, all shown on Laclede Drawing CD-201.

3. At connection 8C - delete connection plate, mark P-4, delete connection bars, mark CB-1, and delete two connection bars, mark CB-4, all shown on Laclede Drawing CD-202.

4. At connection 9C - delete connection plates, mark P-2 and P-7, and delete connection bar, mark CB-1, all shown on Laclede Drawing CD-203.

5. At connection 10C - delete two connection bars, mark CB-2, shown on Laclede Drawing CD-202.

6. At connection 11C - delete connection plate, mark P-2 and delete connection bar, mark CB-1, all shown on Laclede Drawing CD-204.

7. At connections 13C thru 17C - No change

8. At connection 19C - delete connection plate, mark P-6, shown on Laclede Drawing CD-204.

9. Hold clear distance of 1" minimum, from center of panel joint to edge of web struts at both chords so as to permit the use of either field welded option in item A or field bolted option proposed in item C below.

C. Laclede is to submit separate unit price quotations on each of the following bolted alternates on a per floor basis:

1. Connection 2C - furnish, fabricate and ship 3/4" thick plates (F_y=50) and shim stock (F_y=36) shown on Drawing 2-C/2 - revised 6-13-69. Note X - all 3/4" plates to be shop welded to bridging angles by Laclede. This connection occurs 120 times per typical floor.

2. Connection 7C - furnish, fabricate and ship 3/4" thick plates (Fy=50) and shim stock (Fy=36) shown on Drawing 7-C/2 - revised 6-13-69. Note Y - all 3/4" plates to be shop welded to bridging truss chord angles by Laclede. This connection occurs 52 times per typical floor.

3. Connection 8C - furnish, fabricate and ship 3/4" thick plates (Fy=50) and shim stock (Fy=36) shown on Drawing 8-C/2 - revised 6-13-69. See Note Y above. This connection occurs 12 times per typical floor.

4. Connection 9C - furnish, fabricate and ship 3/4" thick plates (Fy=50) and shim stock (Fy=36) shown on Drawing 9-C/2 - revised 6-13-69. See Note Y above. This connection occurs 8 times per typical floor.

5. Connection 10C - furnish, fabricate and ship 3/4" thick plates (Fy=50) and shim stock (Fy=36) shown on Drawing 10-C/2 - revised 6-13-69. See Note Y above. This connection occurs 12 times per typical floor.

6. Connection 11C - furnish, fabricate and ship 3/4" thick plates (Fy=50) and shim stock (Fy=36) shown on Drawing 11-C/2 - revised 6-13-69. See Note Y above. This connection occurs 12 times per typical floor.

7. Connections 13C thru 17C - No change

8. Connection 19C - Furnish, fabricate and ship 3/4" thick plates (Fy=50) and shim stock (Fy=36) shown on Drawing 2-C/2 - revised 6-13-69. See Note X above. This connection occurs 4 times per typical floor.

9. Tolerances for quotations C1 thru C6 and C8, out to out dimension over 3/4" butt plates (example: 19'-11-3/4" for 20'-0" panel) is to be held to a tolerance of (+ 1/8") or (- 1/4") including ASTM A6 allowance for overrun on plate thickness. Vertically, the tolerance on keep dimension of 1'-8-3/4" (connection 7C) or 1' 8-1/4" (connections 8C and 9C) is ± 1/16".

10. All shim stock to be shipped in kegs by thickness. Furnish 2/3 of all shim sets consisting of 2-1/8" plates. Furnish remaining 1/3 of shim sets to consist of one-3/16" plate.

11. Bolts, nuts and washers will be furnished by others. Laclede does not furnish bolt lists.

12. Furnish alternate quote for 3/4" thick plates in Fy=36 in lieu of Fy=50 in items C1 thru C6 and C8. Your comments on availability and effect on delivery dates for Fy=36 vs. Fy=50 material are solicited.

13. In view of the fabrication greater effort required for these minimal weight butt plates we feel the formulas in the Contract Booklet on "Extra Materials" are not equitable for these items. We have therefore requested your separate quotations for these items.

14. Should the Authority accept your quotation on items C1 and C8 and/or items C2 thru C7 please advise us the lead time required from notification to convert fabrication line to these bolted alternate details.

D. With respect to deleted material in item B, please advise us as to effective floor number for deletion, tonnage deleted and credit due to the Authority as per Contract formula.

E. Time is of the essence and your prompt reply is solicited to enable us to balance extra reinforcing bar costs against bolted and welded options.

Sincerely,

Malcolm P. Levy

Attachment: As per Transmittal List 355X

cc: Messrs. R. Abrahams, W. Brewer (8HCR), M. Gerstman (TRCC), w/att.

The World Trade Center
Structural Drawings
Transmittal List 355X
June 16, 1969

Field Welded Option at Panel Joints	Rev. Date
FT-1 - Floors 10 - 70 +	6-2-69

[redacted]

June 20, 1969
File: WTC-221C

Port of New York Authority
Office of the Construction Manager
20 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-221.00, Lacledo
Plate P91, Truss Connector 13-C, Lacledo Drawing ST274

Gentlemen:

We approve the use of 22 plates P91 as fabricated by J. S. Alberici and described in the Lacledo letter dated June 5, 1969 and shown in the attached Lacledo sketch JS-13-91.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

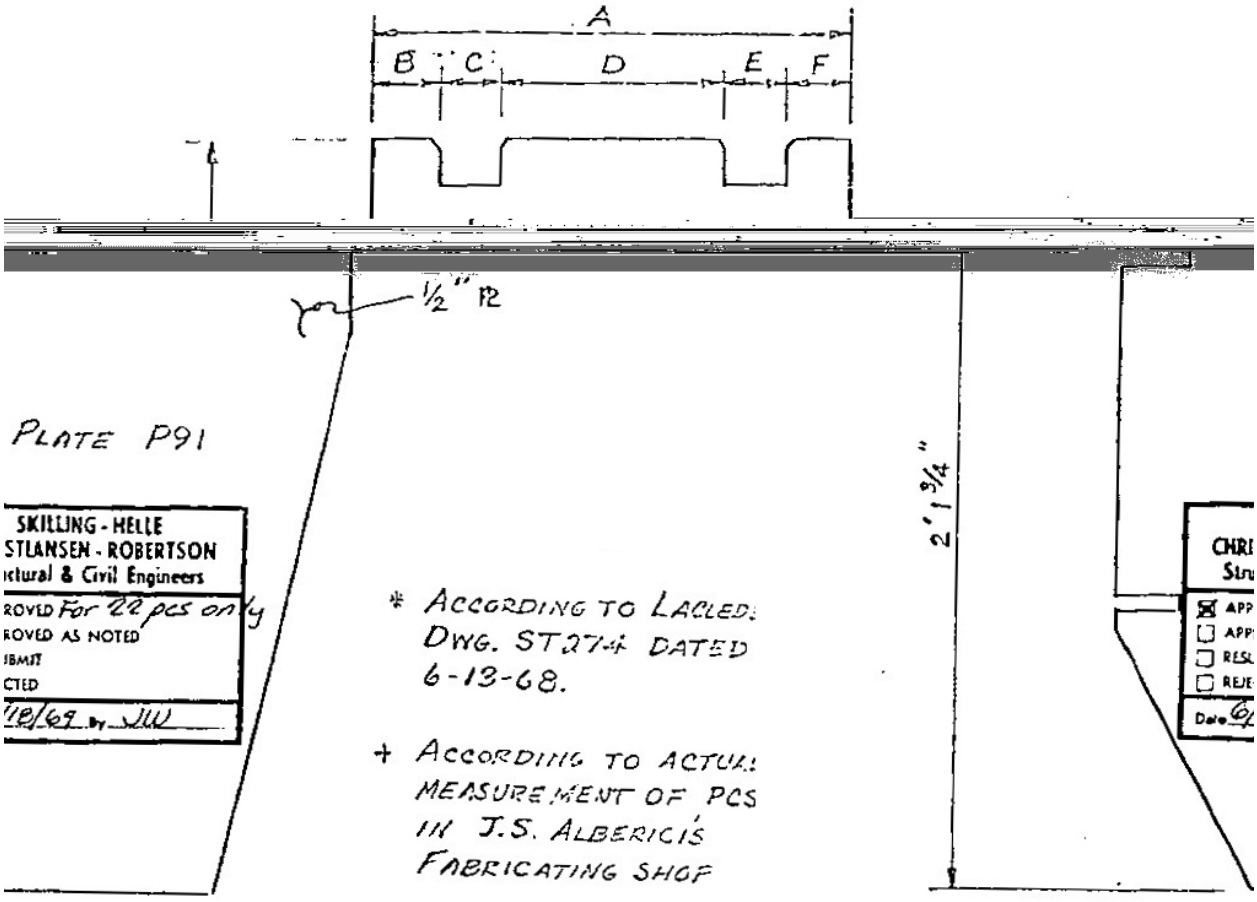
cc: Messrs. L. S. Feld, PEYA
S. May, Lacledo
A. Guttentag, TPCC
B. D. Jackson, PTL, St. Louis

JW/sl

DE STEEL COMPANY

DWG. NO. JS-13-91

ACTUAL LENGTH VS. SPECIFIED LENGTH OF TOP DIMENSIONS OF PLATE P91 OF TRUSS CONNECTOR 13-C



ECIFIED ENGTH *	ACTUAL LENGTH +	DEVIATION	DIMENSION	SP LE
13"	12 3/4"	- 1/4"	A	
1 15/16"	1 15/16"	0	B	
2"	2"	0	C	
5 1/8"	5 1/8"	0	D	
2"	2"	0	E	
15/16"	1 11/16"	- 1/4"	F	

Laclede Steel Company

"General" Offices: Arcade Building

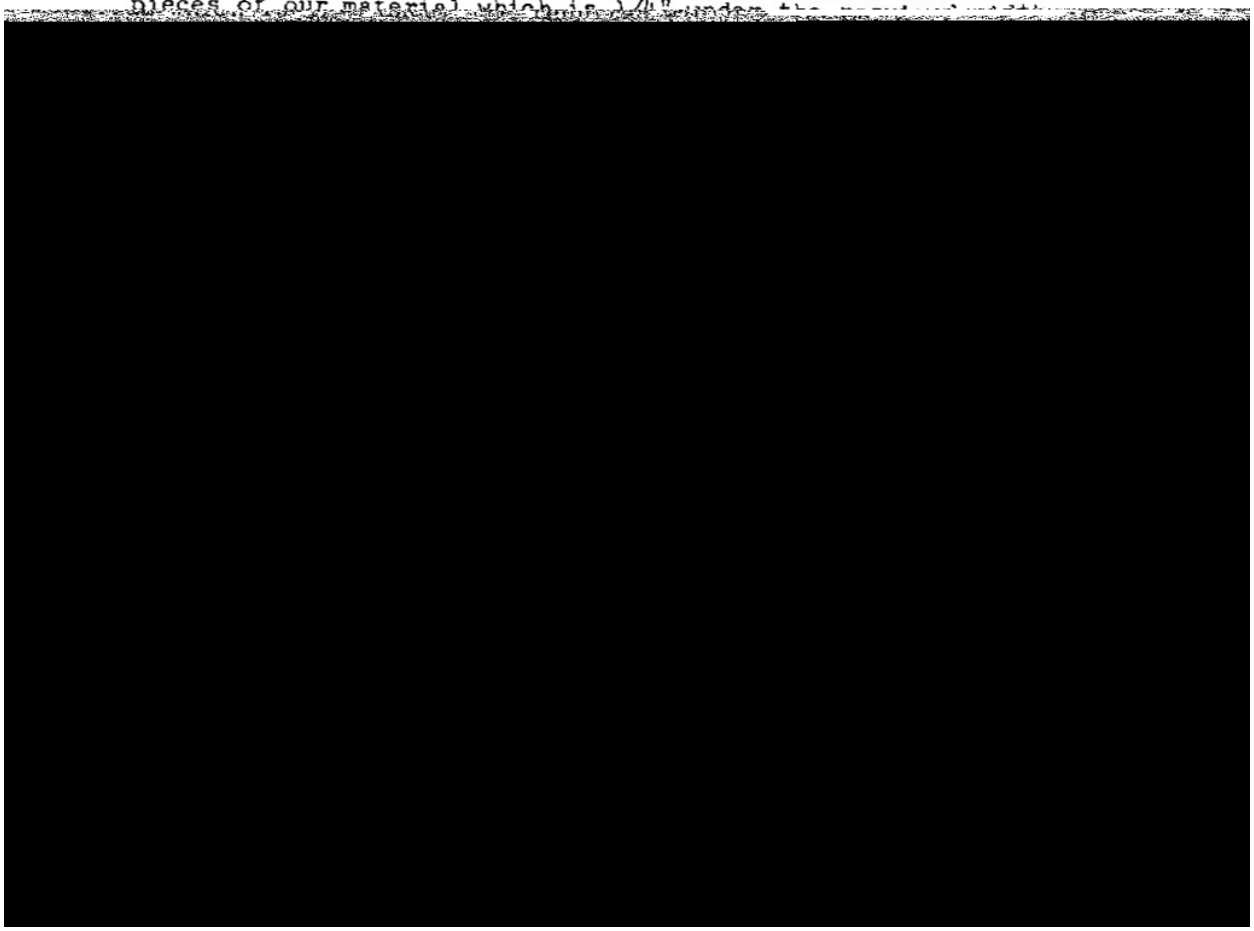
St. Louis, Missouri 63101 June 5, 1969

Mr. Wayne Brewer
Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10017

Dear Mr. Brewer:

Re: World Trade Center
Contract WTC 221.00
Material Supplied J. S. Alberici Co.

Presently the J. S. Alberici Construction Company which fabricates the truss connectors we supply for the World Trade Center has 22 pieces of our material which is 1/4" [redacted]



SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · MU 8-8574

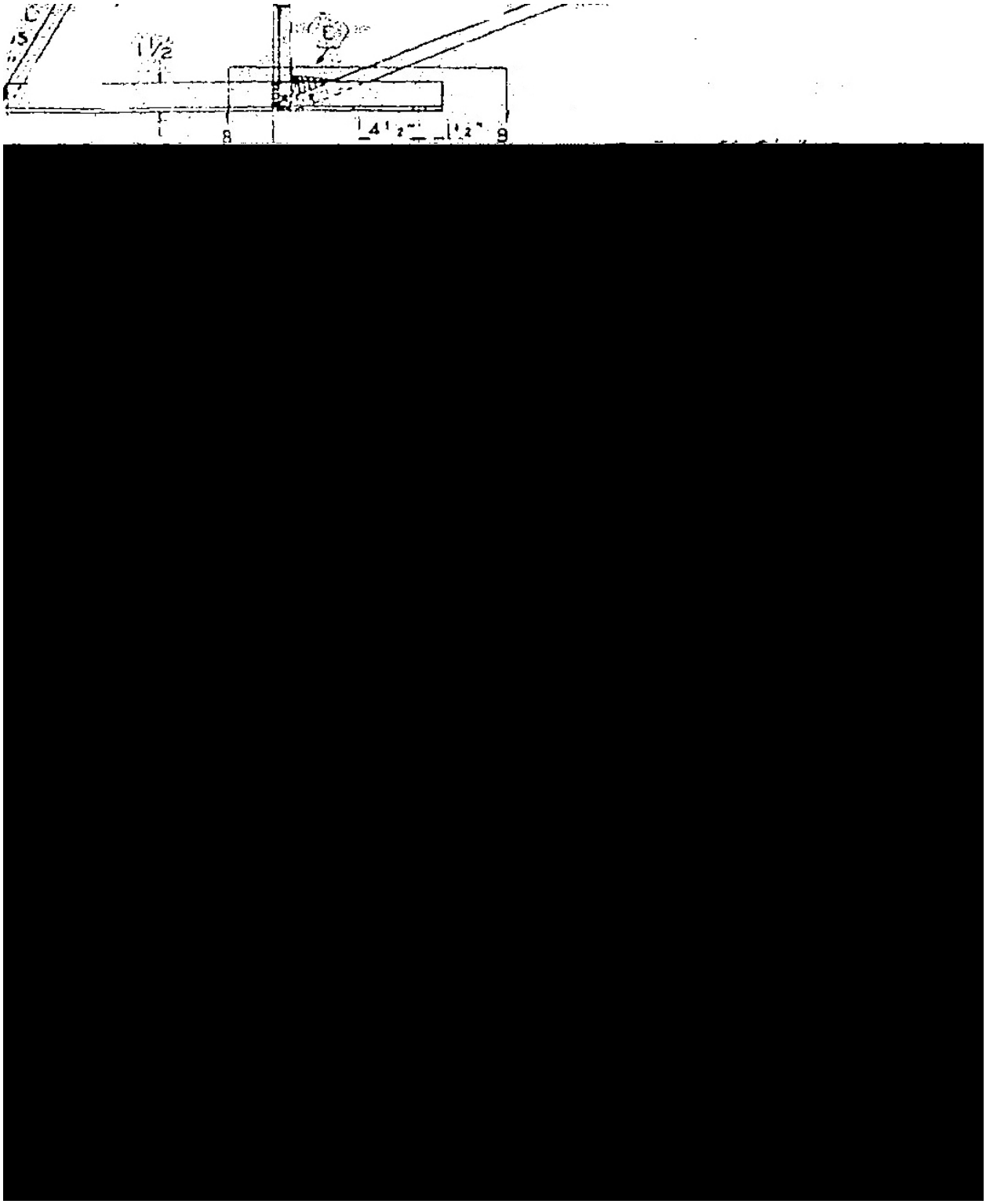
John B. Skilling · Hedge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Breuer
Consultants
Harold L. Worthington
Joseph P. Jackson

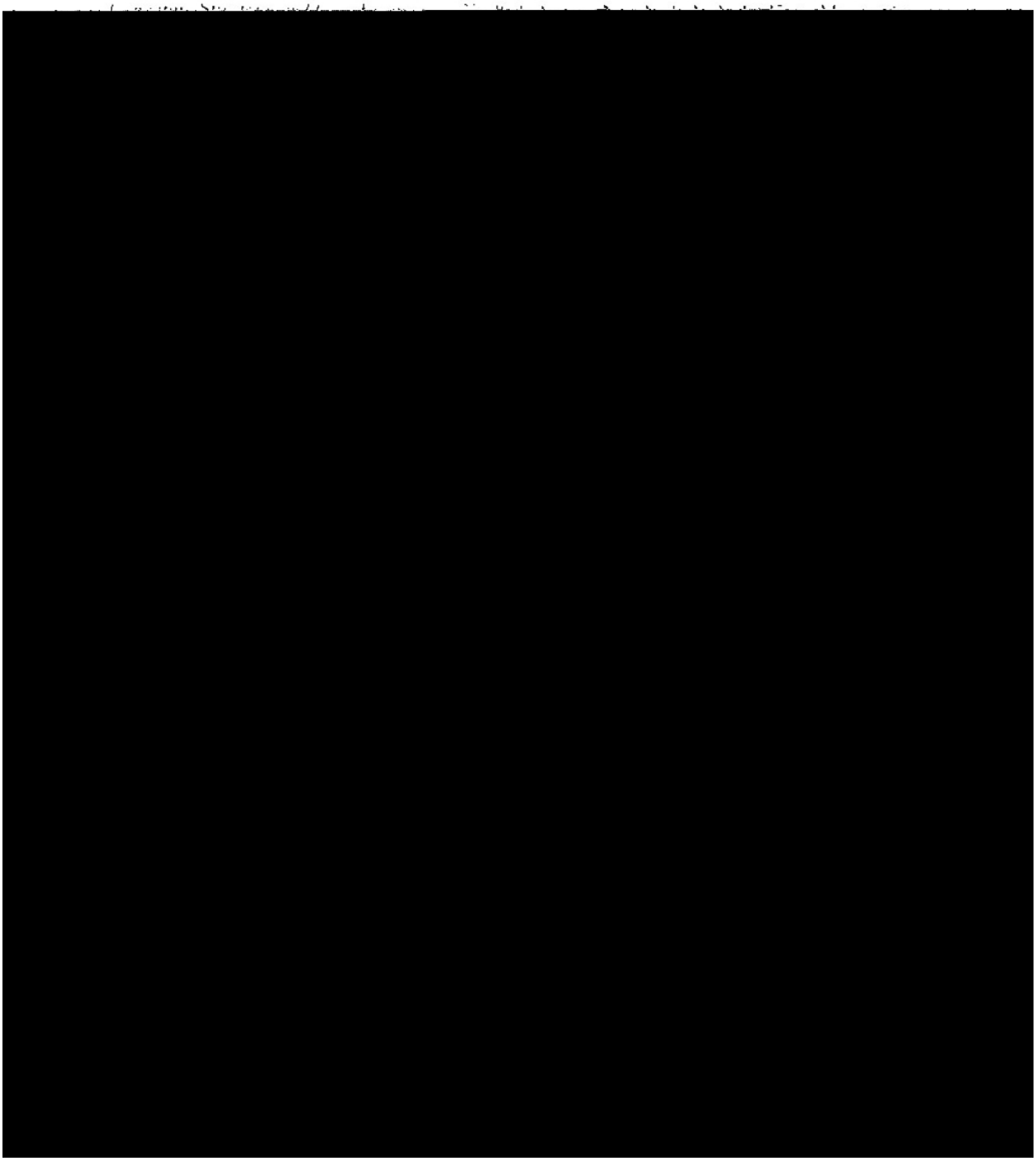
December 15, 1969
File: WTC-221C

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York 10007

[redacted]


1½
8
9

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON



Jacobs Steel Company

General Offices Frank Building

St. Louis, Missouri 63101 June 5, 1969

Mr. James White
Skilling-Helle-Christiansen Robertson
230 Park Avenue
New York, New York 10017

Dear Mr. White:

Please find attached "Repair Procedure for Vertical Struts on 32" Trusses" and drawing W-VS-1 dated 3 June 1969. With the submission of this procedure, formal request is made for approval to repair as necessary the vertical struts on trusses

[redacted]

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · MU 9-5570

John B. Skilling · Hale J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Brewer

Consultants
Donald J. Worthington
Joseph F. Jackson

July 3, 1969
File: WTC 221C

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract 221.00, Laclede
Repair Procedure, Truss Bearing Ends

Gentlemen:

[redacted]

June 3, 1969

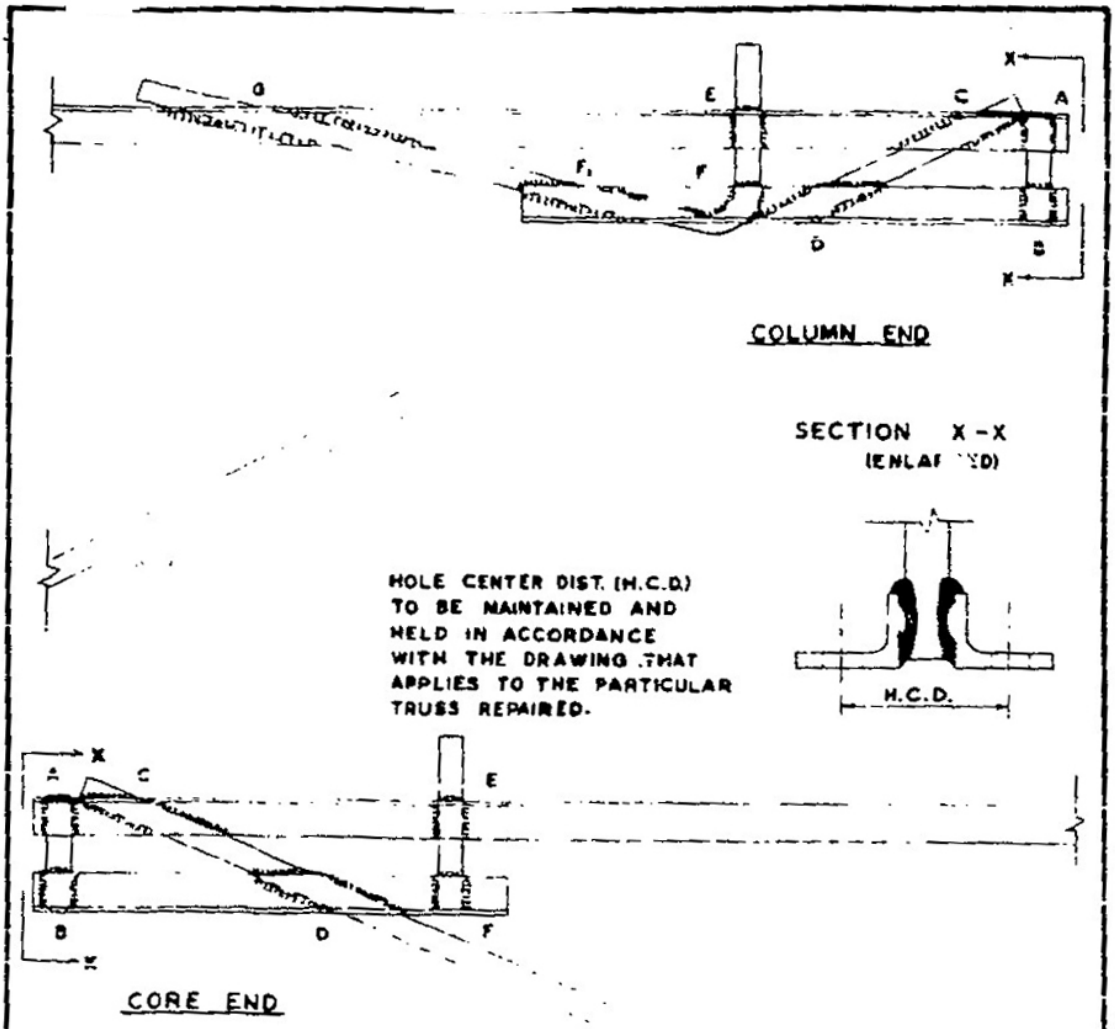
REPAIR PROCEDURE
TRUSS BEARING ENDS

The following procedure is written to cover the repair of bearing ends on trusses provided for the World Trade Center Project under Contract WTC-221.00. Such repairs that may be necessary from time to time will normally be made at the Madison Plant of Laclede Steel Company and may involve one or more of the lettered welds on drawing W-DE-1 dated June 2, 1969 which is attached and a part of this procedure. Briefly the repair welds will be made to adjust the bearing depth of the seats which have a tolerance of ± 1/8".

Arc Welder Foreman, a Cer- Under the supervision of the Certifie
essary repairs. The lettered tified Arc Welder will perform the ne
part with a torch. All weld joint to be repaired will be burned a
weld will be removed from the splatter from the previous resistance
is a clean surface of base surface to be rewelded so that there
ited, burning must be metal. (If the weld is already separ
tter material must be accom- required but removal of the weld spla
plished.)

of the particular lettered With reference to the drawing W-DE-1
be accurately positioned and joint to be welded, the members will
ered in accordance with the the welding of the joint will be com
hich have been previously existing procedures for arc welding
s which are full-length shall approved. The dimensions of the weld
avin, SF299 dated February 24, be in accordance with the table on dr
1968.

e inspected and tested follow The repaired trusses and welds will b
are stated in Section 105 the quality control procedures which
Trade Center 221.00. Quality Control and Inspection, World



NOTES:

1. ALL ARC WELDS TO BE MADE WITH LOW HYDROGEN ROD IN THE E-70 SERIES OR EQUAL.
2. ALL ARC WELDS FULL LENGTH EACH SIDE AS SHOWN.
3. ALL ARC WELD SIZES TO BE IN ACCORDANCE WITH NOTE 1 OF LACLEDE DRAWING ST 290, DATED FEB 24, 1968

SKILLING - HELLE CHRISTIANSEN - ROBERTSON
Structural & Civil Engineers
[X] APPROVED
[ ] APPROVED AS NOTED
[ ] RESUBMIT
[ ] REJECTED
Date 7-3-69 By JW

LACLEDE STEEL COMPANY ST. LOUIS, MISSOURI	CLASS: WORLD TRADE CENTER	DATE JUNE 2, 1969
WELDING PROCEDURE FOR REPAIR OF BEARING ENDS		REV.
		FILE
ENGINEERING DEPARTMENT D.B.J. APPROVED		DRAWING W-BE-1

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · MU 8-5577

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Associates
Warren A. Brewer
Consultants
Harold J. Washington
Joseph E. Jackson

March 31, 1969

Port of New York Authority
Office of the Construction Manager
30 Church Street, Room 1030
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-221.00, Laclede
Rework of C32T1A Trusses

Gentlemen:

Please refer to the Laclede letter dated March 18, 1969, requesting approval for the repair of twenty-four C32T1A trusses. We approve repair of the subject trusses by double-strutting with an additional 0.75" ϕ bar as shown in the Laclede repair drawing dated March 17, 1969, a copy of which was attached to the Laclede letter. One copy each of the Laclede letter and the attached sketch are included with this letter for your ready reference.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

JW:s
Enclosure

cc: Messrs. R. Bay, Laclede
L. Feld, PNYA
L. Thielmeier, PTL

THE PORT OF NEW YORK AUTHORITY

May 8, 1969

Laclede Steel Company
Arcade Building
St. Louis, Missouri 63101

Attention: Mr. Robert B. Bay

RE: The World Trade Center
Contract WTC-221.0: Laclede
Rework of C32TIA Trusses

Gentlemen:

We approve the repair of twenty four (24) C 32 TIA Trusses by double-strutting with an additional 0.75"ϕ bar as shown on your sketch dated March 17, 1969 accompanying your request letter dated March 17, 1969.

Very truly yours,

W. C. Barlage
Engineer of Materials
The World Trade Center

CC: Messrs: R.M. Monti
J. Wolfe (S[illegible]R)

Laclede Steel Company

General Offices Laclede Building

St. Louis, Missouri 63101 March 18, 1969

Mr. Wayne Brewer
Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10011

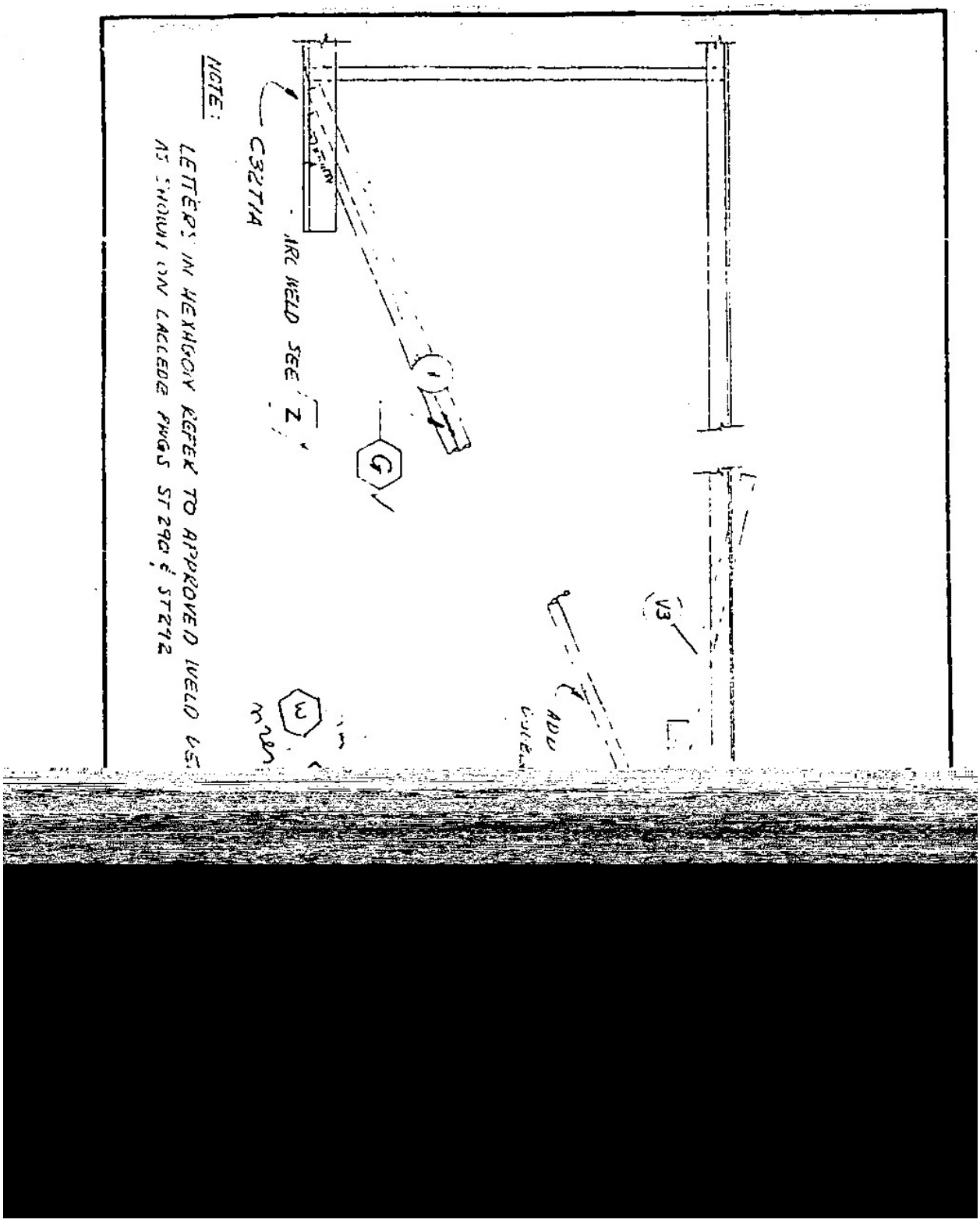
Dear Wayne:

Request for Approval of
Reworked C32T1A Trusses

The 24 C32T1A Trusses have been fabricated at our Madison Plant with the V3 and diagonal strut on the column end with 1.09" web stock instead of 1.14" as shown on the approved drawing.

We request that the trusses be approved after repairing them by double strutting the diagonal strut with a .75 bar as shown on the attached drawing.

[redacted]


C327TA
IRC WELD SEE
NOTE:
LETTERS IN HEXAGON REFER TO APPROVED WELD
AS SHOWN ON LACLEDE PWGS ST290 & ST292
V3

June 6, 1969

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-213.0(), PDH
Repair of Plate "d", Panel 2309

Gentlemen:

Please refer to the PDH letter to PNYA dated May 23, 1969, NDT report sheets 3 and 4 complete our records on the referenced repair. We, therefore, approve Panel 2309 as repaired.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

cc: Messrs. L. Feld, PNYA
H. Fish, PDH
D. Caffery, SIB-Houston

JW/ia

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 150 Park Avenue, New York, N. Y. 10017 · MU 8-8874
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson
Manager
Wayne A. Barnes
Consultants
Harold L. Washington
Joseph L. Jackson

May 16, 1969

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York

Attention: Mr. G. H. Monti

Reference: The World Trade Center
Contract WTC-213.00, PDM
Repair of Plate "d", Panel 230B

Gentlemen:

Please refer to the PDM letter to PNYA dated May 1, 1969. We approve the repairs described contingent upon receipt from PDM of confirming UT reports.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

cc: Mr. L. Feld, PNYA
Mr. H. Vinh, PDM
Mr. J. Caffary, SLB (Houston)

jw:tc

PDM

ENGINEERS · FABRICATORS · CONSTRUCTORS

CABLE ADDRESS
TELEX 000 000

PITTSBURGH-DES MOINES STEEL COMPANY

NEVILLE ISLAND · PITTSBURGH, PENNSYLVANIA · FOUNDED 1891

May 1, 1969

The Port of New York Authority
30 Church Street
New York New York 10007

Attention: Mr. R M. Monti

Reference: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17138

Gentlemen:

We are sending you for your record and approval one (1) copy of our repair procedure sheets No. 1 and 2 showing the repairs of laminations we found in Plate "d" Panel 230B.

These repairs were made in accordance with the "Investigation and Repair of Lamination and Other Discontinuities" dated March 19 1969. They were witnessed by your inspector Mr. Dave Caffery of Southern Inspection

Please send us a letter of approval for our record

Very truly yours

PITTSBURGH DES MOINES STEEL COMPANY

H. M Fish
Project Manager

HMF:kah
Enc

cc: Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10007

Attention: Mr. James White
Plus one copy

Tishman Realty and Constr Co
11th Floor 30 Church St.
New York New York 10007

Attention: Mr. M. Gerstman

75TH ANNIVERSARY

CABLE PITDESMOIN
TELEX 000 [illegible]

PDM

ENGINEERS · FABRICATORS · CONSTRUCTORS

PITTSBURGH-DES MOINES STEEL COMPANY

[illegible]

May 33, 1969

The Port of New York Authority
30 Church Street
New York, New York 10007

Attention: Mr. S. M. Monti

Reference: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17138
Repair of Plate "d", Panel-230B.

Gentlemen:

Reference to SHCR letter of May 16, 1969, to Mr. S. M. Monti approving our repair procedure to plate "d" Panel 230B contingent upon receipt of our NDT reports.

We are enclosing for your records one (1) copy of our NDT reports Sheets No. 3 and No. 4.

Unless we hear from you we will assume that this subject matter is finalized.

Very truly yours,

PITTSBURGH DES MOINES STEEL COMPANY

W. H. Fish
Project Manager

[illegible]
Enc.

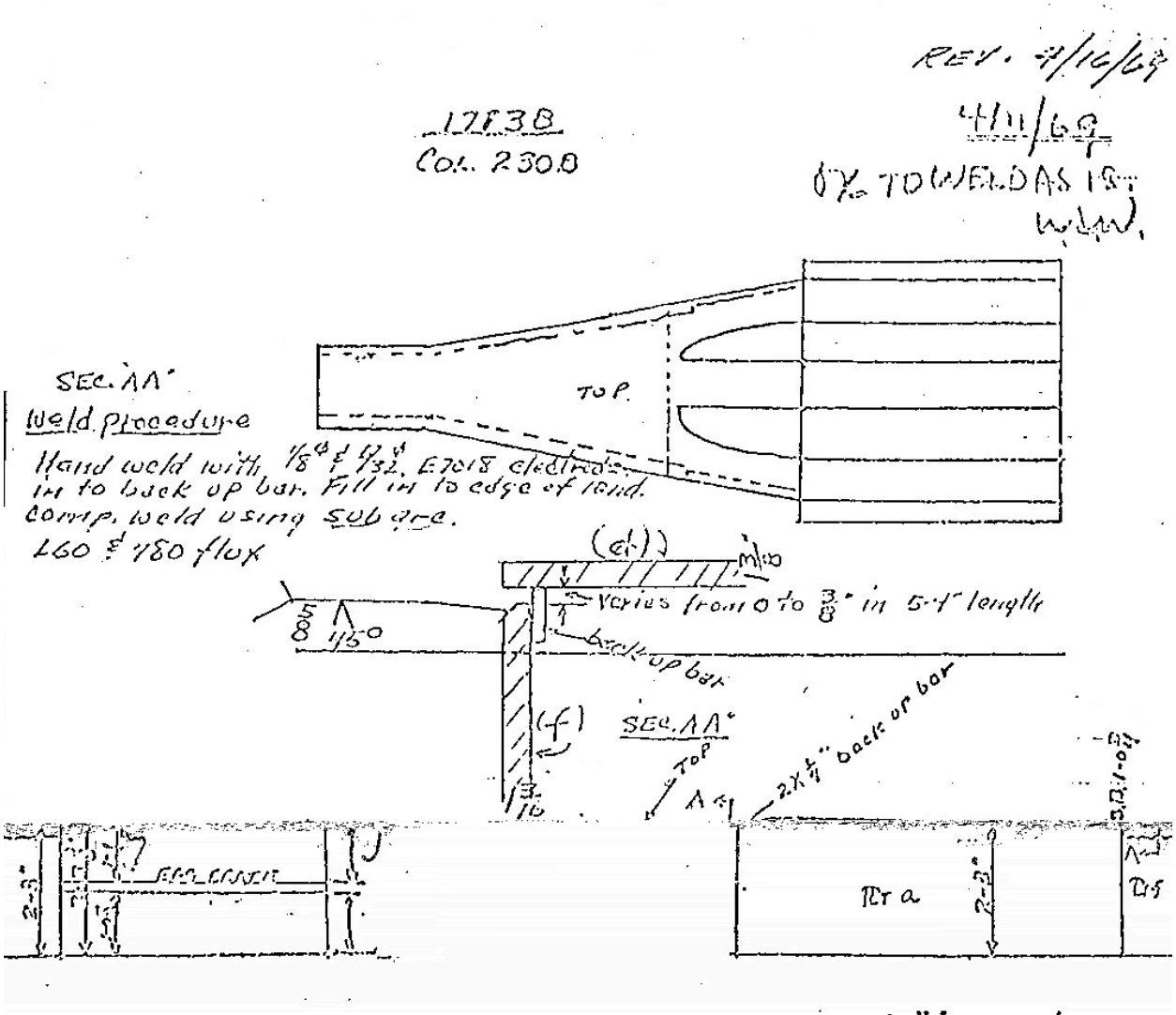
CC: Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10007

Attention: Mr. James White
Plus one copy

Tishman Realty & Constr.
11th Floor, 30 Church St.
New York, New York 1000[illegible]

Attn: Mr. M. Gerstman

75TH ANNIVERSARY

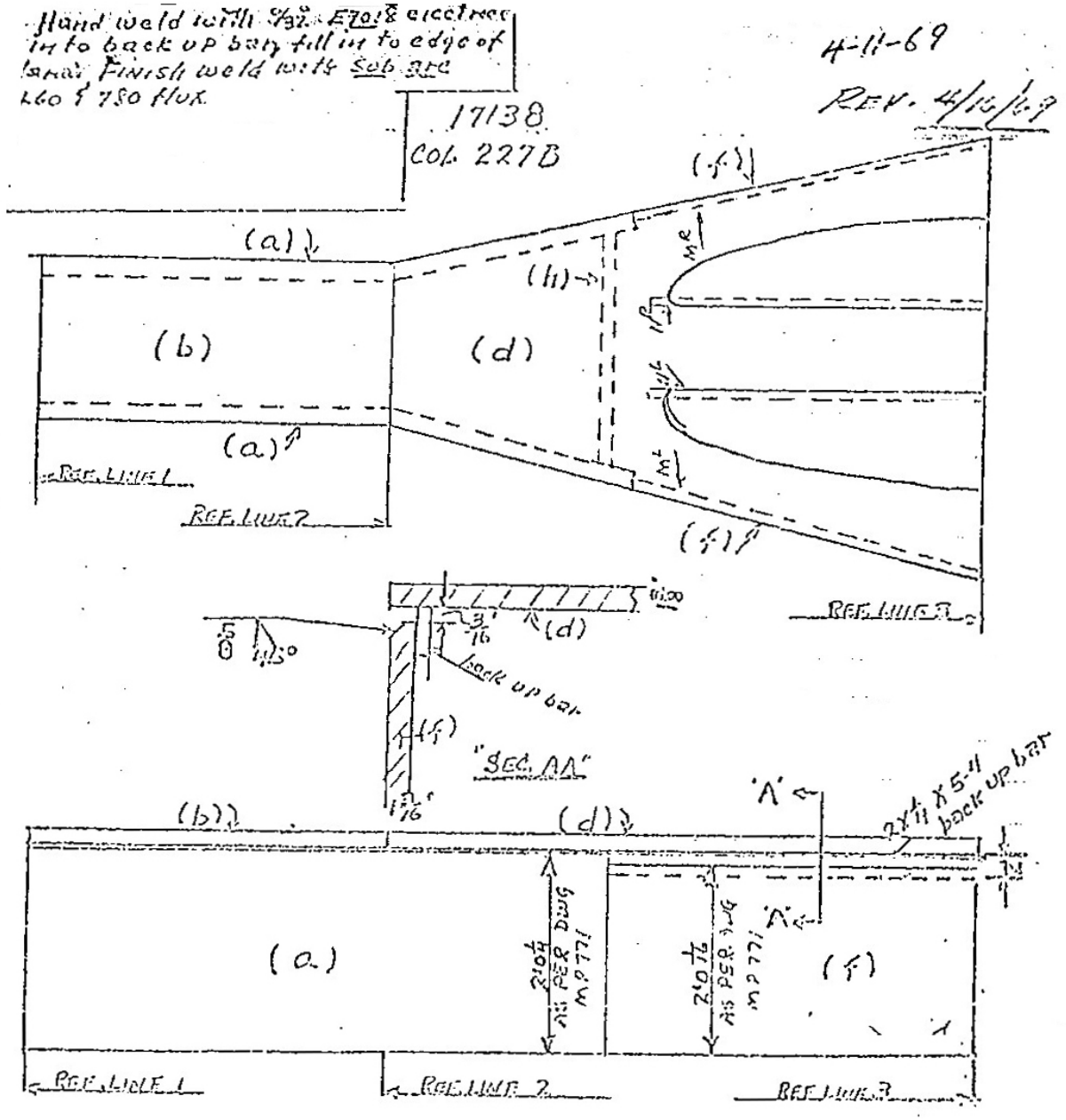


one corner
in side upon weld flush,
and top of Pr. f"
ar, to fill void, ⇨

Egg crate fabricated 3/8" too wide on
in fitting of Pr. to egg crate, ca bolto
leaving 3/8" between top of egg crate
Request permission to use back up b
between f and cover plate d."

Swank P.C.

R.



Verbal approval recieved from H. Fish 11-10-69 to make up difference in width of Plates f. & a by using 2x½" back up bars, tacked to f' Plate. Written approval to follow.
R. Swank Q.C.

PDM

ENGINEERS / FABRICATORS / CONSTRUCTORS

CABLE INTERMOIN
TELEX 960 754

PITTSBURGH-DES MOINES STEEL COMPANY

[illegible]

May 1, 1969

[illegible]no Port of New York Authority
[illegible]ect
[illegible] York New York 10007

Attention: Mr. R M. Monti

Reference: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17138

Gentlemen:

We are sending you for your record and approval one (1) copy of our repair procedure sheets No. 1 and 2 showing the repairs of laminations as found in Plate "d" Panel 2303.

These repairs were made in accordance with the "Investigation and Repair of Lamination and Other Discontinuities" dated March 19 1969. They were witnessed by your inspector Mr. Dave Caffory of Southern Inspection

Please send us a letter of approval for our record.

Very truly yours.

PITTSBURGH DES MOINES STEEL COMPANY

[illegible] Figh
Project Manager

BHF:ksh
Enc

cc: Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York. New York 10007

Attention: Mr. James White
Plus one copy

Tishman Realty and Constr.Co.
11th Floor 30 Church St.
New York. New York 10007

Attention: Mr. M. Gerstman

75TH ANNIVERSARY

Pittsburgh-Des Moines Steel Company

ULTRASONIC REPORT FORM

Sheet 1-1

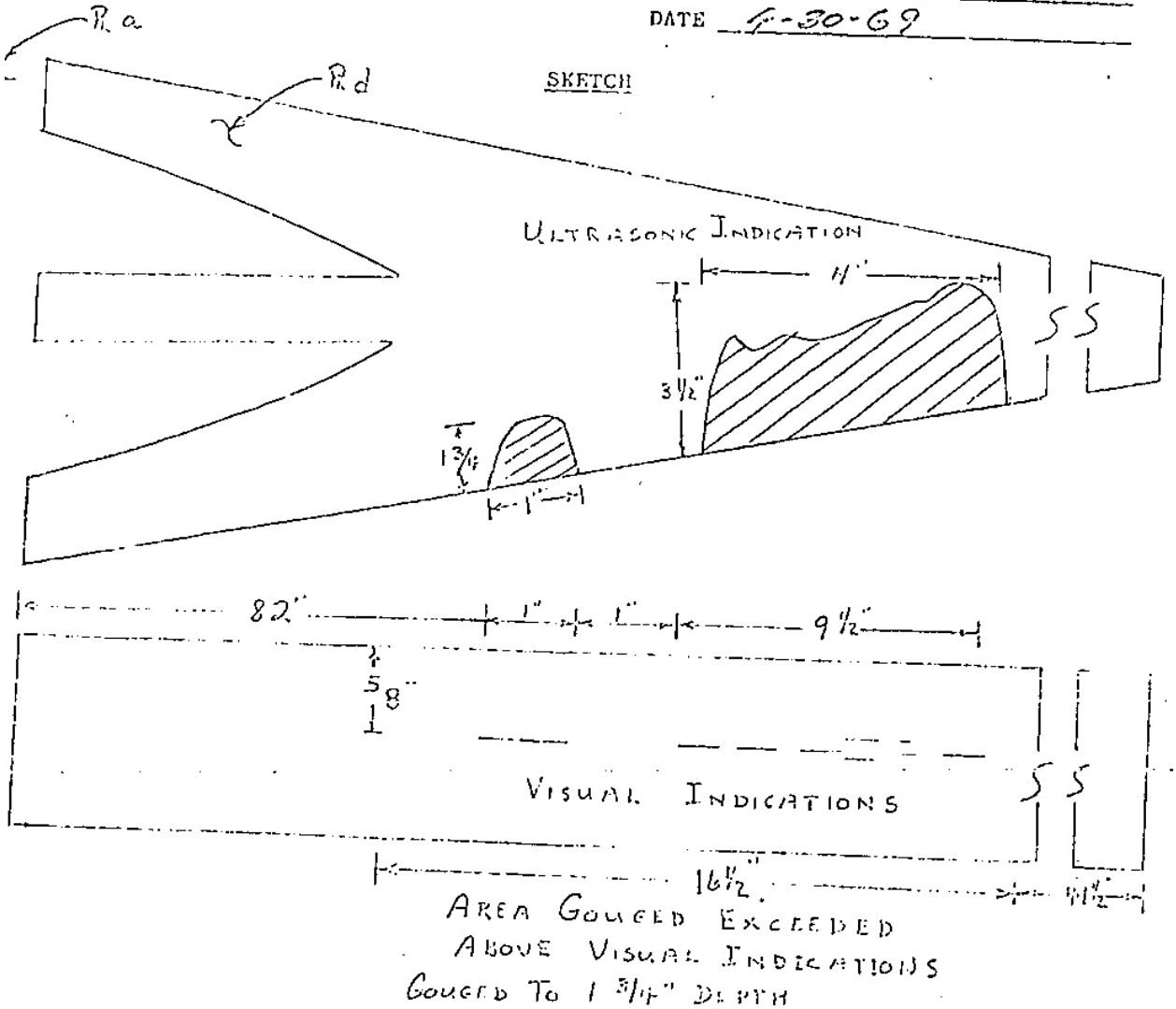
ULR

CONTRACT 17138 A30B
MATERIAL FY55 ULT F A913-68
THICKNESS 13/8"
DRAWING MD 775
SURFACE FINISH SMOOTH
PIECE MARK 10
ULTRASONIC PROCEDURE USED ASTM-435
METHOD USED CONTACT
TECHNIQUE USED PULSE ECHO
PERSONNEL QUALIFICATIONS

EQUIPMENT USK 5M
SEARCH UNIT STRAIGHT BEAM
FREQUENCY - SIZE 2.25MHz - 1"ø
CALIBRATION BLOCK SOUND AREA 0E2
COUPLANT CELLULOSE
BASIC SENSITIVITY R.R.

WITNESSED BY S O Caffrey
OPERATOR C. VIGNE
DATE 5-30-69

SKETCH



AREA GOUGED EXCEEDED
ABOVE VISUAL INDICATIONS
GOUGED TO 1 3/4" DEPTH

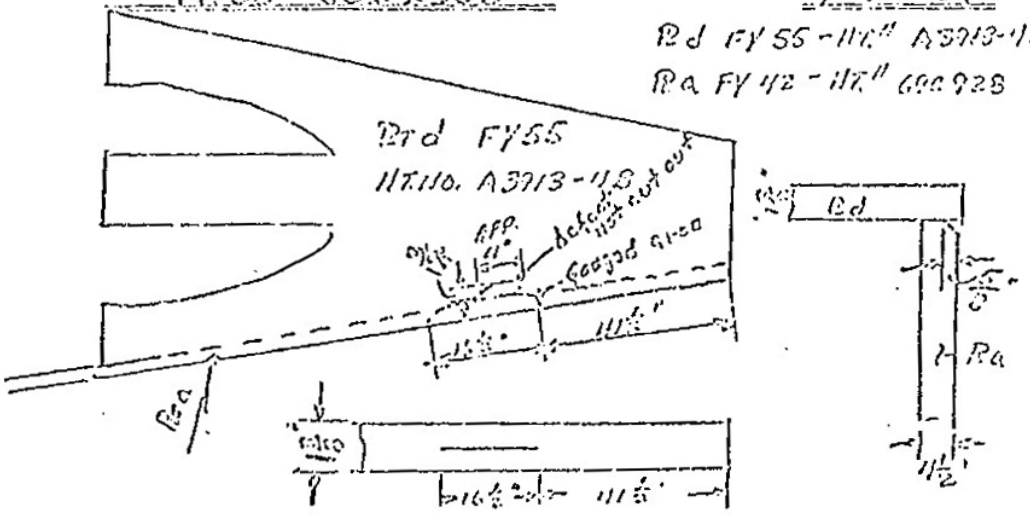
Sheet 2

W138 - Col. 730D

11-30-67

Rd FY 55 - 11K" A3913-45

Ra FY 42 - 11K" 600928



Area to be repaired after gouging and discing = 16½" long x 1⅜" wide x ⅛" dp. (Varies)

Repair Procedure

Pedigent 225° - Arc air gouge out defected area. Disc grind and mt check gouged out area to insure complete removal of defect (one area 4" lg. x 1⅜" dp. not removed) Pedigent 225°, weld one pass of weld, using 7018 electrode, disc grind and mt check to insure sound metal. Finish making repair using stove electrode - Mc 6010 each ½" or more weld bead - grind and mt check - Also ut check repaired area.

R. Swab QC Insp

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · MU 9-8874
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
William V. Brocco
Consultants
Harold J. Worthington
Joseph P. Jackson

May 19, 1969

Port of New York Authority
Office of Construction Manager
30 Church Street
New York, New York

Attention: Mr. E. M. Monti

Reference: The World Trade Center
Contract WTC-213.00, PDM
Repair of Plate "b", Panel 300B

Gentlemen:

Please refer to the PDM letter dated May 8, 1969 transmitting 8½ x 11 sheets 1 through 8 inclusive describing repair procedures and including reports of non-destructive test results for repair work on plate "b", Panel 300B.

The repair of plate "b" is approved as well as the final repaired weld, plate "ab" to "b", as documented by UT test on May 8, 1969.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

cc: Messrs. L. S. Feld, PANYA
R. M. Plen, PDM
D. Caffery, SIS (Houston)

JW/ld

CABLE PITTDEMOIN
TELEX 000 734

PDM

ENGINEERS / FABRICATORS / CONSTRUCTORS

PITTSBURGH-DES MOINES STEEL COMPANY

NEVILLE ISLAND • PITTSBURGH PENNSYLVANIA 15225 • PHONE (412) 331-1000

May 8, 1969

The Port of New York Authority
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17138

Gentlemen:

We are sending you for your record and approval one (1) copy of sheets 1 to 8 inclusive covering the repair procedure for repairing a crack that developed in Plate "b" Panel-3008.

This repair was made in accordance with the Investigation and Repair of Laminations and other Discontinuities dated on March 19, 1969. The repairs were witnessed by your inspector Mr. Dave Caffery.

Please send us a letter of approval for our records.

Very truly yours,

PITTSBURGH DES MOINES STEEL COMPANY

H. M. Fish
Project Manager

HMF:ksh
Enclosure

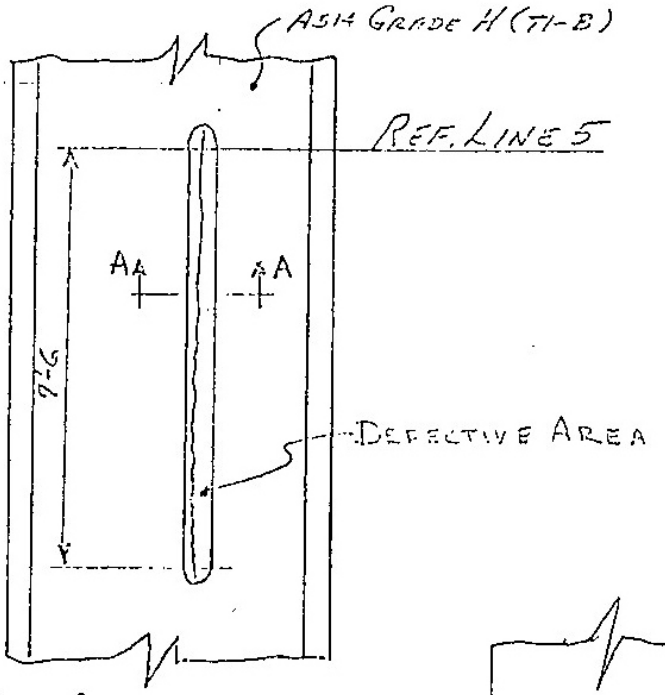
Skilling-Helle-Christiansen-Robertson
Attention: Mr. James White
Plus one (1) Copy

Tishman Realty and Constr. Co.
Attention: Mr. M. Gerstman

ANNIVERSARY

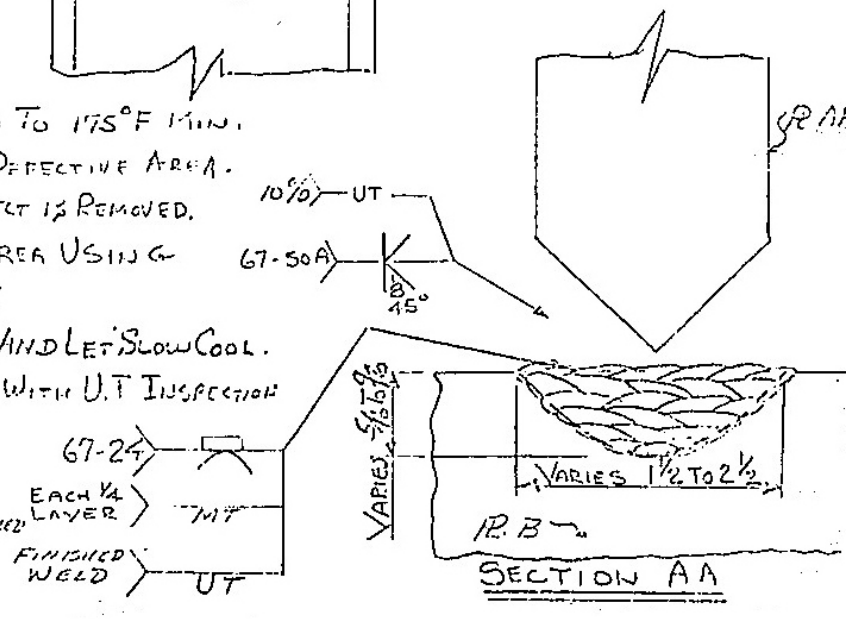
Sheet-1

CONT. 17138 CORNER COLUMN No. 300 B – MP. 817 5-2-69



PROCEDURE

(1) PREHEAT DEFECTIVE AREA TO 175°F MIN.
(2) GOUGE AND DISC OUT DEFECTIVE AREA.
(3) MT TO MAKE SURE DEFECT IS REMOVED.
(4) WELD THE GOUGED OUT AREA USING E8018 M 3/16" ELECTRODE.
(5) AFTER WELDING COVER AND LET SLOW COOL.
(6) CHECK COMPLETED WELD WITH U.T INSPECTION
(7) PREHEAT TO 175°F
(8) FIT AND WELD R. AH
(9) ALL OPERATIONS TO BE WITNESSED BY SOUTHERN INSPECTION AGENCY AND TO BE DOCUMENTED.



PITTSBURGH-DBS NOINES STEEL COMPANY

ULTRASONIC REPORT FORM U-9
WORLD TRADE CENTER

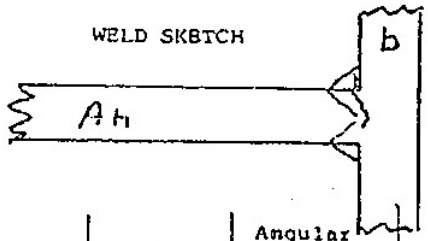
Contract No. - [redacted]-17138
Material FY 42 - T1
Thickness 1 1/2"
Joint Design 67-50A
Drawing MP 818

Equipment - USK5N
Transducer Angle [redacted] - 70°
Frequency 2.25 MH2
Calibration Block Basic + IIW
Couplant: Cellulose - [redacted]

Date - 5-1-69

Inspector - C.V. - [redacted]. Witnessed By - [redacted] S D Caffery

WELD SKETCH



Pc. Mk	Transducer Angle	DB Rating	Length	Angular Distance	Depth	Remarks
[redacted]						

THE PORT OF NEW YORK AUTHORITY

World Trade Department

May 5, 1969

Pittsburgh-Des Moines Steel Company
Neville Island
Pittsburgh, Pennsylvania 15225

Attention: Mr. H. M. Fish

Re: The World Trade Center - Contract [illegible] - PDH:
as fabricated condition of Column 3, Panel 2008

Gentlemen:

Further to your letter dated February 4, 1969, the sub-assembly for Column 3, Panel 2008, is acceptable as fabricated and may be incorporated into Panel 2008.

Please note that approval is given only for this particular sub-assembly. In the event of any similar instance, approval will be given, if warranted, on a unit by unit basis, after submission of complete data for such individual cases.

Very truly yours,

[illegible]. Monti
Construction Manager
The World Trade Center

JAC:gw

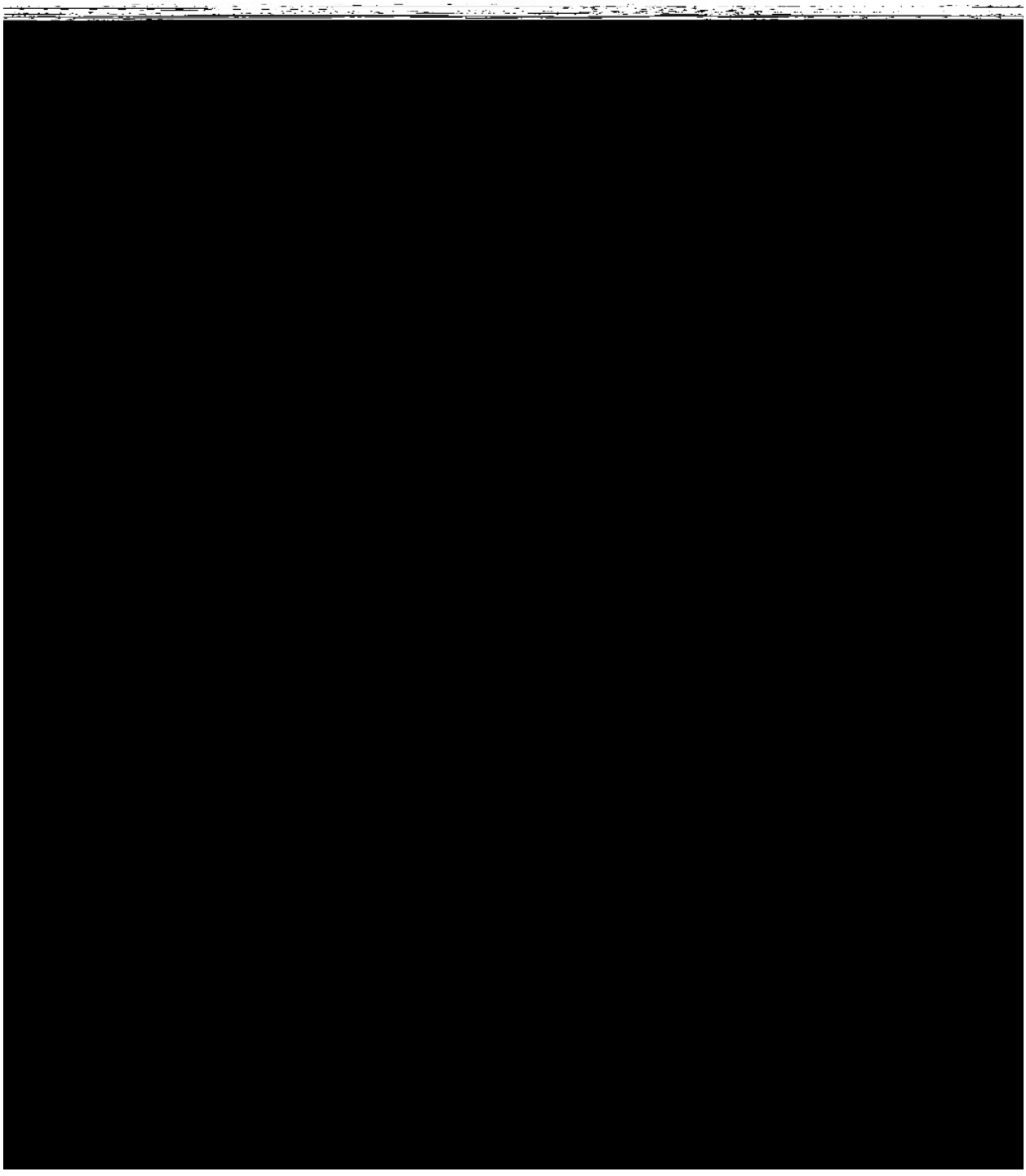
cc: W. Borland, J. White (SHCR)

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · MU. 9-5574
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson
Manager
Wayne A. Brewer
Consultants
Harold L. Worthington
Joseph F. Jackson

March 20, 1959

Port of New York Authority
Office of the Construction Manager
30 Church Street, Room 1030

[redacted]



SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · MU 9-5574

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Managers
Wayne A. Brewer

Consultants
Donald J. Worthington
Joseph J. Jackson

May 16, 1969

Port of New York Authority
Office of the Construction Manager
[illegible] Church Street
New York, New York

Attention: Mr. T. M. Monti

Reference: The World Trade Center
Contract WTC-213.00, MDM
Repair of Misfits, Panels 227B and 230B

Gentlemen:

Please refer to the PDI letter to PNYA dated April 15, 1969. While we are confident that the repairs described in the two (2) attached PDM repair procedure

[redacted]

CABLE PITTDEMOIN
TELEX 000 734

PDM Pittsburgh-Des Moines Steel Company

Engineers
Fabricators
Constructors

NEVILLE ISLAND · PITTSBURGH PENNSYLVANIA 15225 · AREA CODE 412
PHONE 331-3000

April 15, 1969

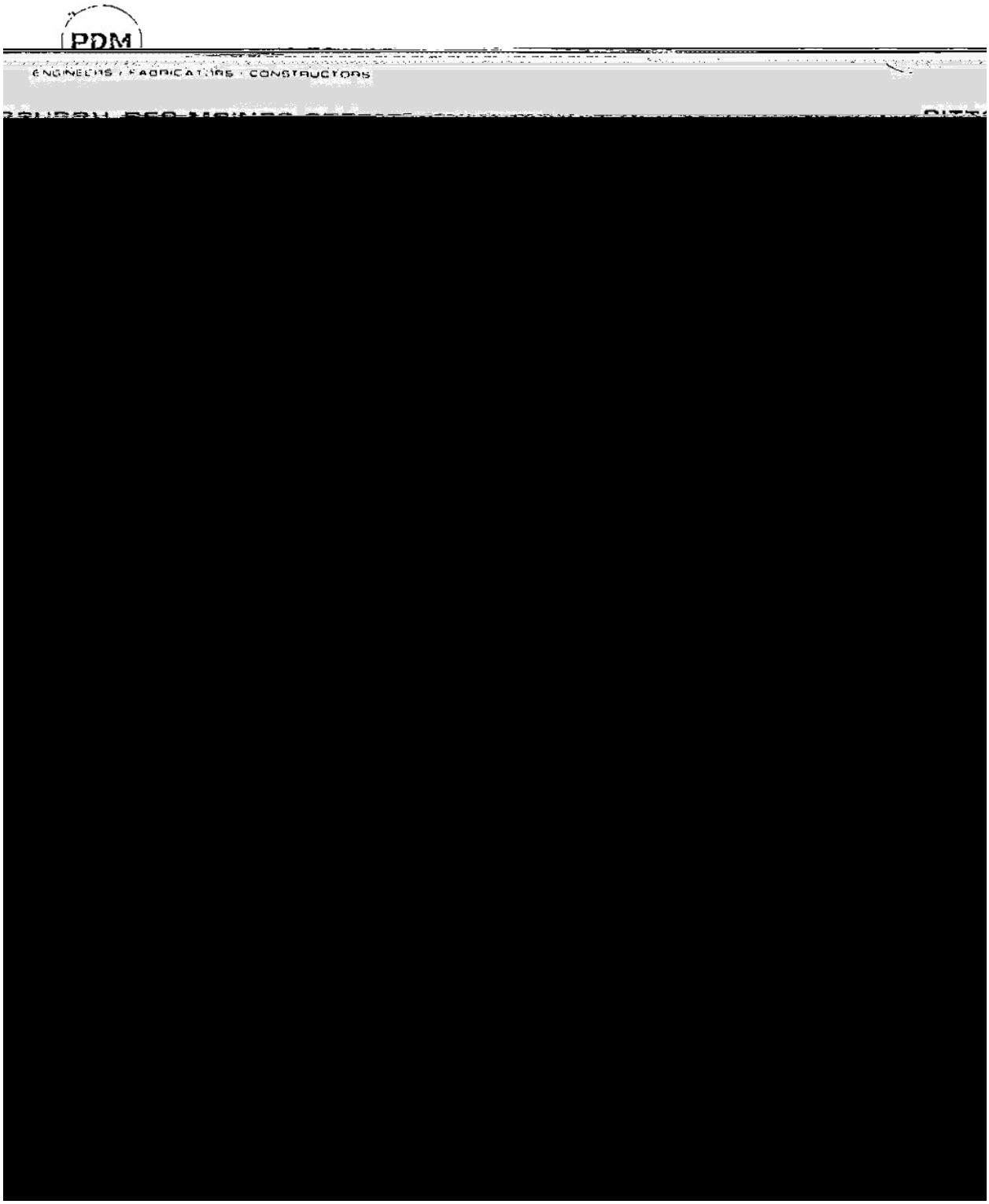
Mr. R. M. Monti
Construction Manager
Room - 1119
The Port of New York Authority
30 Church Street

[redacted]

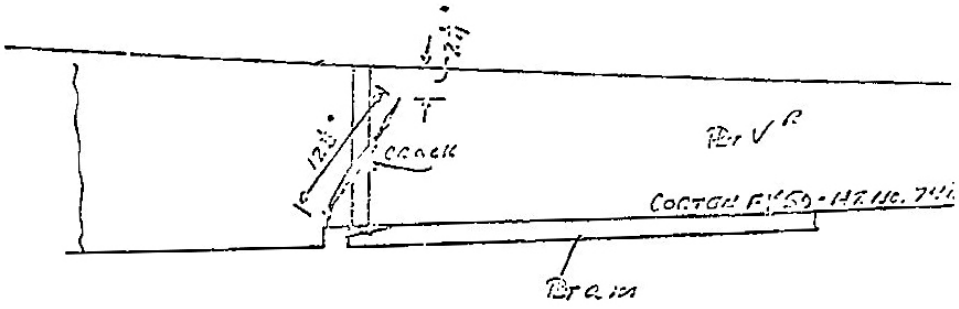
SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · MU 9-8874
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson
Manager
Warren A. Brewer
Consultants
Harold L. Washington
Joseph L. Jackson

May 16, 1969

[redacted]


PDM
ENGINEERS / FABRICATORS / CONSTRUCTORS

17138
COL. 224B

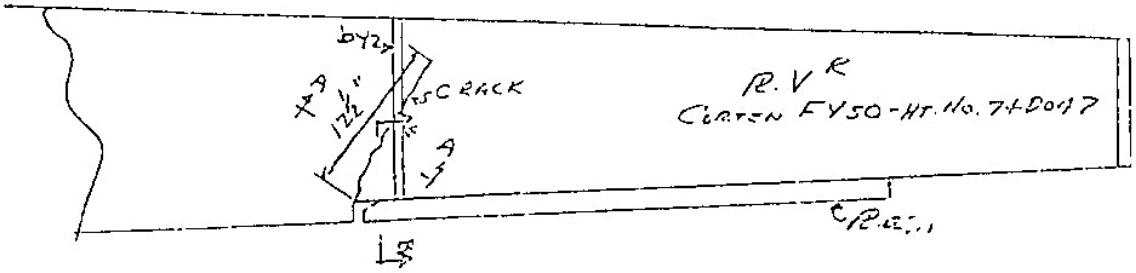


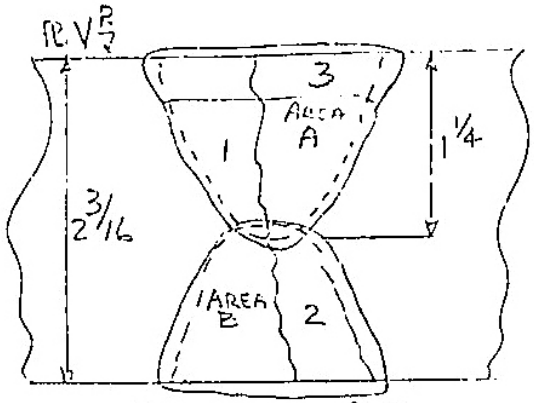
[redacted]

Sheet-2

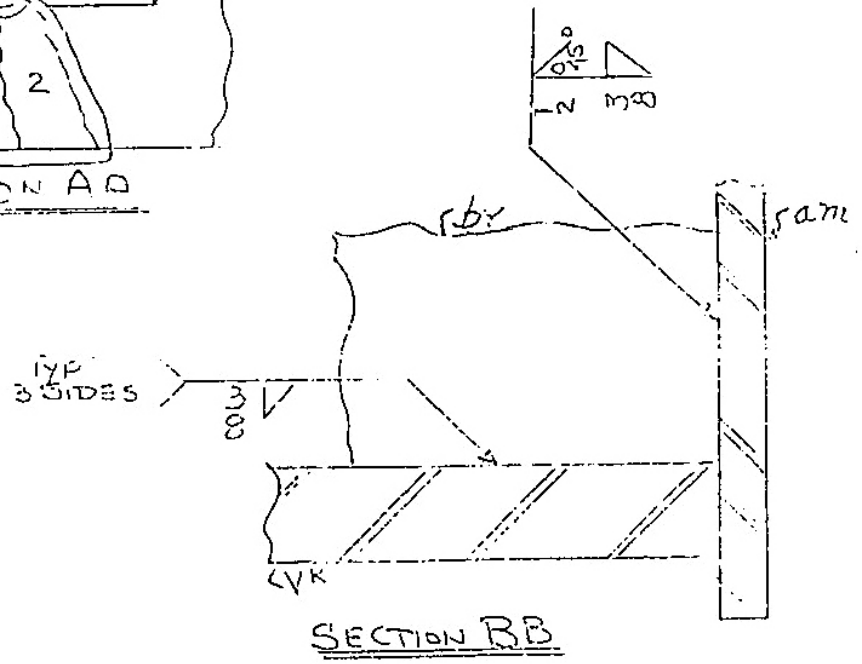
CONT. 17138 COL. 224B SKETCH X1

APRIL 25, 1969





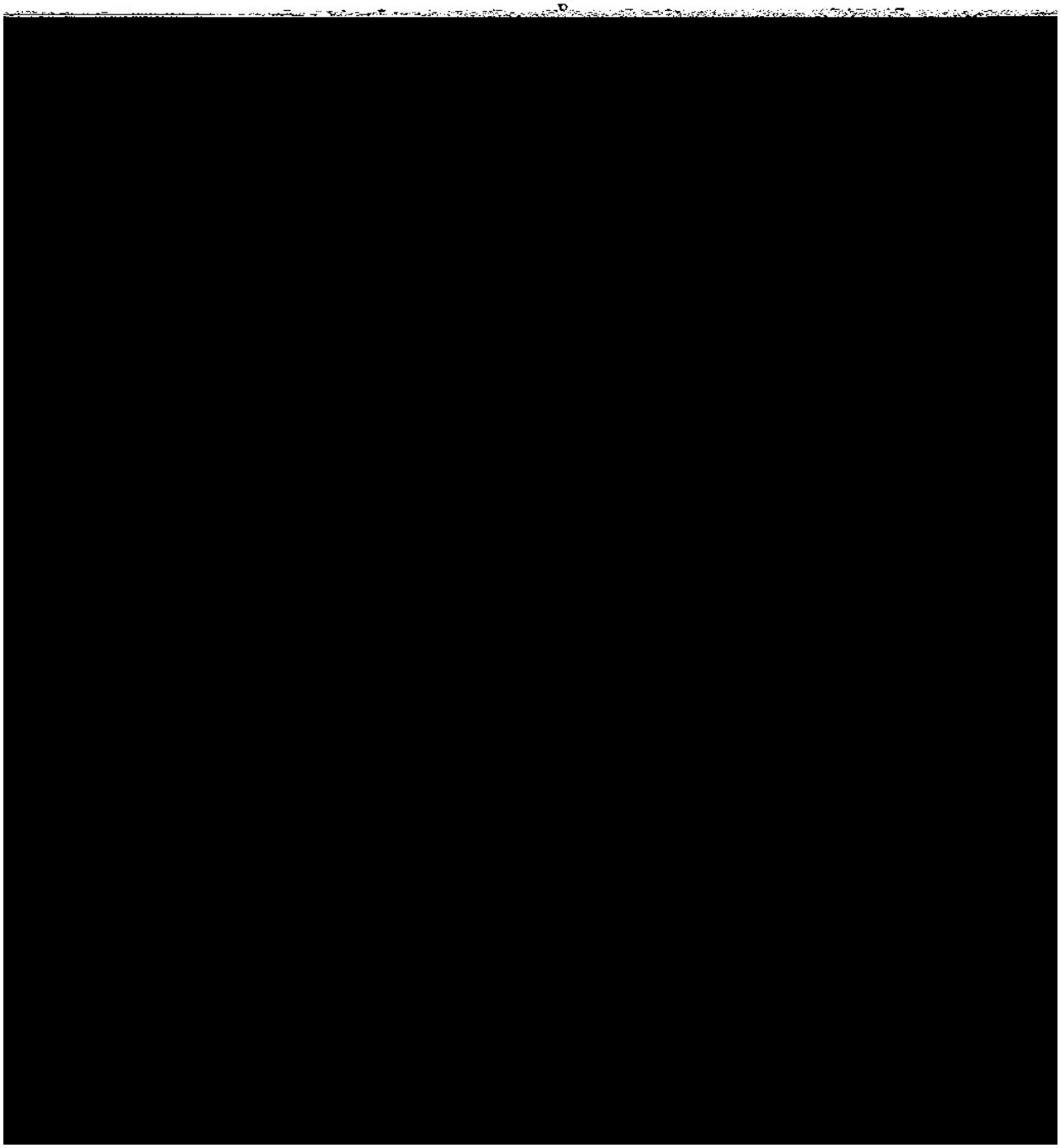
SECTION AA



SECTION BB

Sheet 3

Contract 1713S Col. 224B P.VR. 4-25-69



June 9, 1969

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-213.00, PDM
Repair of Plates C_L^R, Panel 130B; V^L Panel 139B

Gentlemen:

Please refer to the PDM letter to PNYA dated May 23, 1969. The UT reports attached to the PDM letter are sufficient to allow us to approve the referenced repairs.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

cc: Messrs. L. Fald, PNYA
H. Fish, PDM
D. Caffery, SIS-Houston

JW/sl

PDM

ENGINEERS / FABRICATORS / CONTRACTORS

PITTSBURGH-DES MOINES STEEL COMPANY

May 23, 1969

The Port of New York Authority
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17138
Repair of Plate U_L^R Panel - 130B
Repair of Plate V_L^L Panel - 139B

Gentlemen:

Reference to SHCR letter of May 16, 1969 to Mr. R. M. Monti approving our repair procedure to plates U_L^R, Panel 130D and Plate V_L^L Panel - 139B contigent upon receipt of our NDT reports.

We are enclosing for your record one (1) copy of our NDT reports sheets Nos. T-1 and T-2.

Unless we hear from you we will assume that this subject matter is finalized.

Very truly yours,

PITTSBURGH DES MOINES STEEL COMPANY

H. M. Fish
Project Manager

HMF:ksh
Enc.

cc:> Mr. James White/plus one (1) copy
Mr. M. Gerstmann

75TH ANNIVERSARY

Pittsburgh-Des Moines Steel Company

ULTRASONIC REPORT FORM

Sh. T-1

ULR

CONTRACT 17138 130 6
MATERIAL A5
THICKNESS 3 1/2
DRAWING MP 716
SURFACE FINISH smooth

EQUIPMENT USK5 [illegible]
SEARCH UNIT [illegible]
FREQUENCY - SIZE [illegible]
CALIBRATION BLOCK [illegible]
COUPLANT [illegible]

[redacted]

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · MU 9-8874
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson
Manager
Wayne A. Brewer
Consultants
Harold L. Worthington
Joseph L. Jackson

May 16, 1969

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-213.00, PDM
Repair of Plate "af", Panel 412B

Gentlemen:

We approve the repair of plate "af" as documented by the PDM procedure sheet dated 3-28-69 and UT test report dated 3-28-69, both attached to the PDM letter to PANYA dated March 31, 1969. While no UT report is furnished to document the

[redacted]

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · Mu 9-8870

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

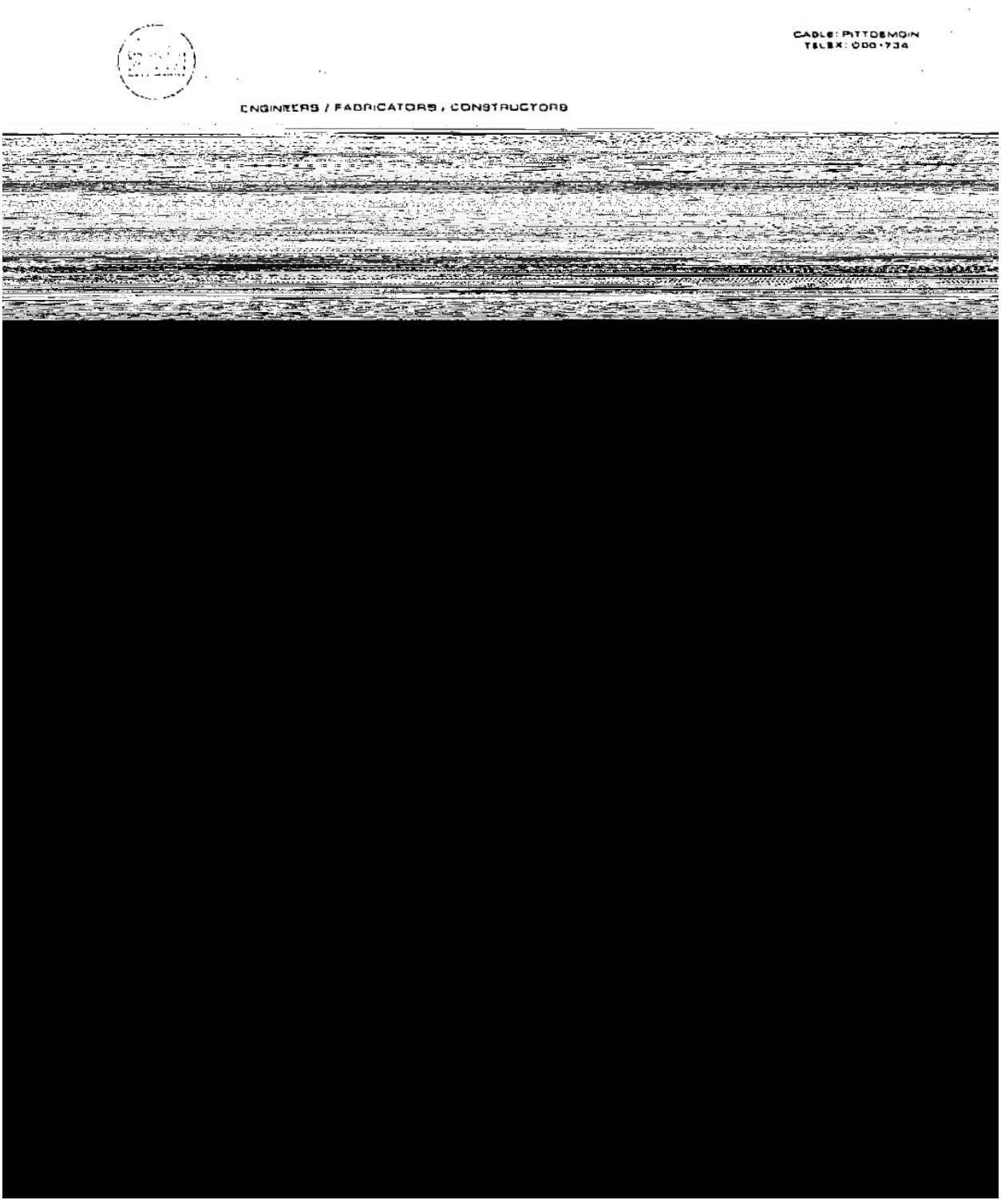
Manager
Warren V. Brewer

Consultants
Harold F. Worthington
Joseph L. Jackson

May 16, 1969

Port of New York Authority
Office of the Construction Manager

[redacted]


CABLE: PITTDEMOIN
TELEX: 000-734
ENGINEERS / FABRICATORS / CONSTRUCTORS

Pittsburgh-Des Moines Steel Company

ULTRASONIC REPORT FORM

(5)

ULR

CONTRACT	17138	3398	
MATERIAL	FY 42		
THICKNESS	3"		
DRAWING	MP632 and 632		
SURFACE FINISH	Smooth		
PIECE MARK	B Plate - 3398		
ULTRASONIC PROCEDURE USED	ASTM 435		
METHOD USED	Contact		
TECHNIQUE USED	Pulse Echo		
PERSONNEL QUALIFICATIONS	SNT Level 2		

EQUIPMENT	USK5-M
SEARCH UNIT	Compression
FREQUENCY - SIZE	2.25 MHz - 1" Diam.
CALIBRATION BLOCK	IIW
COUPLANT	Cellulose
BASIC SENSITIVITY	Back Ref. 80%
WITNESSED BY	S D Caffery / D. Caffery
OPERATOR	R. S. Cammarata
DATE	3-4-69

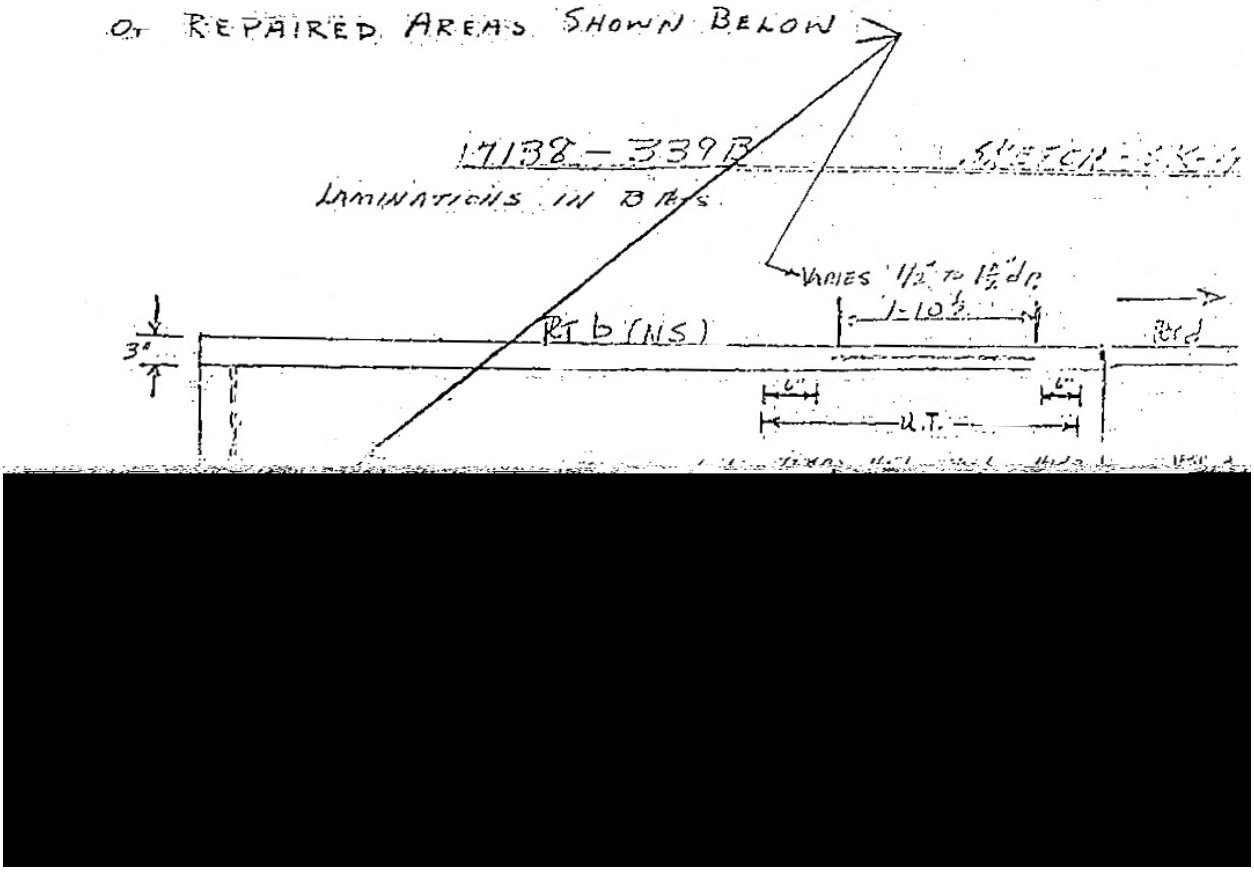
Revised Report: 3-19-69 C. Vigne

SKETCH

b Plates N.S. & F. S. U.T. Inspected as noted on sketch SK-4 shown below.

No indications seen on the machine at above procedure level.

REMARKS: - ULTRASONIC TEST MADE 6" ON ALL SIDES OF REPAIRED AREAS SHOWN BELOW



SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Brewer

Consultants
Harold L. Worthington
Joseph F. Jackson

July 15, 1971
File: WTC-230C
WTC-213C
30C

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti, Construction Manager

Reference: The World Trade Center
Contract WTC-230.00, KKE
Contract WTC-213.00, PDM
Repair of Column 327B
Reference No. 1, SHCR Drawing 2AB2-15, Detail 26
Reference No. 2, PDM Shop Drawings MP610, MP611

Gentlemen:

Please refer to SHCR's May 21 and July 15, 1971 letters to PNYA transmitting repair procedure information for Column 327B. UT evaluation of the repair work required in the SHCR document "Repair Procedure, Column 327B, Elev. 372'-6"(+)" is reported in G&H UT report sheets 1 through 6 of 6 dated 7/6/71. G&H report is enclosed with this letter. G&H sheets 1 and 2 show that the 6'(+) length of repair weld between plates "a" and "d" is acceptable. Sheets 3 and 4 show the extent of a crack which could not be completely removed at Elevation 372'-6"(±) during the repair to the edge of plate "d" and the fractured partial penetration weld. Sheets 5 and 6 show the extent (1½ inches long; 2 to 2¾ inches deep) of a defect found in the horizontal repair weld to plate "d" at Elevation 378'-6"(±).

Subsequent to the above UT testing, the south 2/3 width of the CP weld between plates "d" and "b" (E2 to F2) was repaired as follows:

1. Provide preheat temperature of 200-250°F by use of radiant heaters at repair line.
2. Arcair gouge defective metal within central 1/3 width of column. (Discussion with workmen revealed that surface to one inch deep was sound, that one inch deep to backup bar was extremely porous with cracks running from defective weld metal into the base metal vertically for various short lengths).

ROBERT E. LEVIEN · E. J. WHITE, JR.
RICHARD W. CHAUNER · LORENTZ L. WIDING
PAUL S. A. FORTEN · A. J. BANKSMIRE
FRANK HOELTERHOFF · PETER W. CHEN
ERNEST T. LIU · W. A. PRIBADSKY
KENT R. ROGERS · MICHAEL S. RIGO
CHARLES A. SANDUSKY · HAROLD D. ROET
WILLIAM O. WARD · EDWARD R. WOLFE, CPA

•SEATTLE OFFICE: 1940 WASHINGTON BUILDING, SEATTLE, WASHINGTON 98101

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Port of New York Authority
Attn: Mr. R. M. Monti - 2 - July 15, 1971

3. Allow column to cool at end of work day using asbestos blanket wrapping for slow cool.
4. Elevate temperature at beginning of work day.
5. Perform central 1/3 column width repair weld using E7018 electrodes.
6. Slow cool column at end of work day.
7. Upon completion of work at central 1/3 width, repeat repair sequence of steps 1 through 6 above for south 1/3 length.
8. Upon completion of repair of entire 23 inches of defective weld, Elevation 372'-6"(±), UT entire width of plate "b" and "d" in repair area.

It should be noted that the repair excavation was of the order of two (2) inches wide at the root, extending above the shop backup bar and roughly 1/2 inch maximum into the 1-3/4 inch diaphragm plate CP weld. The workmen reported minimum fusion to the backup bar, very spongy weld metal, and numerous cracks in the base metal running vertical in the plate (normal to the axis of the horizontal CP weld). The shop weld was made in accord with PDM procedure 67-48, a xerox copy of which is attached to this letter.

Also attached to this letter, please find the G&H UT report (one sheet) dated 7/15/71. This report shows that the defect reported at Elevation 378'-6"(±) in the G&H 7/6/71 report (Repair 1 in the 7/15/71 report) has been removed and the repair weld is UT acceptable. The 7/15/71 G&H report also shows that the repair to the defective shop weld at Elevation 372'-6"(±) is acceptable as welded.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

cc: Messrs. M. P. Levy, PNYA
L. S. Feld, PNYA

Attachment #1 G&H UT report dated 7/6/71, pages 1-6
Attachment #2 PDM Weld Procedure 67-48 dated April 6, 1968
Attachment #3 G&H UT report dated 7/15/71

EJW/is

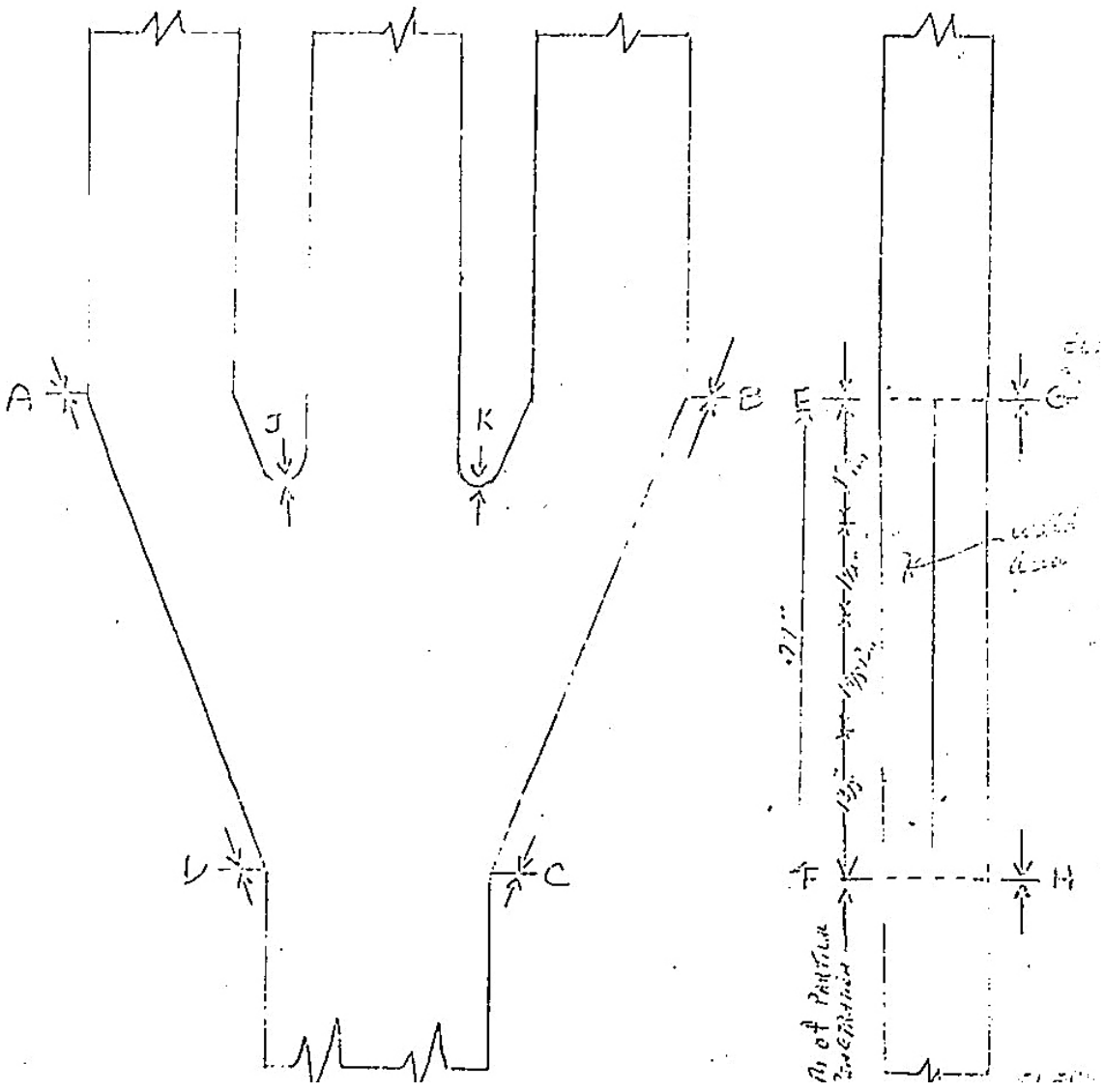
LER

GULICK-HENDERSON LABORA. ATES, INC. P.O. BOX #550 , FIDDLING, NEW YORK Zip - 11358

ULTRASONIC TEST REPORT
Procedure SOP -- Wedge Angle 70°, 60°, 45° KHz 2.25
Couplant (Glycerine)
Calibration Blocks Simulated V.T.N.
Welding Contractor:
Project:
Base Material Thickness I II Length of Weld: 27"

DATE: 7-1-77
INSP.

Side View



SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · Mu. 9-5874

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

August 21, 1968

Port of New York Authority
Office of the Construction Manager
30 Church Street Room 1139
New York, New York 10007

Attention: Mr. [illegible]

Reference: The World Trade Center
Contract WTC-213.00
Laminated plates "d" Drawing SK506

Gentlemen:

Please refer to the PDM letter dated June 11, 1968 referring to laminated plates "d" shown on shop drawing SK506. The repair procedure stated in the attachment to the letter and shown in the PDM sketch dated June 10, 1968 is approved. These laminations were discovered after the plates were welded into a complete column panel assembly.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

[illegible]

[illegible]

cc: Messrs. L. S. Feld - PSYA
[illegible] - PDM

October 7, 1968

Port of New York Authority
Office of the Construction Manager
30 Church Street - Room 1119
New York, New York 10007

Attention: Mr. R. H. Monti

Reference: The World Trade Center
Contract WTC-213.00, Pittsburgh-Des Moines
Repair of Plate for Panel 209A

Gentlemen:

Please refer to the PDM letter dated September 30, 1968, referring to weld repair procedure for plate V^L for panel 209A. We have reviewed this procedure by telephone with Mr. H. M. Fish of PDM, and approve the PDM repair procedure.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

JW:s
cc: Messrs. L. S. Feld, PNYA
H. M. Fish, PDM

CABLE: PITTDEMOIN
TELEX: ORN-234

PDM

ENGINEERS / FABRICATORS / CONSTRUCTORS

PITTSBURGH-DES MOINES STEEL COMPANY

NEVILLE ISLAND • PITTSBURGH, PENNSYLVANIA 15225 • PHONE (412) 331-3000

October 4, 1968

Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10007

Attention: Mr. James White

Reference: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17138

Dear Mr. White:

Enclosed is one (1) copy of the Weld Procedure that was inadvertently not sent to you.

Please notefy us by letter of your approval of this repair procedure.

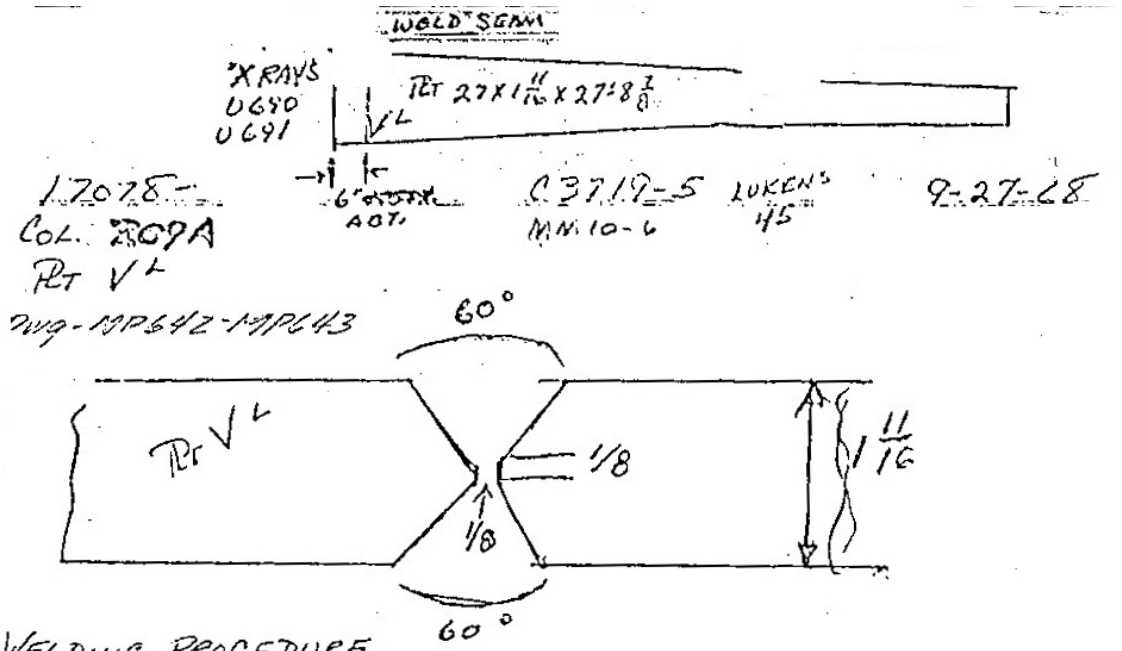
Very truly yours,

PITTSBURGH-DES MOINES STEEL COMPANY

H. M. Fish
Project Manager

HMF:ksh
Enclosure

75TH ANNIVERSARY



WELDING PROCEDURE

1ST - 2 PASS'S ON PLT - 5/32 7018 WIRE - (1ST SIDE
PASS'S - 3 TO 7 INCLUSIVE 5/32 7018 WIRE
TURN OVER PLT AIR-ARC GOUGE OUT ROOT
1ST - 1 PASS ON GOUGED SIDE 5/32 7018 ROD
PASS 8 TO 12 ON 2ND SIDE 3/16 7018 ROD
TURN OVER PLT
PASS 13 TO 20 ON FINAL SIDE 3/16 - 7018
TURN OVER PLT
PASS 21 TO 30 - 2ND SIDE 3/16 - 7018

PRE-HEAT WAS 200°

ABOVE PLATE WAS BURNED ON WRONG LINE IN SHOP. AFTER ERROR WAS DISCOVERED, THE PLATE PART THAT WAS BURNED OFF WAS PREPARED, AND WELDED BACK ON TO MAIN PLATE, USING ABOVE PROCEDURE. PLATE WAS THEN X RAYED TO INSURE SOUND WELD. X RAYED AFTER RE-BURNING TO CORRECT LENGTH.

PDM

ENGINEERS / FABRICATORS / CONSTRUCTORS

PITTSBURGH-DES MOINES STEEL COMPANY

[illegible]

September 30, 1968

Mr. R. M. Monti
Construction Manager
Room 1119
The Port of New York Authority
30 Church Street
New York, New York 10007

Re: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17136

Gentlemen:

We are submitting for approval two (2) copies of our weld procedure for repairing plate V L on panel 209A which was inadvertently cut 6 inches short. This panel is detailed on drawings MP642 and MP643.

Please have the engineer notefy us by letter of his approval of this repair procedure.

Very truly yours,

PITTSBURGH-DES MOINES STEEL COMPANY

H. M. Fish
Project Manager

HMF:ksh
Enclosure

cc: Skilling-Helle-Christiansen-Robertson
Tishman Realty and Construction Company

75TH ANNIVERSARY

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · MU. 8-5874
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Biewer

Consultants
Harold L. Worthington
Joseph F. Jackson

October 18, 1968

Port of New York Authority
Office of the Construction Manager
Room 1119, 30 Church Street
New York, New York 10007

Attention: Mr. R. H. Monti

Reference: The World Trade Center
Contract WTC-213, Pittsburgh-Des Moines Steel Company
Welding of Corner Panels 100A, 200A, 400A

Gentlemen:

We have reviewed the PDM letter dated October 15, 2968 to which is attached an outline of repairs PDM proposes to perform, and stating the actual weld metal placed in corner panels 100A, 200A, 300A and 400A for Tower "A". These are outlined in four (4) three page letters, one for each corner panel. The letters are dated October 10, 1968, signed by Mr. Weisner, PDM Chief of Quality Control, and are addressed to Mr. Fish, PAH Project Manager. Butt welds in eighteen separate locations require repair, and amount to a total length of weld slightly in excess of 22 feet.

Also attached to the PDM letter is a PDM procedural drawing showing, step by step, all details of the required repair work.

SLCE approves in entirety the proposed methods and specific locations of repairs enumerated in the PDM letter.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

cc: Messrs. M. P. Levy, PANYA
W. C. Borland, PANYA
L. S. Feld, PNYA
H. M. Fish, PDM
Holton & Caffrey, SIS

JW/aeb

CABLE INTTDEAN
TELEX 000-734

PDM

ENGINEERS / FABRICATORS / CONSTRUCTORS

PITTSBURGH-DES MOINES STEEL COMPANY

NEVILLE ISLAND • PITTSBURGH, PENNSYLVANIA 15225 • PHONE (412) 331-3000

October 15, 1968

The Port of New York Authority
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-213.00
PDM Contract 17076 & 17136

Gentlemen:

We are sending you for approval two (2) copies of certified weld report pertaining to Panels 100A, 200A, 300A and 400A. All of these panels with the exception of 300A had some of the welds made using the wrong electrode which will require repairing.

We have reviewed these sheets with Mr. James White in our office October 14, 1968 and have noted on the left hand side of the sheets the repair action which will be required.

We are also including two (2) reproducible copies of Page 1 showing the weld procedure for repairing these panels.

Please advise us by letter of your acceptance of this repair procedure.

Very truly yours,

PITTSBURGH-DES MOINES STEEL COMPANY

R. H. Fish
Project Manager

RHF:kah

Enclosure

cc: Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10007
Attention: Mr. James White
plus one copy of weld report and Page 1

Tishman Realty & Constr. Co.
11th Floor, 30 Church Street
New York, New York 10007
Attention: Mr. M. Gerstman

75 TH ANNIVERSARY

THE PORT OF NEW YORK AUTHORITY

World Trade Department

October 16, 1969

Laclede Steel Company
Arcade Building
St. Louis, Missouri 63101

Attention: Mr. Robert D. Bay

Re: The World Trade Center - Contract

[redacted]

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Brewer

Consultants
Harold L. Worthington
Joseph F. Jackson

October 6, 1969
File: WTC-221C

Port of New York Authority
Office of Construction Manager
30 Church Street
New York, New York

Attention: Mr. R. H. Monti

Reference: The World Trade Center
Contract WTC-221.00, Laclede
Automatic CO2 welding

Gentlemen:

Please refer to the Laclede letter to SHCR dated September 8, 1969. We recommend PNYA approve the use of this automatic equipment. While the tests

[redacted]

Laclede Steel Company

General Office Chouteau Building

St. Louis, Missouri 63101 September 8, 1969

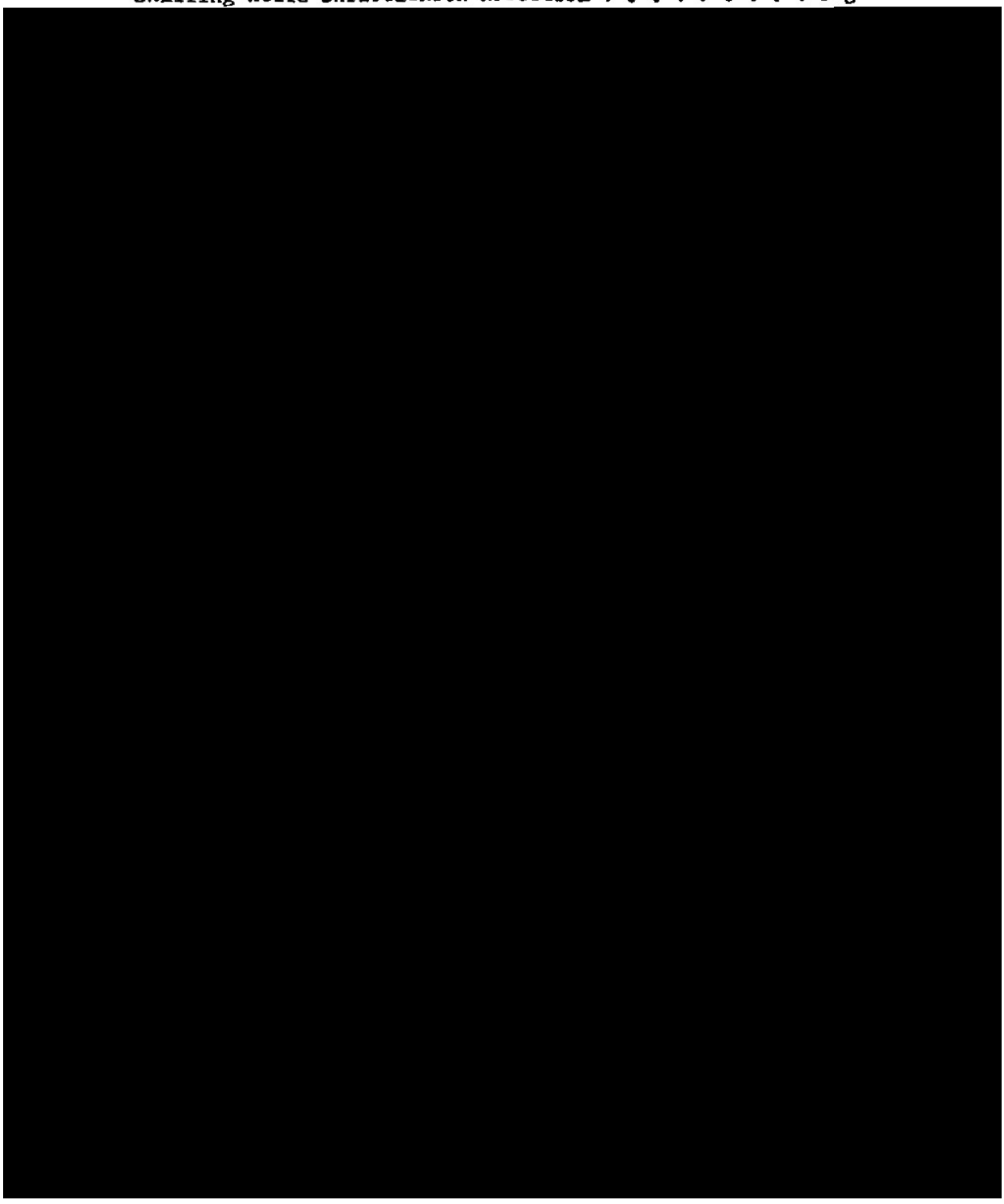
Mr. James White
Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10017

Dear Mr. White:

Approval - Automatic Arc Welding

In accordance with Paragraph 405.300, World Trade Center Contract WTC 421.00, formal request is herewith made for the use of CO_2

[redacted]



SKILLING - HELLE - CHRISTIANSEN - ROBERTSON
Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson
Consultants

December 15, 1967

[redacted]

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON
Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · MU. 9-8574
John B. Skilling · Hedge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne V. Brewer
Consultants
Harold E. Worthington
Joseph F. Jackson

May 26, 1969

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-214.00, PCF
Material Substitutions - Beam Seat Angles

Gentlemen:

Please refer to PCF letter 06-14 dated May 19, 1969. We approve the use of 8X6X1 inch angles in lieu of 8X6X7/8 inch angles for beam seat types 7440 through 7494. PCF must verify that no additional bolt length will be required, or provide revised bolt lists if necessary, at no cost to PNYA.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

cc: Mr. L. Feld, PNYA
Mr. B. Symes, PCF

bcc: Mr. A. Barkshire-SHCR-SEATTLE
JW:l

STRUCTURAL STEEL DIVISION

Pacific Car and Foundry Company

0 SOUTH HUDSON · SEATTLE WASHINGTON 98134 · RO 2-7440

May 19, 1969 D-666 PCF #S-14

Skilling Helle Christiansen Robertson
Consulting Structural and Civil Engineers.
230 Park Avenue
New York, New York 10017

Attention: Mr. James White

Reference: World Trade Center
Contract WTC 214.00
PCF Project D-666

Subject: Material Substitutions

Gentlemen:

On beam seat types 7440 through 7494, the 8" x 6" x 7/8" angles specified on design drawings are not immediately available. We are therefore, using 8" x 6" x 1" angles for these beam seat types on tier 40-43 A and B, 43-50 A, 74-77 A and B, and 77-80 A. No other dimensions or engineering details are being changed.

Please give us your approval to this substitution.

Yours very truly,

R. C. Sykes
Project Manager

RCS:ca
cc: R. Monti (PONYA)
M. Gerstman (TRCC)
A. Barkshire (SHCR)
J. Davis (PCF)

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · MU. 9-8574

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Manager
Wayne A. Brewer

Consultants
Harold L. Worthington
Joseph L. Jackson

May 2, 1969

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-214.00, PCF
Material Substitution

Gentlemen:

Please refer to PCF letter #P-102 dated April 4, 1969 attaching sheets 1 and 2 of 2 titled "Material Substitutions".

All material substitutions shown on the two (2) sheets prepared by PCF are approved by SHCR.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

cc: Mr. L. Feld, PNYA
Mr. E. Symes, PCF

JW:lc

bcc: Mr. A. Barkshire

STRUCTURAL STEEL DIVISION

Pacific Car and Foundry Company
80 SOUTH HUDSON · SEATTLE, WASHINGTON 98134 · RO 2-7440

April 4, 1969 D-666 PCF #P-202

The Port of New York Authority
111 Eighth Avenue - Room 300
New York, New York 10011

Attention: Mr. R. M. Monti

Reference: World Trade Center
Contract WTC 214.00
PCF Project D-6

Subject: Material Subst

Gentlemen:

We have so far received ov … irrived at the point in fabrication w … to suit the materials on hand.

43

IN placing the original or … , we had to make allowances for cutti… e obviously attempted to hold these a… ection of material wastes that we u… ie yield and thickness and insufficien… :itute materials having yield and/or … gn drawings, we will be able to use th… and control problems which could be … ll as holding as close as possible to …

The attached list shows … e to make. Most of these changes ar… Revision 1, approved by Messrs. Skilling Helle Christiansen … ber 25, 1968. Since all substitutions slightly increase either the thickness or the physical properties specified on design drawings, we do not anticipate any problem and are proceeding immediately on this basis. The only exceptions are mechanical floor unit #11, which we downgraded 5 k.s.i. The mill test report for this material, heat #L8799 (copy attached) gives physical properties above design requirements.

If you have any comments, please advise us as soon as possible.

Yours very truly,

R.C.Symes, Project Manager

RCS:ca
Attachments
cc: J. White (SHCR)
M. Gerstman (TRCC)

PACIFIC CAR AND FOUNDRY COMPANY
Attachment to letter PCF #P-202
Sheet 1 of 2

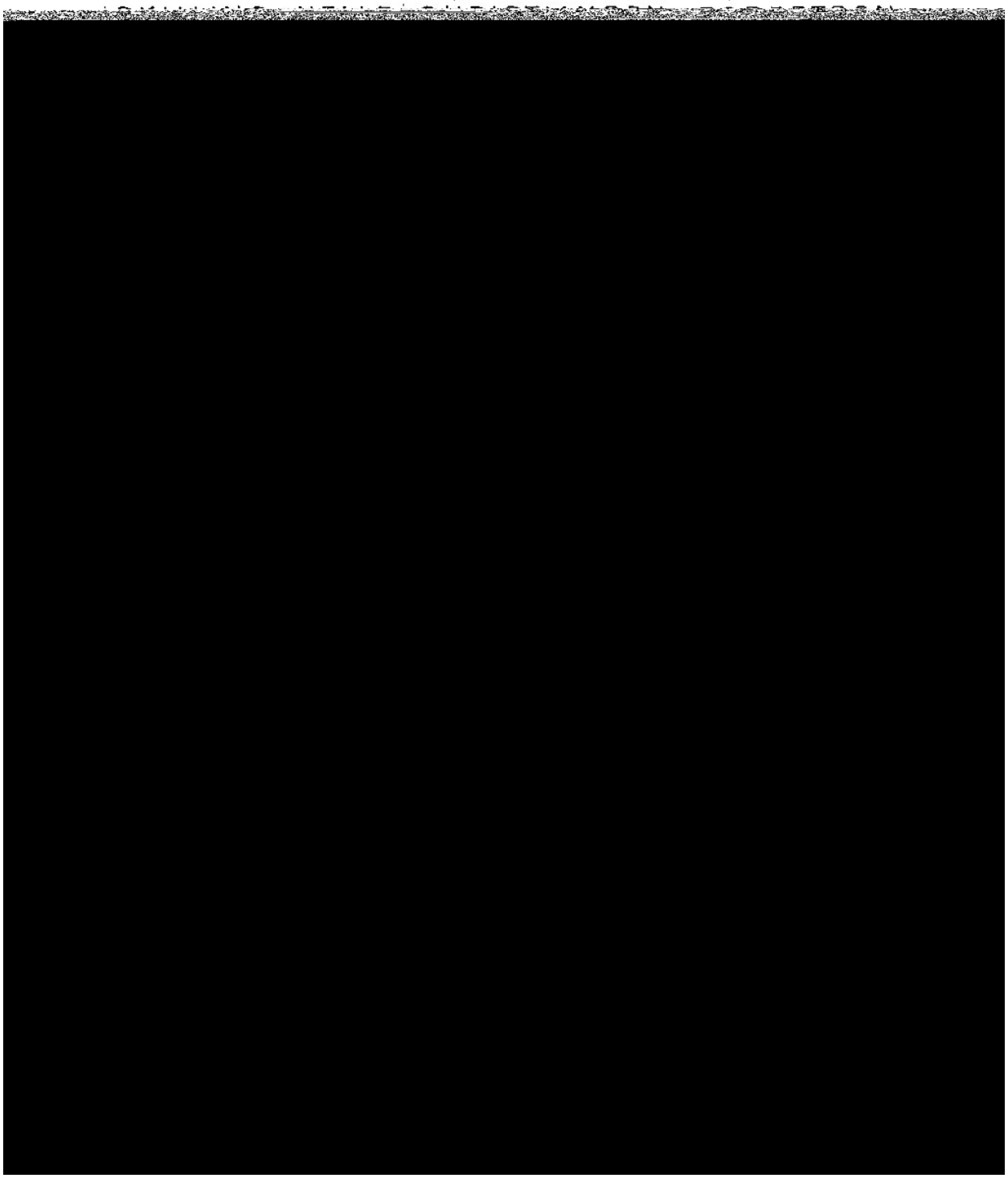
MATERIAL SUBSTITUTIONS

	Prod. Unit No.	Eng. Panel No.	Material Location	Material Specified on Design Drawings	Sub
Side	1156	A 457-53-50	PL 2 Col 1 and 2	FY 100 x 1/4"	FY
	1157	A 206-52-49	PL 2 Col 1, 2 and 3	FY 100 x 1/4"	FY
	1172	A 212-56-53	PL 2 Col 1	FY 100 x 1/4"	FY
	1325	A 333-54-51	PL 1 Col 3	FY 55 x 1 5/8"	FY
	1437	B 357-13-10	PL 1 Col 1	FY 55 x 2 1/8"	FY
	1446	B 303-13-10	PL 1 Col 3	FY 55 x 2 1/8"	FY
	1471	B 157-16-13	PL 1 Col 1	FY 50 x 2 1/16"	FY
	1472	B 103-16-13	PL 1 Col 3	FY 50 x 2 1/16"	FY
	1515	B 239-13-10	PL 1 Col 1 and 2	FY 50 x 1 15/16"	FY
	1539	B 127-17-14	PL 1 Col 1	FY 50 x 2 11/16"	FY

[redacted]

Material Substitutions
Attachment to PCF letter JP-202
Sheet 2 of 2

	Prod. Unit No.	Eng. Panel No.	Material Location	Material Specified on Design Drawings	S
orner	98	A 300-50-52	PL 1 Col 2	FY 80 x 1 1/8"	F
	116	B 200-18-16	PL 1 Col 1	FY 65 x 2 1/16"	F
	120	B 100-23-21	PL 1 Col 1	FY 60 x 1 5/8"	F
	121	B 100-21-19	PL 1 Col 1	FY 60 x 1 11/16"	F
Mech.	11	A 406-43-40	PL 2 Col 2	FY 80 16 3/8 x 3/8"	F
	21	A 248-43-40	PL 1 Col 1	FY 65 x 1 5/16"	F



THE PORT OF NEW YORK AUTHORITY

World Trade Department
Guy F. Tozzoli, Director

Malcolm P. Levy, Chief, Planning & Construction Division
R. M. Monti, Construction Manager Telephone (212) 267-7600 Office of the Construction Manager 30 Church St., New York, N.Y. 10007

December 18, 1967

Pittsburgh-Des Moines Steel Company
Neville Island
Pittsburgh, Pennsylvania 15225

Attention: Mr. H.M. Fish

Subject: The World Trade Center - Contract WTC 213.00 -
Approval of Thickness Substitutions on E-1 Plates

Gentlemen:

My letter of September 29, 1967 granted approval to increase the thickness of certain E-1 plates in accordance with the Pittsburgh-Des Moines sketch No. QT-1 subject to the clarification of several items. Your disposition of these items as outlined in the Pittsburgh-Des Moines letter of October 17, 1967 has been reviewed and found to be satisfactory.

This will confirm that this change is approved subject to the understanding that there will be no additional cost to the Authority from Pittsburgh-Des Moines and that the Authority will not backcharge Pittsburgh-Des Moines for the additional design costs incurred in reviewing this request.

Very truly yours,

R.M. Monti
Construction Manager
The World Trade Center

CC: J. Endler (TRCC), L. Robertson (SCHR), H. Tessler

THE PORT OF NEW YORK AUTHORITY
111 Eighth Avenue - at 15th Street, New York, N.Y. 10011

World Trade Department
Guy F. Tozzoli, Director
Richard C. Sullivan, Director, The World Trade Center

Malcolm P. Levy, Chief, Planning & Construction Division
R. M. Monti, Construction Manager Telephone (212) 620-7978

October 26, 1967

Skilling-Helle-Christiansen-Robertson
230 Park Avenue
New York, New York 10017

Attention: Mr. Emilio R. Robertson

Gentlemen:

Ref: DDM Letter of 8/30/67, SHCR letter dated 9/25/67, R. M. Monti's letter dated 9/23/67

Attached is an October 17, 1967 letter from the fabricator in which he comments on the conditions for approval of substitution of materials contained in my letter dated September 29, 1967. Kindly review these comments and advise the undersigned as to what information or action is now required from the fabricator in order that final approval can be given to this request for substitution. Also, advise as to the time and cost of design for this change.

Very truly yours,

THE PORT OF NEW YORK AUTHORITY

R. M. Monti
Construction Manager
The World Trade Center

RMMirw

cc: Brown, Zadler (TRSC), Feld, Tessler

R.O.C.

Pittsburgh-Des Moines Steel Company

Engineers
Fabricators
Constructors

NEVILLE ISLAND • PITTSBURGH, PENNSYLVANIA 15225 • AREA CODE 412
PHONE 331-3000

October 17, 1967

Mr. R. M. Monti
Construction Manager
Room 1119
The Port of New York Authority
30 Church Street
New York, New York 10007

Re: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17138

Gentlemen:

We wish to thank you for reviewing our letter of August 30, 1967 and granting us permission to increase the thickness of plates E1 as outlined on attached sheet, No. QT-1, for eleven specified columns. We understand that this permission is contingent upon our compliance with certain provisions as outlined in your letter of September 29, 1967, and submit the following comments:

1. Material Specifications:
Proposed plates E1 will have the same thickness and yield strength as the adjacent plates F-1, now called for, and therefore will comply with the same material specifications now included in section 203 of the specification.

2. Welding Procedure:
Welds for proposed plates E1 will be made under the same conditions as welds now called for on plates F-1 and welding procedures with provision for preheat and interpass temperatures will be submitted for both E1 and F-1 plates at an early date.

Pittsburgh-Des Moines Steel Company

Mr. R. M. Monti
PDM Contract 17078 & 17138 October 17, 1967

We recognize that this proposed change in E1 plates for eleven columns is at our request and no additional cost to the Authority will be made by Pittsburgh-Des Moines Steel Company for this change. We also recognize that this proposed change in plates E1 will require redesign work by Skilling-Helle-Christiansen-Robertson structural engineers and revision of design drawings effected by the change. If there will be charge to us or appreciable delays due to this redesign work, we request that we be advised prior to final approval of this change.

Very truly yours,

PITTSBURGH-DES MOINES STEEL COMPANY

H. M. Fish, Project Manager

rw

Enclosure

cc: Mr. H. A. Tessler
Manager, Project Planning
The Port of N.Y. Authority
Room 300
111 Eighth Avenue
New York, New York 10011
w/one copy of QT-1

Mr. J. Endler, Asst. V.P.
Tishman Realty & Construction Co.
11th Floor, 30 Church Street
New York, New York 10007
w/one copy of QT-1

PITTSBURGH-DES MOINES STEEL CO.

PDM 17078 (1)
CONT. NO. 17138 SUBJECT WORLD TRADE CENTER PAGE NO. 9
MADE BY JCD DATE 8-30-67 CHECKED BY DATE
WELDING BY DATE

P.O.N.Y.A. CONTRACT WTC 213.00

PROPOSED CHANGE: (TREE PANELS) PLATES E1 - DECREASE YIELD STRENGTH (FY) AND INCREASE THICKNESS (t) SO THAT PLATES E1 ARE THE SAME AS PLATES F1, IN THE FOLLOWING CASES.

PANELS No.	PRESENT DESIGN FY KIPS	PRESENT DESIGN t INCHES	PROPOSED DESIGN FY KIPS	PROPOSED DESIGN t INCHES
142B, 145B	50	5	42	6
230B, 233B	55	3 3/8	42	4 1/2
* 245B	60	3 1/4	45	4 1/4 *
251B	65	2 3/8	45	3 5/8
315B, 318B	50	5	42	6
409B	55	2 3/8	42	3 5/8
427B, 430B	60	3 3/8	45	4 1/2

* NOTE: IN PANEL 245B, YIELD AND THICKNESS OF PROPOSED PLATE E1 GIVE SLIGHTLY LESS TOTAL STRENGTH THAN YIELD AND THICKNESS OF PRESENT DESIGN. IF THE DIFFERENCE CANNOT BE ABSORBED BY DESIGN SAFETY MARGIN, FURTHER CONSIDERATION MAY BE REQUIRED IN THIS PANEL.

THE PORT OF NEW YORK AUTHORITY

World Trade Department
Guy F. Tozzoli, Director

Malcolm P. Levy, Chief, Planning & Construction Division
R. M. Monti, Construction Manager Telephone (212) 267-7680 Office of the Construction Manager 30 Church St., New York, N.Y. 10007

December 18, 1967

Pittsburgh-Des Moines Steel Company
Neville Island
Pittsburgh, Pennsylvania 15225

Attention: Mr. H.M. Fish

Subject: The World Trade Center - Contract 213.00 - Approval of Lukens' ASTM-A441-Modified

Gentlemen:

Your November 24, 1967 letter which transmitted a Lukens Steel Company letter dated November 20th with accompanying Lukens specification for ASTM-A441-Modified Steel revised November 16, 1967, has been reviewed and approval of this steel is hereby granted provided it does not result in additional costs to the Authority.

Sincerely,

R.M. Monti
Construction Manager
The World Trade Center

CC: Messrs. L. Robertson (SHCR), W.R. Pressler (PTL) - with attach.

CABLE: PITTDESMOIN
TELEX: 066-734

PDM Pittsburgh-Des Moines Steel Company

Engineers
Fabricators
Constructors

NEVILLE ISLAND • PITTSBURGH, PENNSYLVANIA 15225 • AREA CODE 412
PHONE 331-3000

November 24, 1967

Mr. R. M. Monti
Construction Manager
Room 1119
The Port of New York Authority
30 Church Street
New York, New York 10007

Re: The World Trade Center
Contract WTC-213.00
PDM Contract 17078 & 17138

Gentlemen:

As requested in your letter of October 27, 1967 we are enclosing one (1) copy of Lukens Steel Company's specification for ASTM-A441-Modified.

With the receipt of this specification we trust you will give us final approval for the thirty-six E2 plates requested in our letter of August 31, 1967. If possible we will appreciate a phone call so we can release Lukens Steel Company and your formal letter to follow.

Very truly yours,

PITTSBURGH-DES MOINES STEEL COMPANY

A. M. Fish, Project Manager

cc: Mr. H. A. Tessler

Mr. Al Guttentag

THE PORT OF NEW YORK AUTHORITY
111 Eighth Avenue - 15th Street, New York, N.Y. 10011

Construction Manager's Office
30 Church Street - Room 1119
New York, New York 10007

World Trade Department
Guy F. Tozzoli, Director
Richard C. Sullivan, Deputy Director, The World Trade Center

Malcolm P. Levy, Chief Planning & Construction Division
R. M. Monti, Construction Manager, Telephone (212) 466-7818

October 27, 1967

Pittsburgh-Des Moines Steel Co.
Neville Island
Pittsburgh, Pennsylvania 15225

Attention: Mr. H. M. Fish

Re: The World Trade Center - Contract WTC-213.00 -
Approval of Lukens A-441 Steel

Gentlemen:

Approval for the use of the Lukens Steel Company's specification for A441-66 steel was granted in my letter of October 13th, subject to conformance with six items. Please be advised that Item No. 5 - Table II - Tensile Requirements of ASTM A441-66 shall be deleted and replaced as follows:

TABLE II - TENSILE REQUIREMENTS

	Plate only	
	Up to 1½" inclusive	Over 1½" to 3" max.
Tensile strength, min, ksi	75	75
Yield point, min, ksi	50	55
Elongation in 8", min, per cent	18(a)	--
Elongation in 2", min, per cent	--	24(b)

(a) Refer to paragraph 5(c)
(b) Refer to paragraph 5(d)

This change is a result of direct discussions between the Authority's Consultant, Skilling-Helle-Christiansen-Robertson, and the Lukens Steel Co. Kindly obtain from the Lukens Steel Company, a specification for this material which incorporates all of the modifications and forward it to the undersigned for the purpose of confirming these modifications.

Sincerely,

R. M. Monti
Construction Manager
The World Trade Center

Copy to: Messrs. J. R. Endler (TRCC)

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

Consulting Structural and Civil Engineers · 250 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

October 17, 1967

Port of New York Authority
Office of the Construction Manager
30 Church Street
New York, New York

Attention: Mr. R. Monti

Reference: The World Trade Center
Contract WTC-213.00, PDM
Steel Plate Substitutions (ASTM A441 Mod.)

Gentlemen:

Please refer to our letter of October 11, 1967, discussing the above captioned subject. Item 5, Table II, shown on page 2 of our letter shall be replaced with the following:

5. Table II - Tensile Requirements of ASTM A441-66 shall be replaced as follows:

TABLE II - TENSILE REQUIREMENTS

	Plate only	
	Up to 1½" inclusive	Over 1½" to 3" max.
Tensile strength, min, ksi	75	75
Yield point, min, ksi	60	55
Elongation in 8", min, per cent	19(a)	--
Elongation in 2", min, per cent		24 (b)

(a) Refer to paragraph 5(c)
(b) Refer to paragraph 5(d)

WAYNE A. BROWICK
F. B. A. POST
FRANK HOE, JR.
ROBERT E. LEVISON
V. A. PELLANDINI
KENT R. ROBERTS
CHARLES SANDURSKY
WILLIAM D. WARD
E. J. WHITE
LORENTS L. WIDNES

SEATTLE OFFICE 1820 WASHINGTON BUILDING, SEATTLE, WASHINGTON 98101

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

R. Manti - 2 - October 17, 1967

This revision is in accordance with final data received from Lukens Steel Company by telephone on Monday, October 16, 1967.

PDM should ask Lukens to furnish a final copy of Lukens' specification of this material confirming the data in this letter and our letter of October 11, 1967.

Very truly yours,

SKILLING-HELLE-CHRISTIANSEN-ROBERTSON

James White

JW:e
cc: Mr. L. Feld, FHFA
Mr. R. Fish, PDM
cc: RE

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON
Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · MU. 9-5574
John B. Skilling · Helge J. Helle · John V. Christiansen · Leslie E. Robertson
Consultants
Harold L. Worthington
Joseph F. Jackson

May 3, 1968

Port of New York Authority
Office of the Construction
Manager - Room 1119
30 Church Street
New York, New York 10007

Attention: Mr. R. M. Monti

Reference: The World Trade Center
Contract WTC-213.00, Pittsburgh-Des Moines
Radiographic Inspection

Gentlemen:

Mr. Fish of PDM has asked permission to revise the radiographic inspection provisions presently included in the PDM quality control program as they relate to the full-penetration butt weld joining spandrel plate D4 (shown on the shop drawings as plate "c") and plate E3 (shown on the shop drawings as plate "k"). SHCR has reviewed this request, and suggest that the following program be followed.

1. The first 16 column trees in Tower A shall have one radiograph taken at each end of the subject full-penetration weld.

2. Should no defective weld be found, one radiograph at one end of the subject weld will be required for each remaining column tree.

3. For each defective length of weld found, one additional column tree shall be subjected to one radiograph at each end of the subject weld.

WAYNE A. BREWER
F. B. A. FOSTER
FRANK HOELTERHOFF
ROBERT E. LEVIEN
V. A. PRIBADSKY
KENT R. ROGERS
CHARLES SANDUSKY
WILLIAM G. WARD
E. J. WHITE, JR.
LORENTZ L. WIDING

SEATTLE OFFICE: 1940 WASHINGTON BUILDING, SEATTLE, WASHINGTON 98101

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

4. Where a radiograph shows a length of defective weld, the adjacent length of weld (approximately 16") shall be radiographed. If no additional defects are indicated, the subject weld will require no additional length to be radiographed.

5. All defects found by radiography shall be repaired and shall be subjected to re-inspection by radiography.

This program will concentrate radiographic testing performed by PDM on the ends of the full-penetration weld along Reference Line No. 2 (approximately 98-3/4" long), thereby concentrating on the most critical lengths of the subject weld. The additional benefit of the above program is that the amount of radiography reqired for a given panel is greatly reduced in comparison to the 100 percent reqirement stated in the PDM quality control program. The overall percentage of weld inspected in the program outlined above is comparable to that originally required in the PDM quality control program. We suggest that 16 radiographic tests be allocated by PDM to random assignment by the PTL inspector at locations selected by the PTL inspector after the start of fabrication of column-tree panels for Tower B.

In order to make absolutely sure that there is no confusion in identifying the weld referred to in this letter, the weld under discussion is the full-penetration weld shown in detail 19, sheet 2-AB2-11, Drawing Book 2.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

James White

JW:m

cc: Mr. L. S. Feld, PNYA
Mr. H. M. Fish, PDM

SKILLING - HELLE - CHRISTIANSEN - ROBERTSON

Consulting Structural and Civil Engineers · 230 Park Avenue, New York, N. Y. 10017 · Mu. 9-8874

John B. Skilling · Helge J. Helle · John. V. Christiansen · Leslie E. Robertson

Consultants
Harold L. Worthington
Joseph F. Jackson

April 18, 1968

Port of New York Authority
Office of the Construction
Manager - Room 1119
30 Church Street
New York, New York 10007

Attention: Mr. R.M. Monti, Construction Manager

Reference: The World Trade Center
Contract WTC 217.00, Stanray
Magnetic particle testing

Gentlemen:

We have reviewed the Stanray letter dated March 26, 1968, requesting permission to inspect a minimum of ten percent of the linear footage of welds on one flange of one member out of each two fabricated members at such times that the rejection rate of welds allows the minimum inspection rate. We approve this change to the Stanray Pacific quality control program.

Very truly yours,

SKILLING, HELLE, CHRISTIANSEN, ROBERTSON

James White

JW:bc

cc: Mr. Lester Feld, PNYA
Mr. Robert Morris, STANRAY

bcc:Mr. Richard Chauner, SHCR, SE.

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NIST NCSTAR 1-1B

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Comparison of Building Code Structural Requirements

S. K. Ghosh
Xuemei Liang

NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

NIST NCSTAR 1-1B

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Comparison of Building Code Structural Requirements

S. K. Ghosh
Xuemei Liang
S. K. Ghosh Associates, Inc.

September 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

Disclaimer No. 1

Certain commercial entities, equipment, products, or materials are identified in this document in order to describe a procedure or concept adequately or to trace the history of the procedures and practices used. Such identification is not intended to imply recommendation, endorsement, or implication that the entities, products, materials, or equipment are necessarily the best available for the purpose. Nor does such identification imply a finding of fault or negligence by the National Institute of Standards and Technology.

Disclaimer No. 2

The policy of NIST is to use the International System of Units (metric units) in all publications. In this document, however, units are presented in metric units or the inch-pound system, whichever is prevalent in the discipline.

Disclaimer No. 3

Pursuant to section 7 of the National Construction Safety Team Act, the NIST Director has determined that certain evidence received by NIST in the course of this Investigation is "voluntarily provided safety-related information" that is "not directly related to the building failure being investigated" and that "disclosure of that information would inhibit the voluntary provision of that type of information" (15 USC 7306c).

In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

Use in Legal Proceedings

No part of any report resulting from a NIST investigation into a structural failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a; as amended by P.L. 107-231).

National Institute of Standards and Technology National Construction Safety Team Act Report 1-1B
Natl. Inst. Stand. Technol. Natl. Constr. Sfty. Tm. Act Rpt. 1-1B, 280 pages (September 2005)
CODEN: NSPUE5

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WASHINGTON: 2005

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ABSTRACT

This report provides a comparison of the structural provisions of: (1) the New York City Building Code, 1968 edition, (2) the New York City Building Code, 2001 edition, (3) the New York State Building Construction Code, 1964 edition, (4) the Municipal Code of Chicago, 1967 edition, and (5) the Building Officials and Code Administrators (known as BOCA) Basic Building Code, 1965 edition. Detailed comparisons are provided in a tabular form. The comparisons are summarized in the body of the report.

Keywords: Code, construction, design, foundations, loads, materials, standards, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

AA	Aluminum Association
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AF&PA	American Forest and Paper Association
AITC	American Institute of Timber Construction
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ANSI	American National Standards Institute
APA	American Plywood Association
AREA	American Railway Engineering Association
ASA	American Standards Association
ASCE	American Society of Civil Engineers
ASD	Allowable Stress Design
ASTM	ASTM International (formerly American Society for Testing and Materials)
AWPA	American Wood-Preservers' Association
AWS	American Welding Society
BBC	Basic Building Code
BCB	Building Code Bureau (State of New York)
BOCA	Building Officials Conference of America (later Building Officials and Code Administrators, International)
CS	Commercial or Commodity Standards
DFPA	Douglas Fir Plywood Association
FEMA	Federal Emergency Management Agency
LRFD	Load and Resistance Factor Design
NIST	National Institute of Standards and Technology
NLMA	National Lumber Manufacturers Association
NYC	New York City

PCI	Prestressed Concrete Institute
RS	reference standard
SJI	Steel Joist Institute
UBC	Uniform Building Code
USASI	United States of America Standards Institute
USC	United States Code
USDA	United States Department of Agriculture
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

°F	degrees Fahrenheit
D	effects of dead load
E	effects of earthquake
F	effects of weight and pressures of fluids with well-known densities and controllable maximum heights
ft	foot
ft^2	square foot
in.	inch
L	effects of live load
min	minimum
plf	pounds per linear foot
psf	pounds per square foot
psi	pounds-force per square inch
RL	effects of reduced live load
SH	effects of shrinkage
T	effects of thermal forces
UL	effects of unreduced live loads where live load reduction is permitted
W	effects of wind load
Q	the combination of any two or more of *W*, *T*, *SH*, and *UL*
ϕ	strength reduction factor

METRIC CONVERSION TABLE

To convert from	to	Multiply by
AREA AND SECOND MOMENT OF AREA		
square foot (ft^2)	square meter (m^2)	9.290 304 E-02
square inch ($in.^2$)	square meter (m^2)	6.4516 E-04
square inch ($in.^2$)	square centimeter (cm^2)	6.4516 E+00
square yard (yd^2)	square meter (m^2)	8.361 274 E-01
ENERGY (includes WORK)		
kilowatt hour (kW · h)	joule (J)	3.6 E+06
quad (1015 BtuIT)	joule (J)	1.055 056 E+18
therm (U.S.)	joule (J)	1.054 804 E+08
ton of TNT (energy equivalent)	joule (J)	4.184 E+09
watt hour (W · h)	joule (J)	3.6 E+03
watt second (W · s)	joule (J)	1.0 E+00
FORCE		
dyne (dyn)	newton (N)	1.0 E-05
kilogram-force (kgf)	newton (N)	9.806 65 E+00
kilopond (kilogram-force) (kp)	newton (N)	9.806 65 E+00
kip (1 kip=1,000 lbf)	newton (N)	4.448 222 E+03
kip (1 kip=1,000 lbf)	kilonewton (kN)	4.448 222 E+00
pound-force (lbf)	newton (N)	4.448 222 E+00
FORCE DIVIDED BY LENGTH		
pound-force per foot (lbf/ft)	newton per meter (N/m)	1.459 390 E+01
pound-force per inch (lbf/in.)	newton per meter (N/m)	1.751 268 E+02
HEAT FLOW RATE		
calorieth per minute (calth/min)	watt (W)	6.973 333 E-02
calorieth per second (calth/s)	watt (W)	4.184 E+00
kilocalorieth per minute (kcalth/min)	watt (W)	6.973 333 E+01
kilocalorieth per second (kcalth/s)	watt (W)	4.184 E+03

To convert from	to	Multiply by
LENGTH		
foot (ft)	meter (m)	3.048 E-01
inch (in)	meter (m)	2.54 E-02
inch (in.)	centimeter (cm)	2.54 E+00
micron (m)	meter (m)	1.0 E-06
yard (yd)	meter (m)	9.144 E-01
MASS and MOMENT OF INERTIA		
kilogram-force second squared per meter ($kgf \cdot s^2/m$)	kilogram (kg)	9.806 65 E+00
pound foot squared ($lb \cdot ft^2$)	kilogram meter squared ($kg \cdot m^2$)	4.214 011 E-02
pound inch squared ($lb \cdot in.^2$)	kilogram meter squared ($kg \cdot m^2$)	2.926 397 E-04
ton, metric (t)	kilogram (kg)	1.0 E+03
ton, short (2,000 lb)	kilogram (kg)	9.071 847 E+02
MASS DIVIDED BY AREA		
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428 E+00
pound per square inch (*not* pound force) ($lb/in.^2$)	kilogram per square meter (kg/m^2)	7.030 696 E+02
MASS DIVIDED BY LENGTH		
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164 E+00
pound per inch (lb/in.)	kilogram per meter (kg/m)	1.785 797 E+01
pound per yard (lb/yd)	kilogram per meter (kg/m)	4.960 546 E-01
PRESSURE or STRESS (FORCE DIVIDED BY AREA)		
kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	9.806 65 E+04
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	9.806 65 E+00
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	9.806 65 E+06
kip per square inch (ksi) ($kip/in.^2$)	pascal (Pa)	6.894 757 E+06
kip per square inch (ksi) ($kip/in.^2$)	kilopascal (kPa)	6.894 757 E+03
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026 E+01
pound-force per square inch (psi) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
pound-force per square inch (psi) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00
psi (pound-force per square inch) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
psi (pound-force per square inch) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00

To convert from	to	Multiply by
TEMPERATURE		
degree Celsius (°C)	kelvin (K)	T/K = t/°C + 273.15
degree centigrade	degree Celsius (°C)	t/°C ≈ t /deg. cent.
degree Fahrenheit (°F)	degree Celsius (°C)	t/°C = (t/°F - 32)/1.8
degree Fahrenheit (°F)	kelvin (K)	T/K = (t/°F + 459.67)/1.8
kelvin (K)	degree Celsius (°C)	t/°C = T/K 2 273.15
TEMPERATURE INTERVAL		
degree Celsius (°C)	kelvin (K)	1.0 E+00
degree centigrade	degree Celsius (°C)	1.0 E+00
degree Fahrenheit (°F)	degree Celsius (°C)	5.555 556 E-01
degree Fahrenheit (°F)	kelvin (K)	5.555 556 E-01
degree Rankine (°R)	kelvin (K)	5.555 556 E-01
VELOCITY (includes SPEED)		
foot per second (ft/s)	meter per second (m/s)	3.048 E-01
inch per second (in./s)	meter per second (m/s)	2.54 E-02
kilometer per hour (km/h)	meter per second (m/s)	2.777 778 E-01
mile per hour (mi/h)	kilometer per hour (km/h)	1.609 344 E+00
mile per minute (mi/min)	meter per second (m/s)	2.682 24 E+01
VOLUME (includes CAPACITY)		
cubic foot (ft^3)	cubic meter (m^3)	2.831 685 E-02
cubic inch ($in.^3$)	cubic meter (m^3)	1.638 706 E-05
cubic yard (yd^3)	cubic meter (m^3)	7.645 549 E-01
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412 E-03
gallon (U.S.) (gal)	liter (L)	3.785 412 E+00
liter (L)	cubic meter (m^3)	1.0 E-03
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353 E-05
ounce (U.S. fluid) (fl oz)	milliliter (mL)	2.957 353 E+01

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PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

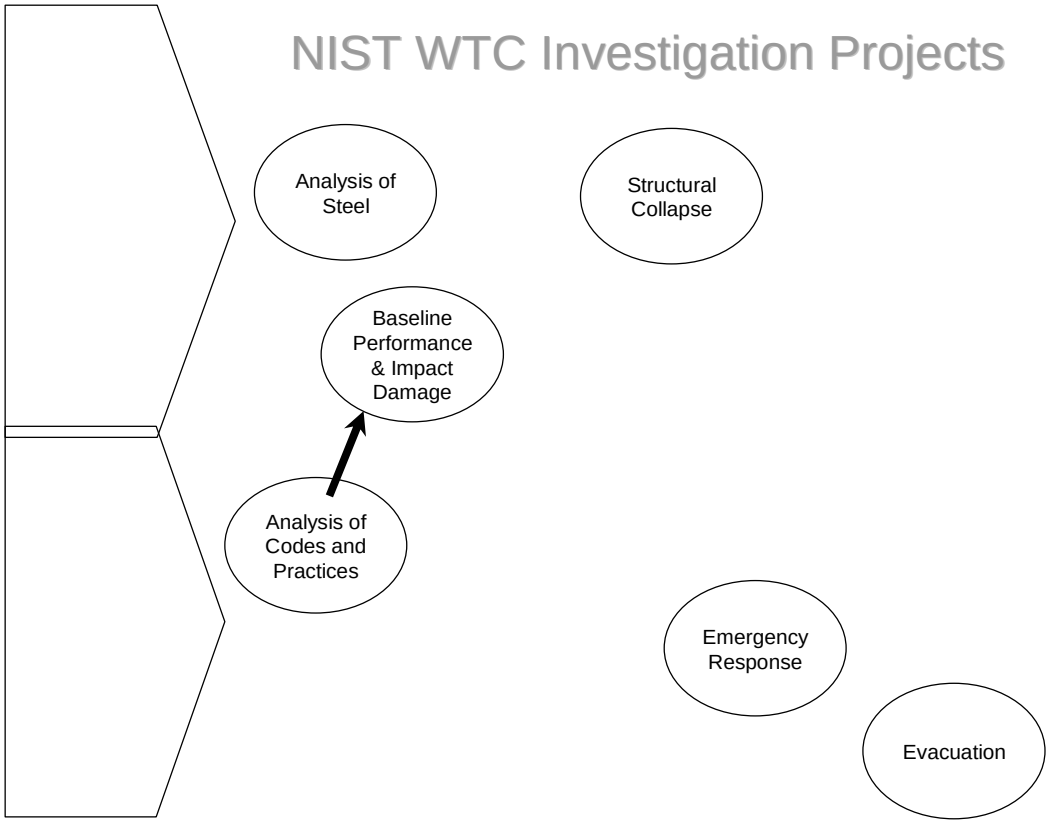
NIST WTC Investigation Projects
Analysis of Steel
Structural Collapse
Baseline Performance & Impact Damage
Analysis of Codes and Practices
Emergency Response
Evacuation

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

NIST (National Institute of Standards and Technology). 2006. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of World Trade Center 7.* NIST NCSTAR 1A. Gaithersburg, MD.

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EXECUTIVE SUMMARY

This report provides a comparison of the structural provisions of the 1968 New York City Building Code, which was used in the design of the World Trade Center (WTC) towers, with those of three contemporaneous building codes as well as the 2001 edition of the New York City Building Code, which is currently in effect. The contemporaneous codes chosen for comparison were:

1. The New York State Building Construction Code, 1964 edition,

2. The Municipal Code of Chicago, 1967 edition, and

3. The Building Officials and Code Administrators (BOCA) Basic Building Code (BBC), 1965 edition.

The New York State code was chosen as the building code in effect in the State of New York at the time the WTC towers were designed. The Chicago code was chosen as the code then in effect in a large city with tall buildings outside of the northeastern states where the WTC towers are located. The BOCA code was chosen as the model code typically adopted at that time in the northeastern states.

Structural provisions include those concerning design loads, materials and methods of construction, design methods including design load combinations, the major materials of construction (concrete, masonry, steel, and wood), and design and construction of foundations. Detailed comparisons of provisions are provided in the form of tables. The comparisons are summarized in the body of this report.

A comparison is provided of uniform design live load values from the reviewed codes for the types of live load (on different floor areas) used in the design of the WTC towers. A summary is provided of the live load reductions permitted by the various codes for columns, walls, piers, beams, and girders. The New York City Building Codes have live load reduction provisions based on contributory floor area and live-to-dead load ratio. For live-to-dead load ratios of 0.625 or less, these provisions may yield higher live load reductions than the other codes. The same comments do not apply to the alternative live load reduction provision of the New York City Building Codes.

Based on the comparison of minimum wind loads on vertical surfaces required by the various building codes, the largest shear force at the base of a building the height of the WTC towers is obtained from the BOCA-BBC. Similarly, the largest overturning moment at the base of a building the height of the WTC towers is also obtained from the BOCA-BBC. The lowest base shear and moment are obtained from the 1968 and 2001 New York City Codes. The base shear from the New York City Codes is approximately 20 percent less than that from BOCA, while the base moment is approximately 10 percent less.

Of the codes compared, only the 2001 New York City Building Code and the BOCA-BBC have seismic design provisions. Those provisions are based on the 1988 edition (including the 1990 Accumulative Supplement) and the 1962 edition of the Uniform Building Code, respectively (ICBO 1962, ICBO 1988).

The primary materials standards referenced in the 1968 New York City Building Code, the Chicago Municipal Code, and the BOCA-BBC are the 1963 edition of ACI 318, *Building Code Requirements for Reinforced Concrete*, and the 1963 edition of the AISC specification, *Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings.* The New York State Building Code, being a performance code, does not adopt any standards by reference. The 2001 New York City Building Code references updated steel and concrete standards.

The New York City Building Codes have extensive and rigorous foundation design and construction requirements; the other codes are less extensive and typically less rigorous.

Chapter 1
INTRODUCTION

The objective of this study was to examine how the structural provisions of the 1968 edition of the New York City Building Code, which was used in the design of World Trade Center (WTC) 1 and WTC 2, compared with the structural provisions in a number of contemporaneous codes, as well as in the 2001 edition of the New York City Building Code, which is currently in effect. One of the selected contemporaneous codes was the building code in effect in the State of New York at the time WTC 1 and WTC 2 were designed. Another selected code was the building code then in effect in Chicago, which represented a large city with tall buildings outside of the northeastern states where the WTC towers are located. The third code selected was the model building code that was typically adopted in the northeastern states at the time the WTC towers were designed. Thus, this report provides a comparison of the structural provisions of the following codes:

1. The New York City Building Code, 1968 edition (The City of New York 1968)
2. The New York City Building Code, 2001 edition (The City of New York 2001)
3. The New York State Building Construction Code, 1964 edition (BCB 1964)
4. The Municipal Code of Chicago, 1967 edition (The City of Chicago 1967)
5. The BOCA Basic Building Code, 1965 edition (BOCA 1965)

Structural provisions include those concerning design loads, such as dead loads, live loads (including live load reduction), wind loads, earthquake loads and other loads. They also include provisions concerning what is called "structural work" in the New York City Building Codes (this term is not used in the other codes). The scope of "structural work" includes, but is not limited to, materials and methods of construction, design methods including design load combinations, and the materials of construction including concrete, masonry, steel and wood. Structural provisions also include those for foundation design and construction.

Detailed comparisons are provided in Tables 7–1 through 7–4. The comparisons are based on detailed section-by-section, subsection-by-subsection reviews of comparable provisions in the five codes included in this study. There is a "Comments" column in each table, which summarizes the differences among the five codes. The comparisons are summarized in the body of this report.

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Chapter 2
CODES INCLUDED IN COMPARISON

The Port of New York Authority (whose name was changed to the Port Authority of New York and New Jersey in 1972 and which will be referred to as "the Port Authority") is not required to comply with the local building code. As an interstate compact created under a clause of the U.S. Constitution, it is not bound by the authority having jurisdiction, which in the case of the World Trade Center (WTC) would be the New York City Department of Buildings. In 1963, the Port of New York Authority, however, instructed the architect and consulting engineers to prepare their designs for WTC 1 and WTC 2 to comply with the New York City Building Code.[1] Although it is not explicitly stated in the 1963 letter, the 1938 edition of the Code was in effect at the time. In areas where the Code was not explicit or where technological advances made portions of it obsolete, the Port Authority directed the consultants to propose designs "based on acceptable engineering practice," and required them to inform the WTC Planning Division when such situations occurred.

In 1965, the Port Authority instructed the design consultants for WTC 1 and WTC 2 to comply with the second and third drafts of the revised New York City Building Code then being finalized and to undertake any design revisions necessary to comply with such provisions.[2] The new edition of the New York City Building Code became effective in December 1968 (The City of New York 1968).

A consortium of Seven World Trade Company and Silverstein Development Corporation designed and constructed WTC 7 as a Port Authority "Tenant Alteration" project. This was very different from the cases of WTC 1 and WTC 2. Section 5A.3 of the WTC 7 project specifications (WTC 7 Project Specifications 1984) required the structural steel to be designed in accordance with the New York City Building Code in effect at the time and the latest edition of the *Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings* published by the American Institute of Steel Construction. When the building was designed in the 1980s, the 1968 edition of the New York City Building Code with amendments was in effect; no revisions were made to the applicable structural provisions in the New York City Building Code until 1987.

The building code in effect in the State of New York at the time WTC 1 and WTC 2 were designed was the New York State Building Construction Code, 1964 edition.

To compare with contemporaneous building code requirements in a major U.S. city with tall buildings outside of the northeastern states at the time the WTC towers were being designed, the structural provisions of the 1967 edition of the Municipal Code of Chicago are included in this review.

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[1] Letter dated May 15, 1963, from Malcolm P. Levy (Chief, Planning Division, World Trade Department) to Minoru Yamasaki (Minoru Yamasaki & Associates).

[2] Letter dated September 29, 1965, from Malcolm P. Levy (Chief, Planning Division, World Trade Department) to Minoru Yamasaki (Minoru Yamasaki & Associates).

In the northeastern region of the United States, which includes the WTC site, the model code typically adopted by local jurisdictions was the Building Officials and Code Administrator (BOCA) National Building Code. This code, prior to the mid-1980s, was called the BOCA Basic Building Code (BBC). The 1965 edition of the BOCA BBC was the latest edition published at the time the WTC towers were being designed.

The 2001 edition of the New York City Building Code is also included in this review, as it is the latest edition in effect at the time of this writing.

Thus, this report provides a comparison of the structural provisions of five building codes: the 1968 and 2001 editions of the New York City Building Code, the 1964 edition of the New York State Building Code, the 1967 edition of the Municipal Code of Chicago, and the 1965 edition of the BOCA BBC.

Tables 7–1 through 7–4 of this report provide detailed comparisons of the structural provisions of the five codes. The reference standards mentioned in the comparisons are listed in Annex A1 through Annex A5. The code tables mentioned in the comparisons are included in Annex B1 through Annex B5. This report summarizes the detailed comparisons presented in Tables 7–1 through 7–4.

Chapter 3
OVERVIEW OF CODES COMPARED

3.1 1968 AND 2001 NEW YORK CITY BUILDING CODES

The report dated June 28, 1968, of the Committee on Buildings to the City Council (The City of New York Committee on Buildings 1968), which favored the adoption of the proposed 1968 Building Code, stated: "Since the existing Building Code was first adopted in 1938, technology has undertaken major revolutionary shifts, producing new materials and methods. Also, workable standards have now been developed and perfected for describing and testing the desired characteristics of materials." It was concluded that there would be nothing to gain by attempting to revise the 1938 code. "Rather an entirely new code should be written." It was decided that the new code should be a combination of performance and prescriptive requirements with strong emphasis on performance, whenever possible, and with liberal reference to acceptable national standards. In the opinion of the Committee on Buildings, the new code thoroughly "futurized" the building laws for the City of New York. In the words of the Committee Chairman, "New construction techniques in New York will only be inhibited by technology itself."

The structural provisions of the 1968 Code are contained principally in Articles 9 through 11 and Article 19. Compared with the 1938 Code, the new structural provisions modernized the method of load analysis and mandated specific consideration of previously neglected phenomena such as thermal forces and shrinkage. Certain loads, such as for private dwellings and roofs, were decreased while wind loads were increased. In view of more rigorous requirements for structural analysis, allowable temporary overstresses were increased. The 1968 code prescribed an approach of performance engineering design, as contrasted with the empirical and prescriptive methods of the 1938 Code. The 1968 Code permitted all modern design concepts including ultimate strength analysis, prestressed concrete, shell and folded plate design, cable suspension, reinforced masonry and structural plywood. The foundation provisions made foundation design much less stringent. Increased foundation loads (in instances, conceivably many times previous limits) were permitted; however, the evaluation procedure was thorough and rigorous. The sub-soil evaluation procedures were revised to produce more meaningful information, and a uniform system of soil classification was adopted. A five-point procedure for determining permissible pile loads was established. Provisions regarding safety of the public and property during construction were revised and unified in Article 19. Rigorous procedures for control of cranes, power buggies and power equipment were newly mandated.

The structure of the City of New York Building Code has two unique features. First, the code is continually updated by incorporating "local laws" that are approved by the City Council. For instance, in the 2001 edition of the New York City Building Code, Reference Standard RS 10-3 is ACI 318-83 "*Building Code Requirements for Reinforced Concrete,*" but the user finds the following statement: "repealed by Local Law 17/1995, eff. 2/21/96. See other Reference Standard RS 10-3 below, added by Local Law 17/1995, eff. 2/21/96." The other Reference Standard RS 10-3 is ACI 318-89 "*Building Code Requirements for Reinforced Concrete*."

The second unique feature is the way Reference Standards (RS) are used. The substantive provisions of the code are supplemented by the Building Code Reference Standards, which are designated as "Building Code Rules." The text of certain reference standards is printed in full. The text of other standards is incorporated by reference to their national designation. However, code modifications to these standards are permitted. There are approximately 300 reference standards. The Building Code Rules may be revised by an administrative procedure. The Board of Standards and Appeals is empowered to amend or revise the building code rules or issue new building code reference standards consistent with the remainder of the code only upon an application by the Building Commissioner and only within the scope of the application.

3.2 1964 NEW YORK STATE BUILDING CODE

The New York State Building Construction Code (Code) is promulgated by the State Building Code Council of the State of New York. The State Building Code Council is concerned with regulations for the construction of buildings and the installation therein of equipment that is essential to building operation and maintenance. The purpose of its regulations is to establish reasonable safeguards for the safety, health, and welfare of the occupants and users of buildings.

The municipalities of the State of New York have the option to adopt the State Building Construction Code. The administration and enforcement of the Code are the responsibility of the local municipality pursuant to its administrative ordinances.

In addition to the Code, the Council publishes a Code Manual to assist in the application and enforcement of the Code. The Code Manual indicates and illustrates acceptable methods of compliance with the performance requirements set forth in the Code, but does not exclude other possible methods of meeting these requirements. Where adopted, the Code is the law; the Code Manual is not.

As a further guide in determining compliance with the performance requirements of the Code, the Council publishes a list of Generally Accepted Standards. Compliance with these standards is deemed to satisfy code requirements.

3.3 1967 CHICAGO MUNICIPAL CODE

The Chicago Municipal Code comprises the ordinances of the City of Chicago on building construction and maintenance. In addition, it includes regulations for environmental control, sidewalks and fire prevention for new construction or major alteration projects.

The structural provisions of the 1967 Chicago Municipal Code are to be found in Chapters 68, 69, and 70. Section 69.4 contains a list of referenced standards. The standards for (a) foundations, (b) masonry, (c) wood, (d) reinforced concrete, (e) reinforced gypsum, (f) steel and metals, (g) plastering, and (h) single family dwellings represent accepted engineering practice.

The regulations of the Chicago Municipal Code are subject to amendment by the Chicago City Council. To keep users abreast of such amendments, the publisher of the code issues a periodic supplement.

3.4 1965 BOCA-BASIC BUILDING CODE

The BOCA-Basic Building Code (BBC) published by the Building Officials Conference of America, Inc. (BOCA, later Building Officials and Code Administrators International) is one of three model codes that used to, and in many cases still do, form the basis of the building codes of various local jurisdictions. The BOCA-BBC has been the model code of choice in the northeastern region of the United States, which includes the cities of New York and Chicago. The City of New York has never adopted the BOCA-BBC or any model code (with the exception of the earthquake design provisions of the 1988 Uniform Building Code (ICBO 1988), which were adopted in later versions of the code). The City of Chicago has used the BOCA-BBC as a basis for its municipal code, but it has never made a complete adoption, as for instance the State of New Jersey has done.

The BOCA-BBC provisions are written in terms of performance, and not in the form of prescriptive requirements for materials and methods. Performance-based codes make it easier to accept new materials and methods of construction that can be evaluated by accepted standards.

The BOCA-BBC accepts nationally recognized standards as the criteria for evaluation of minimum safe practice or for determining the performance of materials or systems of construction. The application of these standards is stated in the text of the code requirements, but the standards are listed and identified in the appendixes to the code. This makes it convenient to update any standard as it is revised or reissued by the standards development organization.

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Chapter 4
LOADS

Article 9 of the 1968 New York City Building Code contains the minimum loads to be used in the design of buildings. According to Section C26-900.2, Reference Standards (RS), the minimum dead, live, and wind loads prescribed in Reference Standard RS 9, Loads (Annex A1 of this report), are a part of Article 9. In no case are the loads used in design to be less than the minimum values contained in that article. The 2001 New York City Building Code has the same provision.

The 1964 New York State Building Code requires that loads include dead load and the following imposed loads where applicable: live, snow, wind, soil pressure including surcharge, hydrostatic, and impact. Notice that earthquake loads are not mentioned. The Chicago Municipal Code prescribes minimum design loads, including dead loads. The 1965 BOCA Basic Building Code (BOCA-BBC) prescribes all superimposed live and special loads in addition to dead load.

4.1 DEAD LOADS

1968 and 2001 New York City Building Codes—Dead loads are defined in Sub-Article 901.0, Dead Loads, of the 1968 New York City Building Code, as the actual weight of the building materials or construction assemblies to be supported, based on the unit weights provided in Reference Standard RS 9-1, Minimum Unit Dead Loads for Structural Design Purposes (Section C26-901.1). Weights in pounds per square foot (psf) of floor area are listed for various types of walls and partitions, floor finishes and fills, ceilings, roof and wall coverings, and floors (wood joist construction). The densities of miscellaneous materials are also given. Actual weights may be determined by analysis or from data in manufacturers' drawings and catalogs, but in no case are the unit weights permitted to be less than those contained in Reference Standards RS 9-1, unless the building commissioner approves them. The 2001 New York City Building Code has the same provision.

According to the 1968 New York City Building Code, weights from service equipment (plumbing stacks; piping; heating, ventilation, and air conditioning; etc.) are to be included in the dead load (Section C26-901.2). The weight of equipment that is part of the occupancy of a given area is to be considered as live load. The 2001 New York City Building Code has the same provision.

The 1968 and 2001 New York City Building Codes require that weights of all partitions be considered, using actual weights at locations shown on plans. The equivalent uniform partition loads in Reference Standard RS 9-1 (Annex A1 of this report) may be used in lieu of actual partition weights, except in stipulated situations, where actual partition weights must be used. Equivalent uniform loads must be used in areas where locations of partitions are not shown on plans, or in areas where partitions are subject to rearrangement and relocation.

New York State Building Code—There are no provisions similar to those of the New York City Building Code concerning dead loads. There is no provision concerning equipment weight. There is also no provision concerning partition loads.

***Chicago Municipal Code*—**There are no provisions similar to those of the New York City Building Code concerning dead loads. There is no provision concerning equipment weight. A minimum partition load of 20 psf is prescribed.

***BOCA-BBC*—**The 1965 BOCA-BBC requires actual weights of materials to be used in estimating dead loads, but the actual weights cannot be less than the unit dead loads prescribed in Appendix J of the code (Annex A5 of this report). The BOCA-BBC has a provision concerning equipment weight that is similar to the corresponding provisions of the New York City Building Code. The BOCA code requires consideration of the actual weight of the partitions or an equivalent uniform load of no less than 20 psf of floor area.

4.2 FLOOR LIVE LOADS

1968 New York City Building Code—Requirements for live loads are given in 902.0, Live Loads, of the 1968 New York City Building Code, with specific requirements for floor live loads given in C26-902.2. Minimum design values for uniformly distributed and concentrated floor live loads for various occupancies are contained in Reference Standard RS 9-2 (Annex A1 of this report), Minimum Requirements for Uniformly Distributed and Concentrated Live Loads (Section C26-902.2). For occupancies that are not listed, design live loads are to be determined by the architect or engineer subject to approval by the building commissioner. Provisions are also given on how to apply concentrated live loads so as to produce maximum stress in the structural elements.

2001 New York City Building Code—The live load provisions in the 1968 Code remained unchanged.

New York State Building Code—This code states that uniformly distributed and concentrated live loads must be the greatest loads provided by the intended occupancy and use, subject to minimum values listed in Table C304-2.2 (Annex B3 of this report). Minimum loads for occupancies and uses not listed are to be in conformity with generally accepted standards.

Chicago Municipal Code—The minimum uniformly distributed and concentrated live loads are given in Table 68-2.1 (Annex B4 of this report).

BOCA-BBC—The minimum uniformly distributed and concentrated live loads are given in Table 13 (Annex B5 of this report).

Table 4–1 of this report provides a comparison of uniform live load values of the codes reviewed for types of live loads used in the design of World Trade Center (WTC) 1 and WTC 2 (see Section 2.2.1, NCSTAR 1-1A).[1]

The New York City Building Codes give the most comprehensive provisions for roofs subjected to special loads.

[1] This reference is to one of the companion documents from this Investigation. A list of these documents appears in the Preface to this report.

Table 4–1. Comparison of uniform live load values of reviewed codes for types of live loads used in design of WTC towers (psf)

Use of Spaces	1968 and 2001 NYC Codes	1964 NY State Code	1967 Chicago Municipal Code	1965 BOCA-BBC
Cafeteria	100	100	100	100
Closets (tenant floors)	100	120	100	125
Concourse	100	100	100	100
Corridors within core (mechanical equipment floor)	75	100	NA	NA
Corridors within core (skylobby floor)	100	100	100	100
Corridors within core (typical office floor)	75	100	75	100
Duct offset space	75	100	NA	NA
Electric closet	75	100	100	125
Electric substation & transformer room	75	100	NA	NA
Elevator machine room (plus elevator reactions)	(a)	100	NA	100
Elevator pits (plus elevator reactions)	(a)	100	NA	NA
Expansion tank room	75	100	NA	NA
Janitor's closets	100	120	100	125
Kitchen	100	100	75	100
Local passenger elevator lobbies (skylobby floors)	100	100	100	100
Main shuttle elevator lobbies (skylobby floors)	100	100	100	100
Mechanical equipment rooms	75	100	NA	NA
Men's toilets	40	60	NA	NA
Observation lobby	100	100	100	100
Office areas	50	50	50	50
Passenger elevator lobbies (tenant floors)	100	100	100	100
Powder rooms	40	60	NA	NA
Restaurant	100	100	100	100
Roof	30	20	25	20
Secondary motor rooms	75	100	NA	NA
Service room[b] (mechanical equipment floor)	75	100	NA	NA
Service room (tenant floor)	75	100	NA	NA
Sprinkler tank room	75	100	NA	NA
Stairs	75	100	100	100
Telephone closets	80	NA	NA	NA
Tenant spaces within core	50	50	50	50

a. Refers to ANSI/ASME A17.1.
b. Considered as mechanical equipment rooms.
Key: NA, not available.

4.3 ROOF LIVE LOADS

***1968 and 2001 New York City Building Codes*—**Roof live load of 30 psf of horizontal projection, reduced by 1 psf for each degree of slope in excess of 20 degrees, is prescribed. The concentrated load provisions of Section C26-902.2 (b) apply.

New York State Building Code—On roofs not used as promenades, the minimum imposed load must be 20 psf perpendicular to the roof surface, where snow plus wind loads total less than 20 psf.

Chicago Municipal Code—The prescribed value is 25 psf of roof area, acting normal to roof surface (this includes snow). May be taken as zero for roofs having a pitch of 30 degrees or more.

BOCA-BBC—The roof live load is 20 psf of horizontal projection. In areas subject to snow loads, it is 30 psf of horizontal projection.

4.4 MOVING LOADS

Only the New York City Building Codes have provisions on moving loads, such as vehicles and machinery, which are detailed in Table 7–2 of this report.

4.5 PARTIAL LOADING CONDITIONS

The New York City Building Codes give simplified methods and the most detailed provisions concerning partial loading conditions (not all spans loaded at the same time with the full design live loads). The Chicago Municipal Code is the only other code that gives provisions that are general in nature.

4.6 ROOF LIVE LOAD REDUCTION

The New York State Code is the only code that allows roof live load reduction. The New York City, Chicago, and BOCA codes do not allow any reduction for roof live load.

4.7 FLOOR LIVE LOAD REDUCTION

1968 New York City Building Code—Provisions for live load reduction are contained in 903.0, Live Load Reduction. The allowable reduced live load for floor members is determined by multiplying the basic live load value from Reference Standard RS 9-2 by the percentages given in Table 9–1 of the Code, which is reproduced here as Table 4–2. These percentages are a function of the contributory floor area, which is defined in Section C26-903.3, and the ratio of live load to dead load.

Table 4–2. Reduced live load per the 1968 New York City Building Code Table 9–1 (percent).

Contributory Area (ft^2)[b]	Ratio of Live Load to Dead Load[a]		
	0.625 or Less	1	2 or More
149 or less	100	100	100
150–299	80	85	85
300–449	60	70	75
450–599	50	60	70
600 or more	40	55	65

a. For intermediate values of live load/dead load, the applicable percentages of live load may be interpolated.
b. Contributory areas are computed as follows (see Section C26-903.3):
For one-way and two-way slabs: product of the shorter span length and a width equal to one-half the shorter span length. Ribbed slabs shall be considered as though the slabs were solid.
For flat plate or flat slab construction: one-half the area of the panel.
For columns, girders, or trusses framing into columns: the loaded area directly supported by the column, girder, or truss. For columns supporting more than one floor, the loaded area shall be the cumulative total area of all the floors that are supported.
For joists and similar multiple members framing into girders or trusses, or minor framing around openings: twice the loaded area directly supported but not more than the area of the panel in which the framing occurs.

No live load reduction is permitted for members and connections (other than columns, piers, and walls) supporting:

- Floor areas used for storage (including warehouses, library stacks, and record storage);
- Areas used for parking of vehicles;
- Areas used as places of assembly, for manufacturing, and for retail or wholesale sales.

The maximum live load reduction is 20 percent for columns, piers and walls supporting such areas.

Live load reduction is also not permitted for calculating shear stresses at the heads of columns in flat slab or flat plate construction. Flat slabs and flat plates are reinforced concrete slabs supported directly on columns, without any beams along the column lines. The provision applies only at the joints of such slabs and supporting columns.

As an alternative to the percentages given in Table 4–2 of this report, live load reduction for columns, piers, and walls are permitted to be taken as 15 percent of the live load on the top floor, increased at the rate of 5 percent on each successive lower floor, with a maximum reduction of 50 percent. For girders supporting 200 ft^2 or more of floor area, the allowable live load reduction is 15 percent.

2001 New York City Building Code—Floor live load reduction provisions of the 1968 New York City Building Code remained unchanged in the 2001 version of the Code.

***New York State Building Code*—**Provisions are given in Section C304.2.1 (c, d) of the New York State Code.

(a) Uniformly distributed live loads on beams and girders supporting other than storage areas and motor vehicle parking areas, when such member supports 150 ft^2 or more of roof or floor area per floor:

- $DL \leq 25$ psf, maximum reduction is 20 percent
- 25 psf < $DL \leq 100$ psf, maximum reduction is the least of
  - 60 %
  - 0.08 % per ft^2
  - $\frac{(DL+LL)}{4.33(LL)} \times 100\%$

(b) For columns, girders supporting columns, bearing walls, and walls supporting 150 ft^2 or more of roof or floor area per floor other than storage areas and parking areas:

Maximum reduction is 20 percent for the top three floors including the roof, increased successively at the rate of 5 percent for each successive lower floor, with a maximum reduction of 50 percent.

***Chicago Municipal Code*—**Provisions are given in Section 68-2.2 of the Chicago Municipal Code.

(a) Columns, walls, piers and foundations: Live load reduction may be taken as 15 percent of the live load for the top floor, increased at the rate of 5 percent on each successive lower floor, with a maximum reduction of 50 percent. This is the same as the alternative live load reduction by the New York City Building Code.

(b) Live load reduction for beams, girders and trusses is reproduced in the following table.

Tributary Area (ft^2)	**Maximum *LL* Reduction (%)**
< 100	0
100-200	5
200-300	10
> 300	15

(c) Alternatively to (a) and (b), when *DL* > *LL*, the *LL* specified in Section 68-2.1 of the Chicago Municipal Code may be reduced by the ratio of the specified *LL* to the *DL*. The reduced *LL* must in no case be less than 2/3 of the *LL* specified in Section 68-2.1.

For storage rooms, reduction must not exceed one-half of the percentage reduction provided above.

BOCA-BBC—Provisions are given in Section 721.0 of the BOCA-BBC.

(a) Live load ≤ 100 psf, maximum reduction is the least of

- 60 %
- 0.08 % per ft^2
- $\frac{(DL+LL)}{4.33(LL)}\times 100\%$

No reduction is permitted for areas of public assembly. Note that the above is the same as in the New York State Building Code requirements for beams and girders supporting more than 25 psf of dead load.

(b) Live load > 100 psf, no reduction, except that *LL* on columns may be reduced 20 percent.

See Fig. 4–1 and Table 4–3 for comparisons of the permitted live load reductions. The New York City Building Code does not permit live load reduction in calculating shear stresses at the heads of columns in flat slab or flat plate construction.

Figure 4–1. Reduced live load of various building codes for columns, walls, and piers.

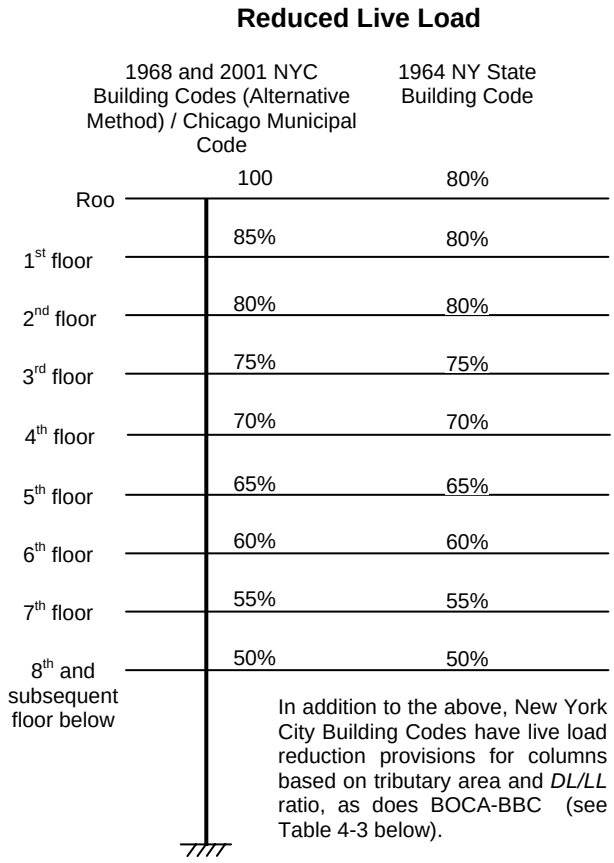

Table 4–3. Reduced live load of various building codes for beams and girders.

Contributary Area (ft^2)	1968 and 2001 NY City Building Codes		1967 Chicago Municipal Code	1964 NY State/1965 BOCA Codes	
100 or less	100 %		100 %	100 %	
100-150	100 %		95 %	100 %	
150-200	80-85 %	Also depends on the *DL*/*LL* ratio.	95 %	84-88 %	These values are determined as the larger of : • [100-0.08×(tributary area)], or • 40 % The percentage values also must not be less than $(1-\frac{DL+LL}{4.33LL})\times 100$, which is not reflected in the ranges listed.
200-300	80-85 %		90 %	76-84 %	
300-450	60-75 %		85 %	64-76 %	
450-600	50-70 %		85 %	52-64 %	
600 and more	40-65 %		85 %	40-52 %	

4.8 WIND LOADS

1968 New York City Building Code—According to Sub-Article 904.0, Wind Loads, wind forces are computed in accordance with the New York City Building Code Reference Standard RS 9-5, Minimum Design Wind Pressures. Wind is assumed to act from any direction, and for continuous framing (structural members continuous over their supports – for example, beams having full moment connections with columns), the effects of partial loading conditions are considered. Minimum design wind pressures acting on vertical surfaces are contained in Table RS 9-5-1, which is reproduced here as Table 4–4.

Table RS 9-5-2 of the 1968 New York City Building Code (reproduced here as Table 4–5) contains the design wind pressures normal to horizontal and inclined surfaces.

Table 4–4. Design wind pressures on vertical surfaces per the 1968 New York City Building Code (Table RS 9-5-1).

Height Zone (ft above curb level)	Minimum Design Wind Pressure on Vertical Surfaces (psf of projected solid surface)	
	Structural Frame	Glass Panels
0–50[a]	15	–
0–100	20	30
101–300	25	30
301–600	30	35
601–1000	35	40
Over 1000	40	40

a. Signs and similar constructions of shallow depth only.

Table 4–5. Design wind pressures on horizontal and inclined surfaces per the 1968 New York City Building Code (Table RS 9-5-2).

Roof Slope	Design Wind Pressure Normal to Surface
30 degrees or less	Either pressure or suction equal to 40 % of the values in Table RS 9-5-1 over the entire roof area
More than 30 degrees	Windward slope: pressure equal to 60 % of the values in Table RS 9-5-1. Leeward slope: suction equal to 40 % of the values in Table RS 9-5-1.

For purposes of design, pressures on vertical, horizontal, and inclined surfaces of the building are to be applied simultaneously.

For the design of wall elements other than glass panels (i.e., mullions, muntins, girts, panels, and other wall elements including their fastenings), the design wind pressure, which includes allowances for gust, acting normal to wall surfaces, is specified as 30 psf pressure or as 20 psf suction for all heights up to 500 ft. Applicable design pressures for heights over 500 ft are to be determined from a special investigation, but are not allowed to be less than those pressures indicated in Table RS 9-5-1. Minimum design wind pressures are also given for roof building elements by multiplying the pressures in Table RS 9-5-1 by the appropriate shape factors in Table RS 9-5-3. The shape factors vary from 0.7 degrees for upright, circular cylindrical surfaces to 2.0 for signs with less than 70 percent solid surface.

In lieu of the wind pressures mentioned above, design wind pressures may be determined by “suitably conducted model tests,” subject to review and approval of the building commissioner. The tests are to be based on a basic (fastest-mile) wind velocity of 80 mph at 30 ft above ground, and are to simulate and include all factors involved in consideration of wind pressure, including pressure and suction effects, shape factors, functional effects, gusts]TJ 195.3242 0 TD 0.001 TD 0.0014 Tc 0.0, and internal pressures and s

600 ft

300 ft

100 ft

Ground Level

Figure 4–2. Minimum wind load (psf) on vertical surfaces required by various building codes.

4.10 SNOW LOADS

1968 and 2001 New York City Building Codes—The minimum roof load is specified to be 30 psf. The value is such that it most likely includes snow loads.

New York State Building Code—Minimum snow loads must be determined from Table C304-3 (Annex B3 of this report) and the given snow map, and must be applied perpendicular to the roof surface. For a horizontal roof, a minimum 30 psf load must be used.

Chicago Municipal Code—A minimum of 25 psf roof live load normal to the roof surface, including snow loads, is specified for roofs having a pitch less than 30 degrees. Such live loads may be neglected for roofs having a pitch of 30 degrees or more. However, wind pressures determined in accordance with Section 68-4.3 must be considered in the latter case. A minimum of 60 psf live load is required for roofs used for terraces, promenades, and similar structures.

BOCA-BBC—Minimum snow load on the roof in snow areas is 30 psf. When the effect of the shape of the roof as determined by actual tests indicates less or greater snow retention than specified in the code, the roof load shall be modified accordingly. Special snow loads as indicated by the average snow depth in the records of the U.S. Weather Bureau must also be considered.

4.11 SOIL AND HYDROSTATIC PRESSURE

The 1968 and 2001 editions of the New York City Building Codes require that foundation walls and retaining walls be designed to resist, in addition to the vertical loads acting on them, the incident lateral earth pressures and surcharges, plus hydrostatic pressures corresponding to the maximum probable ground water level. The three other codes have similar provisions (see Table 7–2 for comparison).

4.12 CONSTRUCTION LOADS

1968 and 2001 New York City Building Codes—Comprehensive provisions for construction loads are provided in Article 19 (1968 Code) or Subchapter 19 (2001 Code), Safety of Public and Property during Construction Operations. Topics covered include general provisions, provisions for maintenance of site and adjacent areas, for protection of adjoining property, for excavation operations, for erection operations, for demolition operations, for repair and alteration operations, for scaffolds, for structural ramps, runways, and platforms, for material, handling and hoisting equipment, for explosive powered and projectile tools, for explosives and blasting, and for flammable and combustible mixtures, compressed gases, and other hazardous materials.

New York State Building Code—All flooring, structural members, walls, bracing, scaffolding, sidewalk sheds or bridges, hoists and temporary supports of any kind incidental to the erection, alteration or repair of any building shall be of such strength as to suffer no structural damage when subject to the temporary loads and wind loads imposed during construction.

Chicago Municipal Code—There are no requirements related to construction loads.

BOCA-BBC—Provisions must be made for resisting temporary construction and wind loads that may occur during the erection of the building.

4.13 FLUID PRESSURES

Only the New York City Building Codes have provisions related to fluid pressure. The design of building components must consider pressures, both positive and negative, of confined fluids and gases.

4.14 ICE LOADS

Only the New York City Building Codes have provisions related to ice loads. The weight of 1/2 in. radial thickness of ice on all surfaces must be considered as part of the live load in the design of open framed or guyed towers.

4.15 THERMAL FORCES

Only the New York City Building Codes have provisions on thermally induced forces. Enclosed buildings more than 250 ft in plan dimension shall be designed for 40 ^{o}F temperature change. Exterior exposed structures regardless of plan dimensions must be designed for 40 ^{o}F temperature change for concrete and masonry construction and 60 ^{o}F for metal construction. Provisions for piping are also given.

4.16 SHRINKAGE

Only the New York City Building Codes have provisions on the effects of shrinkage of concrete structures. Reinforced concrete components must be designed for shrinkage deformation of 0.0002 (normal-weight concrete) or 0.0003 (lightweight concrete) times the length between contraction joints.

4.17 DISTRIBUTION OF VERTICAL AND HORIZONTAL LOADS

Only the New York City Building Codes have provisions related to distribution of loads vertically along the structure and horizontally to various resisting elements.

Vertical Load Distribution—Distribution of vertical loads to supporting members must be determined on the basis of a recognized method of elastic analysis or "system of coefficients of approximation." Elastic or inelastic displacements of supports shall be considered and, for the distribution of dead loads, the modulus of elasticity of concrete or composite sections shall be reduced to consider plastic flow. Secondary effects, due to warping of the floors, must be considered.

Horizontal Load Distribution—Provisions are given for distribution of horizontal loads to vertical frames, trusses and shear walls, which must be based on relative rigidity; and for distribution of horizontal loads within rigid frames of tier buildings, which can be based on elastic analysis, or given simplified assumptions if certain limitations are satisfied, such as requiring approval of simplifying assumptions for buildings over 300 ft in height (see 906.2 for 1968 Code in Table 7–2).

Chapter 5
STRUCTURAL WORK

"Structural work" is a term used in the New York City Building Codes and not in the other codes. The scope of "structural work" includes, but is not limited to, materials and methods of construction; design methods, including design load combinations; and the materials of construction, including concrete, masonry, steel, and wood. Table 7–3 compares code provisions related to these topics.

5.1 STANDARDS

1968 New York City Building Code—The design standards adopted by this code are listed in Annex A1 of this report. The primary references of interest are the 1963 edition of ACI 318, *Building Code Requirements for Reinforced Concrete*, and AISC 1963, *Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings*.

2001 New York City Building Code—The design standards adopted by reference in this code are listed in Annex A2 of this report. The primary references are: the 1989 edition of the ACI 318, *Building Code Requirements for Reinforced Concrete*, AISC 1989, *Specifications for Structural Steel Buildings – ASD and Plastic Design*, and AISC-LRFD 1993, *Load and Residence Factor Design Specifications for Structural Steel Buildings*.

New York State Building Code—This code is a performance code, and does not adopt any standards by reference. However, the State Building Code Council of the State of New York publishes a list of Generally Accepted Standards that are listed in Annex A3 of this report. The list includes the 1963 edition of ACI 318, *Building Code Requirements for Reinforced Concrete*, and the 1963 edition of AISC, *Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings*. The State Building Code Council also publishes a Code Manual to help the user implement the State Building Construction Code. This Manual references standards that are deemed to comply with the requirements of the code.

Chicago Municipal Code—The standards referenced by this code are listed in Annex A 4 of this report. The primary references are the 1963 edition of ACI 318, *Building Code Requirements for Reinforced Concrete*, and AISC 1963, *Specification for the Design, Fabrication and Erection of Structural Steel for Buildings*.

BOCA-BBC—The adopted standards are listed in the appendixes to the BOCA-BBC (see Annex A5 of this report). The referenced design standards for steel and concrete are the same as in the 1968 New York City Building Code and the Chicago Municipal Code.

5.2 ALTERATION OF EXISTING BUILDINGS

1968 and 2001 New York City Building Codes—Requirements for alterations are based on the cost of an alteration as a percentage of building value. Whether the altered building or the alternations only need to

comply with the requirements of the Code depends on the cost of alterations versus the value of the building. When the cost of alterations relative to the value of building is low, the alterations may not have to be in compliance with the current Code "provided the general safety and public welfare are not thereby endangered."

New York State Building Code—It is required that any addition or alteration regardless of building value must be made in conformity with the Code. The New York State Code is silent on the requirements for the remainder of the structure being altered.

Chicago Municipal Code—The provisions are similar to those of the New York City Codes.

BOCA-BBC—The provisions are similar to those of the New York City Codes.

5.3 MATERIALS AND METHODS OF CONSTRUCTION

1968 and 2001 New York City Building Codes—These codes prescribe testing and inspection requirements for materials, assemblies, forms, and methods of construction. The other three codes make a distinction between "controlled" and "ordinary" materials, "ordinary" materials being those that are not "controlled." Materials, assemblies, frames and methods of construction permitted by the New York City Building Codes would fall under the classification of "controlled materials" by the other codes.

New York State Building Code—According to this Code, "controlled materials" are those that have been identified and certified for quality and strength by a recognized authoritative inspection service, grading organization or testing laboratory, or are identified by manufacturer, producer, and mill test as meeting generally accepted standards (Section C303-2 of the Code).

Chicago Municipal Code—According to this Code, "controlled materials" refers to a building, structure, or part thereof, which has been designed or constructed under the following conditions (Section 69-3.1 of the Code):

- All materials must be selected or tested to meet the special strength, durability and fire resistance requirements upon which the design is based.
- The design, preparation of working drawings, including details and connections, the checking and approval of all shop and field details and the inspection of the work during construction must be under the supervision of a registered architect or structural engineer.

BOCA-BBC—According to BOCA-BBC Section 701.0, "controlled materials" are materials that are certified by an accredited authoritative agency as meeting accepted engineering standards for quality.

5.4 USED AND UNIDENTIFIED MATERIALS

***1968 and 2001 New York City Building Codes*—**Used materials and unidentified or ungraded materials must be limited to nonstructural elements except for the following three conditions (see Sec. C26.1000.9 in the 1968 Code):

- The elements or materials will be subject to stress levels that were experienced in previous construction. In lieu of this, the load test procedures in Section C26.1002.4 may be used to determine the load capacity of the materials or elements.
- Unidentified materials may be graded by the recovery and test of representative samples, or by other means satisfactory to the building commissioner.
- Used materials are considered to be graded when the grade is clearly indicated on the approved plans for the existing construction. In such cases, allowable stresses are permitted to be taken equal to those for that grade of like materials that were required at the time of existing construction.

***New York State Building Code*—**No provisions are included.

***Chicago Municipal Code*—**Used materials are permitted to be used as long as they meet the minimum requirements for new materials and all other special requirements of the Code.

***BOCA-BBC*—**Similar to the Chicago Municipal Code, used materials are permitted as long as they meet the minimum requirements of the Code for new materials.

5.5 EQUIVALENT SYSTEMS OF DESIGN

Each of the five codes reviewed permits designs that do not conform to the specific code, yet can provide performance equivalent or superior to that required by the respective code.

5.6 STABILITY

Only the New York City Building Codes contain a provision (1968 Section C26-1001.1; 2001 Section 27-591) requiring that a building, or any element thereof, be proportioned to provide a minimum factor of safety of 1.50 against failure by sliding or overturning. The required stability must be provided solely by the dead load plus any permanent anchorage provided.

5.7 BRACING

Only the New York City Building Codes (1968 Section C26-1001.2; 2001 Section 27-592) specifically require that members used to brace compression members be proportioned to resist an axial load of at least 2 percent of the total compressive design stress in the member braced, plus any transverse shear therein.

5.8 SECONDARY STRESSES

Only the New York City Building Codes (1968 Section C26-1001.3; 2001 Section 27-593) explicitly require that secondary stresses in trusses be considered and, where of significant magnitude, their effects provided for in design.

5.9 LOAD COMBINATIONS

5.9.1 Allowable Stress Design

The following discussion on the load combinations for allowable stress design is applicable in the design of structural steel (as well as masonry or wood) members in buildings.

1968 New York City Building Code—The following is a list of all possible load combinations that are specified in Section C26.1001.4:

1. $D + L + RL$
2. $0.75[D + (W \text{ or } SH \text{ or } T \text{ or } UL)]$
3. $0.75[D + L + RL + (W \text{ or } SH \text{ or } T \text{ or } UL)]$
4. $0.67\{[D \text{ or } (D + L + RL)] + Q\}$

where:

D	=	effects of dead load (basic load)
L	=	effects of live load (basic load)
RL	=	effects of reduced live load (basic load)
W	=	effects of wind load (load of infrequent occurrence)
SH	=	effects of shrinkage (load of infrequent occurrence)
T	=	effects of thermal forces (load of infrequent occurrence)
UL	=	effects of unreduced live loads where live load reduction is permitted by Article 9 (load of infrequent occurrence)
Q	=	the combination of any two or more of W, T, SH, and UL

2001 New York City Building Code—The load combinations for allowable stress design are the same as for the 1968 New York City Building Code, except that the effects from earthquake forces (E) are included as loads of infrequent occurrence.

New York State Building Code—When the stress due to wind is less than one-third of the stress due to dead load plus imposed loads excluding wind loads (live, snow, soil pressure including surcharge, hydrostatic head, and impact), the stress due to wind may be ignored. However, when the stress due to wind exceeds one-third of the stress due to dead load plus imposed loads excluding wind, the allowable stress of the material may be increased by one-third. Thus, the New York State Building Code accommodates loads of infrequent occurrence by permitting higher stresses.

Chicago Municipal Code—For combined stresses due to dead, live (including snow), and wind loads, the allowable stresses may be increased by one-third, provided the section thus determined can resist at least the stresses due to dead and live loads alone.

BOCA-BBC—The provision for allowable stresses due to dead, live, snow, and wind is the same as that in the Chicago Municipal Code. Additionally, BOCA-BBC also allows a one-third increase in the allowable stress when the effects of earthquake forces are combined with the effects of dead, live, and snow loads.

5.9.2 Ultimate Strength Design

This section on load combinations for ultimate strength design is applicable to the design of reinforced concrete members in buildings. At the time of the design of the WTC towers, steel members were designed by the allowable stress method only.

The 1968 New York City Building Code, the Chicago Municipal Code, and the BOCA-BBC reference the 1963 edition of the ACI 318, *Building Code Requirements for Reinforced Concrete*, for the design of reinforced concrete structural members. The New York State Building Code, as has been mentioned previously, is a performance code and does not adopt standards by reference. The following load combinations are specified in ACI 318-63:

1. $1.5D + 1.8L$
2. $1.25[D + L + (W \text{ or } E)]$
3. $0.9D + 1.1(W \text{ or } E)$

The effects of *SH* or *T* are to be considered on the same basis as the effects of *D* (the same load factor should be applied to *SH* or *T* as is applicable to *D* in a particular load combination).

The strength reduction factors corresponding to the above load combinations are 0.90 for flexure; 0.85 for diagonal tension, bond, and anchorage; 0.75 for spirally reinforced compression members; and 0.70 for tied compression members.

The strength design load combinations of ACI 318-89, adopted into the 2001 New York City Building Code, are:

1. $1.4D + 1.7L$
2. $0.75[1.4D + 1.7L + 1.7(W \text{ or } 1.1E)]$

3. $0.9D + 1.3(W \text{ or } 1.1E)$

4a. $1.4D + 1.7L + 1.7H \geq 1.4D + 1.7L$

4b. $0.9D + 1.7H \geq 1.4D + 1.7L$

5a. $1.4D + 1.7L + 1.4F \geq 1.4D + 1.7L$

5b. $0.9D + 1.4F \geq 1.4D + 1.7L$

(F = effects of weight and pressures of fluids with well-known densities and controllable maximum heights.)

6. $0.75\ (1.4D + 1.4T + 1.7L) \geq 1.4\ (D + T)$

If resistance to impact effects is taken into account in design, such effects shall be included with live load L.

The strength reduction factors, to go with the above load combinations, are as follows:

- Flexure, without axial load 0.90
- Axial tension, and axial tension with flexure 0.90
- Axial compression, and axial compression with flexure:
  - Members with spiral reinforcement 0.75
  - Other reinforced members 0.70

  Except that for low values of axial compression, ϕ may be increased gradually to 0.90.
- Shear and tension 0.85
- Bearing on concrete 0.70

There are modifications of the strength reduction factor for regions of high seismic risk.

5.10 DEFLECTION LIMITATIONS

All five codes contain similar limits on vertical deflections of floor and roof assemblies.

1968 and 2001 New York City Building Codes—The relevant provisions of several reference standards cited in the Article (1968 Code) or Subchapter (2001 Code) on Structural Work apply. In addition, the total of the dead plus live load vertical deflections (including effects of creep and shrinkage) of members supporting walls, veneered walls, or partitions constructed of or containing panels of masonry, glass, or other frangible materials must not exceed 1/360 of the span.

***New York State Building Code*—**Under imposed load, the deflection must not exceed 1/360 of the span when the inside is to include plastered partition walls, and 1/240 of the span if it does not. When a roof is not to be used as a promenade, and the underside is not to be plastered, the deflection must not exceed 1/180 of the span.

***Chicago Municipal Code*—**Under design live load, the deflection must not be greater than 1/360 of the span for plastered construction or 1/240 of the span for unplastered construction.

***BOCA-BBC*—**The deflection of floor and roof assemblies must not be greater than 1/360 of the span for plastered construction; 1/240 of the span for unplastered floor construction; and 1/180 of the span for unplastered roof construction.

5.11 LOAD TESTS/CORE TESTS

Load tests and tests of in-situ concrete are carried out for various purposes, as enumerated in the New York City Building Codes.

***1968 and 2001 New York City Building Codes*—**These Codes have provisions for: (1) load tests carried out to verify adequacy of structural design for a member or an assembly, (2) load tests carried out to verify adequacy of questionable construction, (3) core tests to verify adequacy of concrete, (4) prequalifying load tests for structural members before they are incorporated into structure, and (5) load tests of completed construction to verify its strength and compliance with deflection limitations.

New York State Building Code—Provisions are included for (1) and (5) above.

Chicago Municipal Code—Provisions are found for (1), (3), and (5) above.

BOCA-BBC—Provisions are included for (1) and (2) above.

5.12 EXTERIOR WALL MATERIALS

Only the New York State Building Code and the BOCA-BBC have specific provisions related to exterior wall materials. These are required to be weather-resistant and durable.

5.13 PREFABRICATED CONSTRUCTION

Only the Chicago Municipal Code and the BOCA-BBC have provisions concerning prefabricated construction.

5.14 MASONRY CONSTRUCTION

1968 and 2001 New York City Building Codes—Requirements for unreinforced masonry design and construction are given in Reference Standard 10-1 (Annex A1 of this report). *American Standard Building Code Requirements for Masonry*, USASI A-41.4, 1960, is adopted as Reference Standard 10-2 for reinforced masonry design and construction in the 1968 New York City Building Code. ACI 530-92/ASCE 5-92 *Building Code Requirements for Masonry Structures* and

ACI 530.1-92/ASCE 6-92 *Specification for Masonry Structures* are adopted as Reference Standard 10-2 for reinforced masonry design and construction in the 2001 edition of the New York City Building Code.

New York State Building Code—This code contains a general statement requiring that all structural units of natural or manufactured materials must comply with applicable specifications of authoritative agencies, or must be subjected to test in conformity with generally accepted standards in order to determine their characteristics.

Chicago Municipal Code—The 1954 edition of the *American Standard Building Code Requirements for Masonry*, USASI A-41.4, is adopted by reference. Provisions for allowable stresses for grouted brick masonry and for reinforcement and allowable stresses for reinforced brick masonry are also given.

BOCA-BBC—Specific provisions for various masonry elements are given.

5.15 CONCRETE

1968 New York City Building Code—ACI 318-63 is adopted to regulate concrete materials, design and construction. ACI 525-1963, *Minimum Requirements for Thin-Section Precast Concrete Construction,* is adopted to regulate precast concrete construction "utilizing a thin skin or slab stiffened or supported by a system of ribs." In both cases, modifications are made. In addition, the 1968 New York City Building Code has provisions on:

- Identification of metal reinforcement;
- Concrete mixtures (concrete may be proportioned, batched, and mixed by Method I, which stipulates a minimum cement content, or Method II, performance concrete);
- Documentation;
- On-site inspection;
- Admixtures;
- Licensed concrete testing laboratories;
- Short-span concrete floor and roof construction supported on steel beams;
- Pneumatically placed concrete (shotcrete);
- Formwork; and
- Preplaced-aggregate concrete.

2001 New York City Building Code—ACI 318-89 has been adopted to regulate concrete materials, design and construction. ACI 318-89 as well as MNL-120 1985, *PCI Design Handbook*, Third Edition, has been adopted to regulate precast concrete construction. In both cases modifications have been made. Additional provisions are included on the same topics as in the 1968 Code. In many cases, these provisions have been updated, as detailed in Table 7–3 of this report. For instance, in mix design

Method I, "cement factor" has been replaced by "cement content." Mix design Method II, Performance concrete, has been changed to "Proportioning on the basis of field experience."

New York State Building Code—This Code contains a general statement requiring that all structural units of natural or manufactured material must comply with applicable specifications of authoritative agencies, or must be subjected to test in conformity with generally accepted standards in order to determine their characteristics.

Chicago Municipal Code—The design and construction of reinforced concrete is required to be in accordance with ACI 318-63. Detailed provisions for steel-concrete composite beams are given.

BOCA-BBC—The following documents are adopted for reinforced (including precast) concrete design and construction: (1) ACI 711 1958, *Minimum Standard Requirements for Precast Concrete Floor and Roof Units*, (2) ASA (American Standards Association) A59.1 1954, *Specifications for Reinforced Gypsum Concrete*, (3) ACI 318 1963, *Building Code Requirements for Reinforced Concrete*, (4) ACI 315 1965, *Manual of Standard Practice for Detailing Reinforced Concrete Structures*, (5) AWS D12.1 1961, *Recommended Practices for Welding Steel, Metal Inserts and Connections in Reinforced Concrete Construction*. In addition, a number of material standards are adopted in Appendix C (Annex A5 of this report).

The Code has provisions on Concrete Aggregates (817.0), Ready-Mix Concrete (818.0), Reinforcing Steel (830.0), Reinforced Concrete (842.0), Controlled Concrete (843.0), Ordinary Concrete (844.), Structural Cinder (lightweight) Concrete (845.0), Short Span Floor Filling (846.0), Concrete-Filled Pipe Columns 9847.0), Pneumatic Concrete (848.0), Minimum Concrete Dimensions (849.0), and Reinforced Gypsum Concrete (850.0).

5.16 STEEL

1968 New York City Building Code—Materials, design, and construction methods must meet the requirements of:

- AISC 1963, *Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings*
- AISI 1962, *Specification for the Design of Light Gage Cold-Formed Steel Structural Members*
- AISI/SJI July 1, 1966, *Standard Specifications and Load Tables for Long Span Steel Joists, LJ-Series and LH-Series*
- AISI/SJI February, 1965, *Standard Specifications and Load Tables for Open Web Steel Joists, J-Series and H-Series*

In each case, modifications are made. In addition, there are specific identification (i.e., marks on steel) and quality control requirements.

2001 New York City Building Code—Materials, design and construction methods must meet the requirements of:

- AISC 1989, *Specification for Structural Steel Buildings - Allowable Stress Design and Plastic Design*
- AISC-LRFD 1993, *Load and Resistance Factor Design Specification for Structural Steel Buildings*
- Uniform Building Code 1988, including 1990 Accumulative Supplement, Section 2723, *Steel Structures Resisting Forces Induced by Earthquake Motions in Seismic Zones No. 1 and 2.*
- AISI 1986, *Specification for the Design of Cold Formed Stainless Steel Structural Members*
- AISI 1974, *Specification for the Design of Cold-Formed Steel Structural Members*
- SJI 1978, Revised 1983, *Standard Specifications for Open Web Steel Joist, H-Series*
- SJI 1985, Revised 1987, *Standard Specifications for Open Web Steel Joists, K-Series*
- SJI 1978, Revised 1987, *Standard Specifications for Longspan Steel Joists, LH-Series and Deep Longspan Steel Joists, DLJH-Series*
- SJI 1078, Revised 1987, *Standard Specifications for Joist Girders*
- SJI 1988, *Standard Specifications, Load Tables and Weight Tables for Steel Joists and Joist Girders*

Modifications are made to each of the above standards.

New York State Building Code—This Code is a performance code. It contains a general statement requiring that all structural units of natural or manufactured materials must comply with applicable specifications of authoritative agencies, or must be subjected to test in conformity with generally accepted standards in order to determine their characteristics.

Chicago Municipal Code—The following standards are adopted by reference:

- AISC 1963, *Specifications for the Design, Fabrication and Erection of structural Steel for Buildings*
- AISI 1962, *Light Gage Cold-Formed Steel Design Manual*
- SJI 1963, *Open Web Joist – Standard Specifications and Load Tables*

There are also provisions for cast iron, cast steel, and special steels.

BOCA-BBC—The following standards are adopted:

- AISC 1963, *Specifications for the Design, Fabrication and Erection of structural Steel for Buildings*
- AISC 1960, *Specifications for Architectural Exposed Structural Steel*
- AISC 1964, *Specifications for Structural Joints using ASTM A325 or A490 Bolts*
- AISI 1962, *Light Gage Cold-Formed Steel Design Manual*
- AISI 1962, *Specifications for Light Gage Cold-Formed Steel Structural Members*
- AISC-SJI 1961, *Standard Specifications for Open Web Steel Joists, Longspan or LA-Series*
- SJI- AISC 1965, *Specifications and Load Tables for Open Web Steel Joists, J-Series and H-Series*
- SJI-AISC 1962, *Standard Specifications for open Web Steel Joists, Longspan or LH-Series*

There are also provisions for cast steel construction, cast iron construction, special steels, lightweight metal alloys, alloy, and special steel.

5.17 WOOD

1968 New York City Building Code—Materials (other than non-stress graded lumber), design and construction methods must meet the requirements of the following:

- Lumber and Timber – NLMA (National Lumber Manufactures Association) 1962, *National Design Specification for Stress-Graded Lumber and its Fastenings*
- Plywood – Specifications are given as part of the code itself in Reference Standard 10-9 (Annex A1 of this report)
- Structural glued-laminated lumber – U.S. Department of Commerce CS 253-1963, *U.S. Commercial Standard for Structural Glued Laminated Lumber*

Modifications are made to the NLMA and U.S. Department of Commerce standards.[1] In addition, there are provisions on: identification, use of non-stress graded wood, quality control, general construction requirements, empirical provisions in lieu of design, heavy timber construction, and construction methods.

[1] U.S. Department of Commerce (DOC) Voluntary Product Standards are developed by U.S. industry and published by DOC following *Procedures for the Development of Voluntary Product Standards* contained in Title 15 Code of Federal Regulations Part 10. The National Institute of Standards and Technology administers this program, on behalf of the DOC, on a fee for service basis.

2001 New York City Building Code—Materials (other than non-stress graded lumber), design, and construction methods must meet the requirements of:

- Lumber and Timber – AF&PA (American Forest and Paper Association) 1991, *National Design Specification for Wood Construction* and its 1991 Supplement with 1993 Revisions
- Plywood – Specifications are given as part of the code itself in Reference Standard 10-9 (Annex A2 of this report)
- Structural glued-laminated lumber – ANSI/AITC (American Institute of Timber Construction) A190.1 1992, *Structural Glued Laminated Timber* and AITC 200-92 *Inspection Manual*
  - AITC 117 1987, *Specification for Structural Glued Laminated Timber of Softwood Species –Design Standard*
  - AITC 117 1988, *Specification for Structural Glued Laminated Timber for Softwood Species – Construction Standard*

Modifications are made to the AF&PA Standard. In addition, there are provisions on the same items as in the 1968 code.

New York State Building Code—This is a performance code. It contains a general statement requiring that all structural units of natural or manufactured materials must comply with applicable specifications of authoritative agencies, or must be subjected to test in conformity with generally accepted standards in order to determine their characteristics.

Chicago Municipal Code—NLMA – 1957 *National Design Specifications for Stress-Graded Lumber and its Fastenings* is adopted by reference. In addition, maximum allowable unit stresses for lumber used as ordinary material (as opposed to controlled material) are given. Also given are provisions for bolted joints and ventilation of enclosed wood construction.

BOCA-BBC—The following are adopted by reference:

- AITC-200 1963, *Inspection Manual for Structural Glued Laminated Lumber*
- NLMA 1962, *National Design Specifications for Stress Graded Lumber and Its Fastenings*
- NLMA 1957, *Wood Structural Design Data*
- AITC-100 1962, *Timber Construction Standards*
- USDA Handbook No. 72 1955, *Wood Handbook*

In addition, a number of American Plywood Association (APA, formerly DFPA, or Douglas Fir Plywood Association) standards are adopted.

There are detailed provisions for Lumber and Timber Construction (853.0), Heavy Timber Type Construction (854.0), Wood Frame Construction (855.0), Stress Skin Panels (856.0), and Glued Laminated and Built-Up Lumber Construction (857.0).

5.18 ALUMINUM

The 1968 New York City Building Code adopted ASCE-1963 *Suggested Specifications for Structures of Aluminum Alloy*. The 2001 New York City Building Code adopts:

- AA (Aluminum Association) SAS 30 1986, *Specifications for Aluminum Structures,* Fifth Edition
- ASTM B209 1988, *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate*
- ASTM B308 1988, *Standard Specification for Aluminum* –Alloy 6061-T6 *Standard Structural Shapes, Rolled or Extruded*
- ASTM B429 1988, *Standard Specification for Aluminum –Alloy Extruded Structural Pipe and Tube*

In addition, there are specific requirements on identification, quality control, and erection.

The only other code with provisions for structural aluminum is the BOCA-BBC, which has adopted:

- AA 1963, *Aluminum Construction Manual, Section A – Specifications for Structures of Aluminum Alloys*

5.19 REINFORCED GYPSUM CONCRETE

Gypsum concrete is intended for use in the construction of poured-in-place roof decks or slabs.

1968 New York City Building Code—USASI A59.1-1954, *American Standard Specification for Reinforced Gypsum Concrete* is adopted. Also contained are provision on identification of metal reinforcement and limitation of use.

2001 New York City Building Code—ASTM C 317-1976, *Standard Specification for Gypsum Concrete* (Reapproved 1981) is adopted. Also included are provisions on identification of metal reinforcement and limitation of use.

New York State Building Code—This is a performance code; thus, no specific standard is adopted by reference.

Chicago Municipal Code—ASA (American Standards Association) A59.1-1954 (described as USASI A59.1-1954 in the 1968 New York City Building Code) is adopted.

BOCA-BBC—Refers to the same standard as the Chicago Municipal Code.

5.20 THIN SHELL AND FOLDED PLATE CONSTRUCTION

Only the New York City Building Codes have specific provisions summarized in Table 7–3 of this report.

5.21 SUSPENDED STRUCTURES

Only the New York City Building Codes have specific provisions summarized in Table 7–3 of this report.

Chapter 6
FOUNDATIONS

6.1 GENERAL REQUIREMENTS

1968 and 2001 New York City Building Codes—Foundations of buildings including retaining walls and other structures are required to bear on, or be carried down to, satisfactory bearing materials in such a manner that the entire transmitted load will be distributed over the supporting soils at any depth beneath the foundation at unit intensities within the allowable bearing values. In addition, foundations must be proportioned to limit settlements to a magnitude that will not cause damage to the proposed construction or to existing adjacent or nearby buildings during and after construction. The New York City Building Codes specifically adopt a number of American Wood–Preservers' Association and ASTM International (ASTM) standards as Reference Standard RS 11. The specified depth of foundation is below "the lowest level of the adjoining ground or pavement surface that is exposed to frost."

New York State Building Code—Protection is required whenever structural material or assemblies are subject to deterioration from causes such as freezing and thawing and might become structurally unsound if unprotected. Also required is prevention of ground and surface water penetrating into habitable spaces, basements and cellars. There is no requirement concerning depth of foundation.

Chicago Municipal Code—Encroachment of foundations on public property is discussed. The depth of foundation must be below the adjoining ground surface.

BOCA-BBC—Foundations must have adequate strength to support the superimposed live and specified loads in addition to their own dead load without exceeding the allowable stress specified in the Basic Code or in accepted engineering standards. The Building Officials and Code Administrator (BOCA) Basic Building Code (BBC) also requires: "Except when erected on rock or when otherwise protected from frost, foundation walls, piers and other permanent supports shall extend below the frost line….No footings shall be founded on frozen soils unless such frozen condition is permanent."

6.2 SOIL INVESTIGATIONS

1968 and 2001 New York City Building Codes—Soil investigation (borings or test pits) is mandatory, although certain exceptions are allowed. The New York City Codes have provisions concerning boring methods and provisions for the use of probings, auger borings, or geophysical methods to substitute for borings. The other codes do not have similar provisions. The New York City Codes also allow existing boring data to be used, provided certain specified conditions are met.

New York State Building Code—Soil investigation is mandatory for buildings in which the sum of snow load and live loads of all floors that are transmitted by columns or walls to the soils, divided by grade-floor area, exceeds 200 psf.

Chicago Municipal Code—Where there is reasonable doubt as to the character and bearing capacity of the soil, the building commissioner may require borings, test pits, or test loads.

BOCA-BBC—Only one exploratory boring is mandatory for other than low-rise buildings or for deep foundations "in the absence of satisfactory data from immediately adjacent areas."

6.3 FOUNDATION LOADS

1968 and 2001 New York City Building Codes—The loads to be used in computing the bearing pressures on materials directly underlying footings, and the loads to be used in computing pile reactions are clearly set forth. Provisions are given for: (a) earth and ground water pressures, (b) wind and other superstructure loads, and (c) soil movements. Provision for eccentricity of loading on foundations is given. Uplift and overturning forces due to wind and hydrostatic pressure are required to be considered. Impact loads are allowed to be neglected except in certain specified cases.

New York State Building Code—Overturning and uplift forces due to wind or hydrostatic head are required to be considered, but no other provisions are included.

Chicago Municipal Code—No provisions concerning foundation loads are included.

BOCA-BBC—All retaining walls and other walls below grade are required to be designed to resist lateral soil pressures with due allowance for hydrostatic pressures for all superimposed vertical loads. All foundation slabs and other footings subjected to water pressure are also required to be designed to resist a uniformly distributed uplift equal to the full hydrostatic pressure.

6.4 ALLOWABLE SOIL BEARING PRESSURES

1968 and 2001 New York City Building Codes—Soils are classified in Code Table 11–1 (Annex B1 of this report). Some soils are designated as satisfactory bearing materials, others are designated as nominally unsatisfactory bearing materials. The allowable bearing pressures on satisfactory bearing materials are given in Code Table 11–2 (Annex B1). Provisions are included for construction on nominally satisfactory bearing materials. Provisions are also given to prevent damage to utility service lines laid in soil materials.

New York State Building Code—The bearing value of soil is required to be determined so that foundations are proportioned to provide a minimum of absolute and differential settlement. Soil or pile tests, presumptive bearing values of the soil, reduction factors for pile groups, and pile driving formulas, referred to in the code, must be in conformity with generally accepted standards. When it can be proven conclusively that the presumptive soil bearing value is adequate for the proposed load, the enforcement officer may accept such proof in lieu of the bearing capacity determination

Chicago Municipal Code—Soils are classified into: solid rock, soft rock, boulders, gravel, sand, inorganic silt, clay, hardpan, and organic soil. Maximum allowable pressures on the supporting soils at the bottom of footings are given in Code Table 70–2.4(a) (Annex B4 of this report).

BOCA-BBC—Presumptive surface bearing values of foundation materials are given in Table 15 (Annex B5 of this report). Except when determined by field loading tests or as otherwise provided in the code, the maximum allowable pressure on supporting soils under spread footings at or near the surface is required not to exceed the values specified in Table 15. Surface values of allowable bearing pressures may be adjusted for deep footings and for bearing under piles as provided for in the BOCA-BBC.

6.5 SOIL LOAD BEARING TESTS

1968 and 2001 New York City Building Codes—Soil load bearing tests may be accepted as evidence of allowable bearing capacity of a given soil stratum, subject to a number of limitations, one of which is that such tests must not be used to justify allowable bearing pressures in excess of the maximum allowable bearing values in Code Table 11–2 (Annex B1 of this report). Provisions are given for preparation, loading of the soil, and determination of bearing capacity.

New York State Building Code—Acceptance criteria for field loading soil tests are given.

Chicago Municipal Code—Whenever the bearing value of soil is in reasonable doubt or when it is desired to use soil-bearing values in excess of those established in Code Table 70–2.4(a) (Annex B4 of this report), the allowable load on a bearing material may be determined by test in accordance with requirements given in the Code.

BOCA-BBC—The maximum allowable pressure on supporting soils may be determined by field loading test. Test procedure and acceptance criteria are given.

6.6 FOOTINGS, FOUNDATION PIERS, AND FOUNDATION WALLS

1968 New York City Building Code—There are provisions concerning wood footings, wood and steel poles supporting buildings, foundation grillages, concrete footings that must conform to ACI 318-63 and masonry footings that must conform to USASI A-41.2 1960. The Code also has provisions concerning foundation piers, which must be designed as columns, of unreinforced and reinforced concrete as well as unreinforced and reinforced masonry. Finally, there are provisions concerning concrete and masonry foundation walls. Provisions regulating construction of footings, foundation piers, and foundation walls are also included.

2001 New York City Building Code—The same provisions as in the 1968 Code are included, but the standards have been updated.

New York State Building Code—There are no specific provisions on footings, foundation piers, or foundation walls.

Chicago Municipal Code—There are provisions concerning concrete footings, which must be constructed of solid masonry or concrete with or without reinforcement. There are provisions concerning foundation columns, which must consist of steel pipe shells extending to rock and completely filled with concrete with or without steel reinforcement or cores. There are provisions concerning foundation piers and caissons, which must be of concrete with or without steel reinforcement, extending to solid rock or to hardpan.

BOCA-BBC—There are provisions concerning footing design, timber footing, steel grillages, unreinforced concrete footings, masonry unit footings, reinforced concrete footings, and mat, raft and float foundations. There are provisions concerning foundation piers—unreinforced, reinforced, and with steel shells, and foundation walls.

6.7 PILE FOUNDATIONS—GENERAL REQUIREMENTS

1968 and 2001 New York City Building Codes—Provisions are included concerning minimum pile penetrations, use of existing piles at demolished structures, tolerances and modification of design due to field conditions, minimum spacing of piles, minimum section, capping and bracing of piles, splicing of piles, general requirements for installation of piles, use of uncased concrete pile shafts, use of more than one pile type, pile capacity, or method of pile installation and pile materials.

New York State Building Code—There are no specific provisions on any of the above.

Chicago Municipal Code—Provisions are included concerning minimum spacing of piles and pile caps.

BOCA-BBC—A building site must be investigated for all conditions that might promote deterioration of pile foundations, and approved protective measures must be taken. The BOCA-BBC also contains provisions concerning minimum length and penetration of piles, precautions (including tolerance to lateral deviation from plumb), spacing of piles, minimum dimensions, piles in wall foundations, isolated pier plies, splices, and corrosion protection.

6.8 PILE FOUNDATION—LOADS

1968 and 2001 New York City Building Codes—The allowable axial load on a pile must be the least value considering (a) the capacity of the pile as a structural member, (b) allowable bearing pressure on soil strata underlying the pile tips, (c) capacity as indicated by resistance to penetration, (d) capacity as indicated by load test, and (e) maximum allowable loads – (1) Basic maximum load values are given in Code Table 11–6 (Annex B1 of this report); (2) Loads higher than the basic values can be substantiated on the basis of tests and analysis. Provisions for allowable lateral load are given. A minimum factor of safety of two is required against withdrawal. The safety factor needs to be greater if the pile is subject to dynamic loading. If the safety factor is three or more, no pull-out test is required.

New York State Building Code—No specific provisions are included concerning allowable pile load.

Chicago Municipal Code and BOCA-BBC—Both codes have detailed provisions, summarized in Table 7–4, which are similar to those in the New York City Building Codes.

6.9 PILE DRIVING OPERATIONS

The New York City Building Codes have provisions concerning equipment and procedures for pile driving with the proviso that the provisions do not apply to piles driven with a vibration hammer or other equipment wherein the energy of impact cannot be evaluated. The BOCA-BBC is the only other code with provisions on pile driving operations, but regulates jetting only.

6.10 PILE TYPES – SPECIFIC REQUIREMENTS

1968 and 2001 New York City Building Codes—There are provisions concerning timber piles, precast concrete piles, cast-in-place concrete piles, compacted concrete piles (a concrete pile formed with an enlarged base in which the concrete in the base is placed in small batches that are compacted prior to attaining an initial set), steel H piles, concrete filled pipe piles, caisson piles (concrete filled pipe piles that are socketed into bedrocks of certain classes and constructed with steel cores), and composite piles.

New York State Building Code—There are no specific provisions.

Chicago Municipal Code—There are provisions concerning timber piles, precast concrete piles, cast-in-place concrete piles, structural steel pipe piles, concrete-filled steel piles, and special type of piles, including composite piles.

BOCA-BBC—This code contains provisions concerning timber piles, precast concrete piles, cast-in-place concrete piles, structural steel pipe piles, concrete-filled steel piles, drilled caissons, composite piles, as well as special piles and caissons.

6.11 UNDERPINNING

The New York City Codes are the only ones among the five codes reviewed to have specific provisions concerning support of adjacent existing structures.

6.12 STABILITY

The New York City Building Codes specify minimum factors of safety against sliding and overturning. There is no such explicit requirement in the other codes. (Section 5.6 of this report dealt with stability of structural elements; this section deals with stability of foundation elements.)

6.13 INSPECTION

The New York City Building Codes specifically require inspection of the following: boring operation; piling; footings, foundation piers, foundation walls and pile caps; subgrade for footing, foundation piers, and foundation walls; construction required for or affecting the support of adjacent properties or buildings. The other codes do not have any specific foundation inspection requirements.

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Chapter 7
DETAILED COMPARISON TABLES

Tables have been prepared to provide detailed comparisons of the structural provisions of the five codes that were reviewed. Comparisons of provisions concerning definitions, loads, structural work, and foundations are given in Tables 7–1 through 7–4, as follows:

- Table 7–1, Definitions
- Table 7–2, Loads
- Table 7–3, Structural Work
- Table 7–4, Foundations

These tables can be found following Chapter 9 of this report. The tables include "comments" that summarize the comparisons.

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Chapter 8
SUMMARY

The structural provisions of the New York City Building Code, 1968 edition, which were required by the Port Authority to be followed in the design of World Trade Center (WTC) 1 and WTC 2, are compared in this report with the structural provisions of the 2001 edition, the edition currently in effect. Also compared are the structural provisions of three other contemporaneous codes: the New York State Building Code, 1964 edition; the Municipal Code of Chicago, 1967 edition (Chicago was chosen as a major U.S. city with tall buildings, outside of the northeastern states); and the Building Officials and Code Administrator (BOCA) Basic Building Code (BBC), 1965 edition (chosen as the model building code typically adopted as the basis of local codes in the northeastern states).

With respect to structural design provisions, the major changes from the 1968 to the 2001 edition of the New York City Building Code are the inclusion of seismic design requirements and updating of standards. Of the codes contemporaneous with the 1968 New York City Building Code, only the BOCA-BBC had seismic design requirements, which were adopted from the 1962 edition of the Uniform Building Code (UBC). Taller buildings have longer periods of vibration, which means lower seismic design forces. Also, since New York City is in an area of moderate seismicity (UBC Zone 2A), additional seismic detailing requirements are minimal to nonexistent.

The alternate live load reduction provisions for columns, walls, and piers of the 1968 and 2001 New York City Building Codes are the same as in the Chicago Municipal Code; the New York State Building Code has more liberal live load reduction provisions for upper portions of buildings (see Fig. 4–1 of this report). The New York City Building Codes also have live load reduction provisions based on contributory floor area and live-to-dead load ratio. For live-to-dead load ratios of 0.625 or less, the New York City code provisions may yield higher live load reduction for columns, walls, and piers than allowed by the other codes. For beams and girders, the live load reduction provisions of the New York City Building Codes are comparable to those of the New York State Building Code and the BOCA-BBC. The Chicago Municipal Code has more conservative requirements (see Table 4–2 of this report). The maximum live load reduction allowed for beams and girders in the Chicago Municipal Code is 15 percent, compared with 40 percent in the other codes.

Minimum wind loads on vertical surfaces required by the various building codes are compared in Fig. 4–2. The largest shear force at the base of a building is obtained from the BOCA-BBC when the height of the building is taken equal to 1,368 ft (i.e., the height of WTC 1). Similarly, the largest overturning moment at the base of a building the height of the WTC towers is also obtained from the BOCA-BBC. Thus, the New York City Building Codes do not have the most stringent wind load provisions. Base shear forces and overturning moments from the codes reviewed for a building the height of WTC towers are compared in Table 4–6 of this report.

The primary materials design standards referenced by the 1968 New York City Building Code, the Chicago Municipal Code and the BOCA-BBC are the 1963 edition of ACI 318, *Building Code Requirements for Reinforced Concrete*, and AISC 1963, *Specifications for the Design, Fabrication and*

Erection of Structural Steel for Buildings. The New York State Building Code, being a performance code, does not adopt any specific standards by reference. The 2001 New York City Building Code adopts the 1989 edition of ACI 318, AISC 1989, *Specifications for Structural Steel Buildings – ASD and Plastic Design*, and AISC-LRFD 1993, *Load and Resistance Factor Design Specifications for Structural Steel Buildings*.

The New York City Building Codes have extensive and quite rigorous foundation design and construction requirements. The foundation related provisions of the other codes are less extensive and typically less rigorous.

New York City Building Codes prescribe testing and inspection requirements for all materials, assemblies, forms and methods of construction. The other three codes require that materials and methods of construction meet the criteria of generally accepted standards. With respect to foundations, only the New York City Building Codes have specific requirements for foundation inspection.

Chapter 9
REFERENCES

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Table 7–1. Definitions.

NYC Building Code (1968)		NYC Building Code (2001)		NY State Building Construction Code (1964)	
Article 2 Definitions				C108 Abbreviations and Definitions	
Sub-Article 200.0 General				C108-1 General	
200.1	Application of terms	27-229	Same		
200.2	Definitions in reference standards	27-230	Same		
200.3	Tense, gender, and number	27-231	Same		
				C108-2	Abbreviations
Sub-Article 201.0 Definitions		27-232		C108-3 Definitions	
Accessory building		Accessory Building		Accessory structure	
Accessory use		Accessory use		Accessory use	
		Accessible			
		Accessible route			
Access stair					
		Adaptable dwelling units			
Addition		Addition		Addition	
Adjoining grade elevation		Adjoining grade elevation			
				Alley	
		Allowable soil pressure			
		Allowable stress			
Alteration		Alteration		Alteration	
Apartment house		Apartment house			
		Approved		Approved	

Table 7–1. Definitions (continued).

Municipal Code of Chicago (1967)	BOCA Building Code - Basic Code (1965)	Comments
	Construction equipment	
	Construction operation	
Controlled materials	Controlled materials	
	Corridor	
Court, inner	Court	
	Curb level	
	Dwellings	
Dwelling unit	Dwelling unit	
Building, existing	Existing building	
Exit	Exitways	
	Exterior masonry wall construction	
	Concrete masonry unit	
Floor area		
	Formed steel	
	Foundation	
Foyer	Foyer	
	Frame construction	

Table 7–1. Definitions (continued).

NYC Building Code (1968)	NYC Building Code (2001)	NY State Building Construction Code (1964)
		Generally accepted standard
Grade	Grade	Grade, finished
Grade beam	Grade beam	
Grandstand	Grandstand	
Habitable room	Habitable room	Habitable space
		Hallway
		Hanger
Height (buildings)	Height (buildings)	Height, building
	High rise	
Hoistway	Hoistway	Hoistway
Horizontal exit	Horizontal exit	Horizontal exit
Impact load	Impact load	
Inner court	Inner court	
		Interior finish
Interior stair	Interior stair	
		Interior trim
		Kitchen
		Kitchenette
Lagging	Lagging	
Lamella	Lamella	
		Legal open space
Live load	Live load	Load, live
		Load, design
		Load, imposed
		Load, racking
Load bearing	Load bearing	
Loading ramp	Loading ramp	
		Lobby
Lot line	Lot line	Lot line
	Low rise	
		Luminous ceiling
	Mall	
		Masonry
Mezzanine	Mezzanine	Mezzanine
Minor alterations	Minor alterations	

Table 7–1. Definitions (continued).

Municipal Code of Chicago (1967)	BOCA Building Code - Basic Code (1965)	Comments
Garage	Garage	
	Grade	
	Grade hallway	
	Habbitable room	
	Hallway, grade; hallway, public	
	Airplane hanger	
Height	Height, building	
	Hoistway enclosure	
	Light gauge steel construction	
	Limit control	
	Load	
	Lobby	
	Lot line	
	Masonry	
Mezzanine	Mezzanine	

Table 7–1. Definitions (continued).

NYC Building Code (1968)	NYC Building Code (2001)	NY State Building Construction Code (1964)
		Mixed occupancy
		Municipality
Multiple dwelling	Multiple dwelling	
Nonbearing	Nonbearing	
Nonconcurrent loads	Nonconcurrent loads	
Nonloadbearing	Nonloadbearing	
		Nonhabitable space
		Nursing home
Occupancy	Occupancy	Occupancy
Occupancy group	Occupancy group	Occupancy classification
Occupant load	Occupant load	
Occupiable room	Occupiable room	
		Occupied
		Occupied space
		Old-age home
Open parking lot	Open parking lot	
Open parking structure	Open parking structure	Open parking structure
Open shaft	Open shaft	
Ordinary repairs	Ordinary repairs	
Outer court	Outer court	Court, outer
		Court, outer, width
		Owner
Parapet	Parapet	Wall, parapet
		Parking lift, automobile
Parking tier	Parking tier	
Partition	Partition	
		Passage way
Penthouse	Penthouse	
Pile	Pile	
Pile car	Pile car	
Place of assembly	Place of assembly	
Platform frame	Platform frame	

Table 7–1. Definitions (continued).

Municipal Code of Chicago (1967)	BOCA Building Code - Basic Code (1965)	Comments
	Minimum habitable room height	
	Minimum habitable room size	
	Mortar	
	Municipality	
Occupancy		
	Occupancy load	
	Occupiable room	
	Occupied	
Ordinary construction	Ordinary materials	
	Oriel window	
Court, outer		
	Owner	
	Panel	
	Panel wall	
Partition		
Partition, bearing		
	Passageway	
Penthouse	Penthouse	
	Place of assembly	

Table 7–1. Definitions (continued).

NYC Building Code (1968)	NYC Building Code (2001)	NY State Building Construction Code (1964)
Pole footing	Pole footing	
Ponding	Ponding	
		Premises
Private garage	Private garage	
		Projection, street
		Property line
Public garage	Public garage	
Public space	Public space	Public space
Rebound	Rebound	
		Repair
Required	Required	Required
		Residual deflection
Retaining wall	Retaining wall	
Roof	Roof	
Roof covering	Roof covering	Roof covering
Roof structure	Roof structure	
Safe area	Safe area	
School	School	
Self-relieving construction	Self-relieving construction	
Service equipment	Service equipment	
Shaft	Shaft	Shaft
Shall	Shall	Shall
Shell	Shell	
Spandrel wall	Spandrel wall	Wall, spandrel
Spray booth	Spray booth	
Stack	Stack	
		Stage
		Stairway
		Store

Table 7–1. Definitions (continued).

Municipal Code of Chicago (1967)	BOCA Building Code - Basic Code (1965)	Comments
	Prefabricated	
	Prefabricated building	
	Prefabricated sub-assembly	
	Prefabricated unit	
	Preservative treated wood	
	Primary member	
	Professional engineer or architect	
	Public space	
	Reinforced concrete	
	Repair	
	Required	
	Roof	
	Roof covering	
	Roof structure	
	Rubble masonry	
	Secondary member	
	Shaft	
	Shall	
	Solid masonry	
	Stage	
	Stairway	

Table 7–1. Definitions (continued).

NYC Building Code (1968)	NYC Building Code (2001)	NY State Building Construction Code (1964)
Story		
Street floor		
		Structural failure
Structure	Structure	
Sump pit	Sump pit	
Transfer column	Transfer column	
Uniformly distributed load	Uniformly distributed load	
Use (used)	Use (used)	
		Wall, curtain
		Wall, panel
		Wall, party
		Watchman's system
Yard	Yard	Yard
		Yield strength
Zone	Zone	
Zoning resolution	Zoning resolution	

Table 7–1. Definitions (continued).

Municipal Code of Chicago (1967)	BOCA Building Code - Basic Code (1965)	Comments
	Story	
	Street	
	Street lot line	
	Structure	
	Structural clay tile	
	Tile	
	Use group	
	Apron wall	
Wall, bearing	Bearing wall	
	Curtain wall	
	Panel wall	
	Party wall	
	Division wall	
Wall, non-bearing	Non-bearing wall	
Wall, parapet	Parapet wall	
Wall, retaining	Retaining wall	
	Skeleton or panel wall	
	Spandrel wall	
	Yard	
	Zoning	

Table 7–2. Loads

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Article 9 Loads			*Subchapter 9 Loads*		*C304 Design Loads*	
Sub-Article 900.0 General			*Article 1 General*		*C304-1 General Requirements*	
900.1	Scope	Buildings and parts thereof, shall be capable of resisting all loads actually imposed thereon without exceeding the allowable stresses prescribed in Articles 10 (Structural Work) and 11 (Foundation). In no case shall the assumed loads be less than the minimum values established herein.	27-550	Same; In addition, within special flood hazard areas, and below the flood datum, as described in Article 10 of Subchapter 4 of this chapter, applicable load requirements of Reference Standard RS 4-5 [Annex A2][a] shall be applied.	C301-a C304-1	C301 a- Buildings and parts thereof shall be capable of sustaining safely their own weight and the loads to which they may be subject. C304-1 A building and all parts thereof shall be of sufficient strength to support the design loads and to resist the deformations caused by such loads to which they may by subjected, without exceeding the allowable stresses as described in C305-1. Such loads shall include the dead load and the following imposed loads where applicable: live, snow, wind, and soil pressure including surcharge, hydrostatic head, and impact loads.
900.2	Reference Standards	The provisions of Reference Standard RS-9 [Annex A1] shall be a part of this article.	27-551	Same		
900.3	Definitions	For definitions used in the interpretation of this article, see Article 2- Definitions.	27-552	Same	C108-3	Definitions

a. These are references to Annexes to this report that contain the items referenced in the codes.

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
Chapter 68 Minimum Design Loads			*Article 7 Structural and Foundation Loads and Stress*			
68-1 General			*700.0 Scope*			
		Buildings or other structures hereafter erected shall be designed and constructed to support safely the minimum design loads, including dead loads as required in this section, without exceeding the allowable stresses required in this code for the materials of construction in the structural members.			The provisions of this article shall control the structural design of all buildings and structures and their foundations hereafter erected to insure adequate strength of all parts thereof for the safe support of all superimposed live and special loads to which they may by subjected in addition to their own dead load, without exceeding the allowable stresses prescribed in the Basic Code or in accepted engineering practice.	
		See Chapter 48 (Definitions).			See Article 2. Definitions for the following terms are also given in Section 701.0: Controlled construction; Controlled materials; Foundation wall; Light gage steel construction; Load: (dead load; earthquake load; impact load; lateral soil load; live load; wind load); Ordinary materials; Primary member; Secondary member; Steel joist; Structural steel member.	Besides the definitions in Article 2, BOCA includes some additional definitions for terminologies used in Article 7.
			702.0	Design Safe Load	702.1 Structural analysis. The safe load shall be determined by accepted analysis or tests if not capable of analysis. 702.2 Check tests. When there is reasonable doubt as to the design capacity.	
			703.0	Test Safe Load	703.1 When required. When not capable of design by accepted engineering analysis, any system shall be subjected to tests prescribed in Article 8 or test standards in Appendixes D, E [Annex A5], or other tests accepted by building officials. 703.2 Test load. When approved by test, every structural assembly shall sustain without failure minimum superimposed loads equal to 2.5 times the required live load; and under the approved working load, the deflection shall not exceed the limits prescribed in Section 804.	

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 901.0 Dead Loads			***Article 2 Dead Loads***			
901.1	Construction Materials and Assembled Elements of Construction	Except as provided in Section 901.3, the dead load shall be the actual weight of the building materials or construction assemblies to be supported, computed from the unit weights given in Reference Standard RS 9-1 [Annex A1]. Where unit weights are not established in RS 9-1, the actual weights may be determined by analysis or from data in manufacturer's drawings or catalogs. Unit weights less than those given in RS 9-1 may be used only with approval of the commissioner.	27-553	Same		
901.2	Service Equipment	Provision shall be made for the weights of all building service equipment. The weights of such equipment (or the allowances therefore) shall be included in the dead load. The weight of equipment that is part of the occupancy of a given area shall be considered as live load. See also Sections C26-902.2 (b) (2) and C26-902.2 (d).	27-554	Same		
901.3	Partition Loads	Weights of all partitions shall be considered, using either actual weights or the equivalent uniform load given in (b) below. (a) Actual loads. - Where actual partition weights are used, the uniform design live load may be omitted from the strip of floor area under each partition. (b) Equivalent uniform load. - The equivalent uniform partition loads in Reference Standard RS 9-1 [Annex A1] may be used in lieu of actual partition weights except for bearing partitions or partitions in toilet room areas (other than in one- and two-family dwellings), at stairs and elevators, and similar areas where partitions are concentrated. In such cases, actual partition weights shall be used in design. Except as otherwise exempted, equivalent uniform loads shall be used in areas where partitions are not definitely located on the plans, or in areas where partitions are subject to rearrangement or relocation.	27-555	Same		

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			705.0 Design Dead Load			
			705.1	Construction Materials	In estimating dead load for the purposes of structural design, the actual weights of materials shall be used, but in no case less than the unit dead loads prescribed in Appendix J [Annex A5].	There are some differences in the dead load values prescribed in the NYC and BOCA codes, e.g.: 12" hollow concrete block: 85 psf (NYC) vs. 74 psf (BOCA); 6" hollow concrete block: 42 psf (BOCA), vs. not found in NYC. No corresponding provisions are given in NY State and Chicago codes.
			705.2	Service Equipment	The weight of all building service equipment shall be included in the dead load supported by the structural frame.	NYC Building Code is more specific than BOCA. The NY State and Chicago Building Codes do not have comparable provisions.
68-2.7	Partitions	In office buildings or similar structures in which subdividing partitions may be erected, dead load for such partition of not less than 20 psf shall be assumed	705.3	Partition Load	In office or other buildings, provisions shall be made to support the actual weight of the partitions where they occur or for an equivalent uniform load, which shall be not less than 20 psf of floor area.	NYC 1968 and 2001: Equiv. uniformly distributed partition loads are given, which are less than or equal to 20 psf (See RS 9-1). NY State: No relevant provisions are given. Chicago & BOCA: Not less than 20 psf.

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 902.0 Live Loads			*Article 3 Live Loads*		*C304-2 Live Loads*	
902.1	General	In addition to the applicable dead, wind, and other loads, the building shall be designed for uniform live loads, for concentrated live loads, or for concurrent combinations of uniform and concentrated live loads, whichever produce the greatest stress.	27-556	Same	C304-2.1	General a- Loads set forth in Table C304-2.2 do not include unusual concentrations, such as heavy machinery, equipment, water tanks and elevator machine loads. Where such loads occur, suitable provisions shall be made for their support. b- Where such unusual concentrations do not occur, structural members and floors shall be designed to support the uniformly distributed loads or the concentrated loads in Table C304-2.2 [Annex B3], whichever produce the greater stress.
902.2	Floor Live Loads	(a) Uniformly distributed live loads.- The minimum design values established in Reference Standard RS 9-2 [Annex A1] for various occupancies or uses shall be used subjected to the provisions of (d) below. Where the occupancy or use of a space does not conform to any of those listed, the design load shall be determined by the architect or engineer subject to approval by the commissioner. (b) Concentrated live loads.- (1) The bldg shall be able to support concentrated live load established in RS 9-2 [Annex A1], placed so as to produce maximum stress. (2) Floors that support any items of machinery, electrical or mechanical equipment, or other concentrated live load in excess of 1000 lbs. (including the weights of pads or bases) shall be designed to support such weight as a concentrated load or group of concentrated loads. (c) Where RS 9-2 [Annex A1] indicates that the concentrated live load is nonconcurrent with the uniform live load, it may be assumed that the total concentrated load is to be omitted when the uniform load is present and that the total uniform load is to be omitted when the concentrated load is present. (d) Conformance. - For purpose of determining that the magnitude of the actual live load conforms to or is less than the minimum design live load established in this section, the actual uniform live load shall be approximated by averaging the total load actually applied over a rectangular area of 150 sft having no side less than 8 ft.	27-557	Same	C304-2.2	**Uniformly distributed and concentrated live loads:** Shall be the greatest loads produced by the intended occupancy and use, but in no case less than the minimum LL in conformity with Table C304-2.2 [Annex B3]. Minimum loads for occupancies and uses not included in the table shall be in conformity with generally accepted standards. Where a concentrated load is not given, load shall be > 250 lbs on an area of 1in. in diameter. Load values for some specific concentrated load situations are given.

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			704.0	***Design Live Load***		
					704.1 Required live load: Shall be the greatest load produced by the intended use and occupancy, but in no case less than required in section 707. 704.2 Load not specified.- Building official shall determine the value for the loads not listed in Table 13 [Annex B5].	As in the case of dead load, the live load provisions are categorized in a similar, but not completely comparable way in the four codes (NYC 1968 and 2001 are the same). The values specified are similar.
68-2	Floor Loads	68-2.1 Uniformly distributed floor loads: The live loads assumed for purpose of design shall be the greatest combination of loads that it is estimated will be produced by the intended occupancies or uses; provided that the live loads to be considered as uniformly distributed shall be not less than the values established in Table 68-2.1 [annex B4], with reductions as permitted in 68-2.2. 68-2.3 Concentrate live load: Floors shall be designed to carry the specified uniformly distributed live load or the following minimum concentrated loads, whichever may produce the greater stress. The indicated concentrations shall be assumed to occupy an area of 2.5 sft and to be so placed as to produce maximum stresses in the affected members. Office floors: 2000 lbs. Garages for passenger automobiles: 2000 lbs. Garages for buses and trucks: not less than actual rear wheel load when fully loaded.	707.0 708.0	Unit Live Loads Concentrated Loads	707.1 Uniform live load.- The minimum uniformly distributed live load shall be as provided in Table 13 [Annex B5] and for all concentrated loads wherever they occur as provided in Section 708. 707.2 Heavy truck loads.- The floor loads for garages designed to house trucks or buses exceeding 20,000 lbs shall be determined by the actual load conditions; but in no case shall the assumed load be less than 150 % of the max wheel load. 708.0 Concentrated loads.- Floors of buildings in the use groups specified in Table 14 [Annex B5] shall be designed to support the uniformly distributed live loads in Section 707 or the following concentrated loads, whichever produces the greater stresses. Unless otherwise specified, the indicated concentration shall be assumed to occupy an area of 2.5 sft and shall be positioned to produce maximum stress condition. Exceptions are given for steel joist constructions.	Code requirements are similar.

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
902.3	Live Loads for Sidewalks, Driveways, and Railings	(a) Sidewalks and driveways. - All sidewalks and driveways or portions thereof that are structurally supported shall be designed for a live load of 100 psf uniformly distributed and in accordance with the provisions of Article 10. When subjected to intentionally or accidentally imposed wheel loads of vehicles, the sidewalks and driveways shall be designed for 600 psf uniformly distributed load or maximum vehicular wheel load that could be imposed thereon, whichever develops greater stress. (b) Railings and parapets. - Other than those for place of assembly, railings and parapets shall be designed to resist the simultaneous application of a lateral force of 40 plf and a vertical force of 50 plf to the top of the railing. In places of assembly, the lateral loads shall be increased to 50 plf and the vertical load to 100 plf. An exception is made for railings in one- and two-family dwellings, where a lateral force of 20 plf and a vertical force of 20 plf shall be considered. The total lateral and the total vertical force shall be at least 200 lbs each. Intermediate and bottom rails: Shall be designed for simultaneous application of 40 plf lateral and 50 plf vertical forces. For railings with solid panels: 20 psf. In parking area: 300 plf applied at least 21 in. above the roadway, but no less than 2500 lbs per vehicle.	27-558	(a) Same. (b) Same		
902.4	Columns in Parking Areas	Unless specially protected, columns in parking areas subject to impact of moving vehicles shall be designed to resist the lateral load due to impact and this load shall be considered a load of infrequent occurrence. For passenger vehicles, this lateral load shall be taken as a minimum of 2500 lbs. applied at least 21 in. above the roadway and acting simultaneously with other design loads.	27-559	Same		
902.5	Stage Areas using Scenery or Scenic Elements	Shall be designed for 30 plf of batten length. Locking rails shall be designed for a uniform uplift of 500 psf with a 1000 lbs concentration. Impact factor for batten shall be 75 % and for loft and head block beam shall be 25 %.	27-560	Same		

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
68-2.4	Special Loads	Driveways, sidewalks, spaces for storage of loaded or unloaded trucks and buses, and tanks and tracks shall be designed for the actual weight.	702.3	Railings	Railings around stairwells and other floor openings shall be designed to resist a lateral force applied horizontally at the top of the railings of 40 plf, and railings at front of balconies of theatres and similar locations a lateral force of 50 plf. In addition to the lateral load, railings and guards of outdoor assemblies shall sustain a vertical load of 100 plf.	The NYC Building Codes give the most comprehensive provisions. Chicago Code has provisions similar to those in the NYC code. BOCA only has provisions for railings, not covering driveways and sidewalks. NY State Code does not have provisions on this topic.
68-6	Other Loads	Other loads: Railings- Shall be designed to resist a horizontal thrust of 50 plf applied at the top of the railing. Scuttles and Skylights- Shall be designed to support a concentrated load of 200 lbs occupying an area of 2.5 sft and so placed as to produce maximum stresses in the affected members.				

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
902.6	Roof Loads	Roofs and marquees shall be designed for wind, live, and other loads as prescribed in (a) through (d) below. It may be assumed that maximum wind load occurs with zero live load and that maximum live load occurs with zero wind load. For dwellings an exception is made for awnings, canopies, and patio covers, which may be designed for a live load of 20 psf of horizontal projection. (a) Live load. - Minimum design live loads: (1) For roofs with slopes up to and including 20° from the horizontal, the minimum design live load shall be 30 psf of horizontal projection. (2) For roofs with slope >20°, shall be 30 psf of horizontal projection, reduced by 1.0 psf for each degree in excess of 20°. (3) For valleys, live load shall be increased to provide for accumulation of snow. (4) Other shapes, established by architect or engineer. (b) Wind load. - The provisions of Section C26-904.0 shall apply. (c) Concentrated loads.- The provisions of Section C26-902.2(b) shall apply. (d) Special loads.- (1) For roofs used as promenades, assembly areas, or roof gardens, design live load shall be as indicated in RS 9-2 [Annex A1] . (2) When roofs are intended for the ponding of water, the roof shall be designed for maximum possible depth of water. (3) Girders and roof trusses that are regularly utilized for repair of vehicles shall resist, in addition to LL+W, a concentrated live load of 2000 lbs applied on lower chord. (4) When roofs are landscaped, the LL shall be 30 psf, the landscape materials shall be considered as DL computed based on saturated earth, and the area adjacent to the landscape shall be considered as assembly areas unless otherwise specified. (5) When equipment is placed on roof, the design shall provide support.	27-561	Same	C304 - 10 (c)	On roofs not used as promenades, the minimum imposed load shall be 20 psf perpendicular to the roof surface, where snow plus wind loads total less than 20 psf.

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
68-3	Roof Loads	68-3.1 Roofs having a pitch of less than 30^o shall be designed for a live load normal to the roof surface (including snow load) of 25 psf of roof area. Such live load may be neglected in the design of roofs having a pitch of 30^o or more, which shall be designed for wind pressures as required in 68-4.3. 68-3.2 Roofs used for terraces, promenades or similar uses shall be designed for a minimum live load of 60 psf.	711.0	Roof Loads	The structural supports of roofs shall be designed to resist wind and where applicable snow and EQ loads in addition to the dead load and the live load. 711.1 Minimum roof load.- Flat and pitched roof shall be designed for a live load of not less than 20 psf of horizontal projection. In areas subject to snow loads, the roof shall be designed for 30 psf in the absence of specific information as described in 712.2. When used for incidental promenade purposes, roof shall be designed for a minimum of 60 psf; and 100 psf when designed for roof-garden or assembly use. 711.2 Curved roofs.- Roofs with a radius not less than 1/2 span nor more than 3/4 span shall be designed to resist 10 psf of horizontally projected area on buildings 40 ft or less in height; and 15 psf for buildings higher than 40 ft. 711.3 Overhanging eaves.- Minimum 60 psf.	NYC Code: 30 psf (max), reduce 1 psf /1^o for pitch > 20^o. Chicago: 25 psf; 0 for pitch > or = 30^o. BOCA: > or = 20 psf of horizontal projection. In areas subjected to snow loads, 30 psf. NYC Building Codes gives the most comprehensive provisions for roofs subjected to special loads, while NY State Code does not have such provisions.

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
902.7	Moving Loads	(a) General. - C26-902.2 (a) and C26-902.2 (b). (b) Passenger vehicles.- RS 9-2 [Annex A1]. (c) Truck load.- Shall conform to RS 9-3 [Annex A1]. Impact shall be taken as 10 % of vertical load. (d) Railroad equipment.- Shall conform to RS 9-4 [Annex A1]. (e) Crane runways and supports.- (1) Vertical loads: increase 25 % of the lifted loads or 15 % of the wheel loads for impact, whichever is larger. (2) Horizontal load: a- lateral load; b- longitudinal load. (f) Monorail beams and supports (g) Loads on supports for elevators, dumbwaiters, and escalators. (h) Loads on machinery supports (i) Assembly structures (j) Heliports and helistops	27-562	Same		
902.8	Partial Loading Conditions	(a) Uniformly distributed loads. - In continuous framing and cantilever construction, the design shall consider live load on all spans and arrangements of partial live load that will produce maximum stresses in the supporting members. The simplifications given in (1) through (3) below are permissible. (1) Floor and roof framing. - a. For vertical live load applied to the level under consideration, the far ends of the columns above and below that level may be assumed as fixed. b. Combinations of live load may be limited to the following: 1. Live load placed on two adjacent spans. 2. Live load placed on alternate spans. The effects of live load on spans more than two spans away from the span under consideration may be neglected. (2) Arches and gabled frames (3) Columns (b) Moving concentrated loads. - To be arranged to produce maximum stress.	27-563	Same		
902.9	Floor Load to be Posted	(a) Posting required: Shall conform to Section 27-225. (b) Data required: Provisions are given for required data to be shown for uniformly distributed and concentrated loads.	27-564	Same		

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only the NYC Building Codes have provisions.
68-2.6	Partial Loads	When the construction is such that the structural elements thereof act together as an elastic frame due to their continuity and the rigidity of the connections, the effect of such partial loading as will produce maximum stress in any member shall be provided for in the design.				The NYC Building Codes give simplified methods, and the most detailed provisions; Chicago is the only other code that gives provisions, which are general in nature.
68-2.8	Posting of Floor Loads	Provisions are given for buildings used for mercantile, industrial or storage purposes. Postings are not required for buildings used for production and distribution of electricity, gas and steam.				Only NYC Building Codes and Chicago Code have provisions concerning posting of floor loads.

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 903.0		*Live Load Reduction*	*Article 4*	*Live Load Reduction*		
903.1	Roof Loads	No reduction shall be permitted.	27-565	Same		Roof load reduction allowed. See C304-2.1.
903.2	Floor Live Loads	The uniform live load to be used for design shall be the basic values in RS 9-2 [Annex A1] multiplied by the percentages given in (a) through (d) below. (a) Except as provided in subdivisions (b),(c),and (d), the percentage in Table 9-1 [Annex B1] shall apply. Contributory areas shall be computed in accordance with C26-903.3. (b) No live load reduction shall be permitted for the following: members and connections (other than columns, piers, and walls) supporting floor areas used for storage (including warehouses, library stacks, and record storage); areas used for parking of vehicles; and areas used as place of assembly, for manufacturing, and for retail or wholesale sales. For columns, piers, and walls supporting such floor areas, the maximum live load reduction shall be 20 %. (c) No live load reduction shall be permitted for calculating shear stresses at the heads of column in flat slab or flat plate construction. (d) In lieu of the percentages given in Table 9-1 [Annex B1], the live load reductions for columns, piers and walls may be taken as 15 % of the live load on the top floor, increased successively at the rate of 5 % on each successive lower floor, with a maximum reduction of 50 %; and for girders supporting 200 sft or more of floor area, the live load reduction may be taken as 15 %. The limitations of (b), (c), and (d) above shall apply.	27-566	Same	C304-2.1	c- Uniformly distributed live loads on beams and girders supporting other than storage areas and motor vehicle parking areas, when such member supports 150 sft or more roof area or floor area per floor, may be reduced as follows: when the DL is not more than 25 psf, the reduction shall be not more than 20 %. When the DL>25 psf, and LL< or = 100 psf, the reduction shall not exceed the least of the following 3 criteria: 60 %; 0.08 %/sft; or 100 %*(DL+LL)/4.33(LL) (psf). d- For columns, girders supporting columns, bearing walls, and foundation walls supporting 150 sft or more roof area or floor area per floor other than storage areas and parking area, the uniformly distributed LL shall not be less than the following percentages of the total LL on the following levels: 80 % on the roof, the floor immediately below the roof, the 2nd floor below the roof; 75 % on the 3rd floor below the roof; 70 % on the 4th floor below; 65 % on the 5th floor below; 60 % on the 6th floor below; 55 % on the 7th floor below; 50 % on the 8th and subsequent floors below.

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)	BOCA Building Code - Basic Code (1965)	Comments

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 904.0 Wind Loads			*Article 5 Wind Loads and Earthquake Loads*			
		The structural frame and exterior components of all buildings, signs, tanks, and other exposed constructions shall be designed to resist the pressures due to wind as prescribed in RS 9-5 [Annex A1]. Wind shall be assumed to act from any direction. For continuous framing, the effects of partial loading conditions shall be considered. RS 9-5: 1. Design wind pressures on structural frames. Minimum design pressure due to wind acting on vertical surfaces shall be in accordance with Table RS 9-5.1 [Annex B1], and minimum design pressure acting normal to horizontal or inclined surfaces shall be in accordance with Table RS 9-5.2 [Annex B1]. The occurrence of the pressure on vertical, horizontal, and inclined surfaces of the bldg shall be considered as simultaneous. 2. Wall element. For design of wall elements other than glass panels, the wind pressure acting normal to wall surfaces shall be 30 psf or a 20 psf suction, for all height zones up to 500 ft. These values shall be deemed to include allowance for gust factor. For height zones over 500 ft, the pressure shall be specifically investigated, but not less than the value in Table RS 9-5.1. 3. Roof elements. Wind pressure acting on roof elements supporting small contributory area of wind presentment shall be 1.5 times the value in Table RS 9-5.2. 4. Other bldg elements. Minimum wind pressure to be used in the design of other bldg elements (signs, tanks, chimneys, etc) shall be the values in Table RS 9-5.1 multiplied by the shape factors given in Table RS 9-5.3 [Annex B1]. 5. Eaves and cornices. Overhanging elements of the bldg shall be designed for upward pressures of twice the values in Table RS 9-5.1. 6. Wind load by model test. In lieu of the design wind pressure established in sections 1 &2, design wind pressure may be approximated from suitably conducted model tests. The tests shall be predicted on a basic wind speed of 80 mph at 30 ft level, and shall simulate and include all factors including pressure and suction effects, shape factors, functional effects, gusts, and internal pressures and suctions.	27-569	Article 5 Wind Loads and Earthquake Loads (a) Wind load: same	C304-4 Wind Loads	Minimum wind loads shall be in conformity with Tables C304-4a [Annex B3] and C304-4b [Annex B3], and shall be applied normal to the surface. These loads are based on a design wind speed of 75 mph at a height of 30 ft above grade level. Minimum wind load on signs shall be in conformity with generally accepted standards.

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
68-4	Wind Load	68-4.1 Minimum design pressure. Buildings shall be designed and constructed to withstand the horizontal pressures in Table 68-4.1 [Annex B4], allowing for wind from any direction. The height is to be measured above the average level of the ground adjacent to the building. 68-4.2 Exterior wall. Shall be designed and constructed to withstand the pressure required in 68-4.1, acting either inward or outward. 68-4.3 Roofs. Shall be designed for outward pressure equal to 75 % of those in Table 68-4.1. Roofs with slopes greater than 30^{o} shall be designed for inward pressure equal to those in Table 68-4.1. Overhanging eaves and cornices shall be designed and constructed for upward pressure equal to twice those in Table 68-4.1. 68-4.4 Chimneys, tanks and towers. Shall be designed and constructed to withstand the pressures in Table 68-4.1 applied to the projected vertical area multiplied by the following factors: square or rectangular shape: 1.0; hexagonal, octagonal, and round or elliptical shape: 0.8. 68-4.5 Provisions for signs are given. 68-4.6 Provisions for flagpoles are given. 68-4.7 For combined stresses due to dead, live, and wind loads, the allowable stresses in materials may be increased by 1/3, provided that the section thus determined is at least as strong as that required for dead and live load alone. Snow load shall be considered a live load. 68-4.8 Provisions for overturning and sliding are given. 68-4.9 Adequate anchorage of the roof to walls and columns, and of walls and columns to the foundations to resist overturning, uplifting, and sliding shall be provided. 68-4.10 Provisions shall be made for wind stress during erection of a building or other structures.	713.0	Wind Load	The structural frame of all buildings, signs, tanks and other exposed structures or parts thereof shall be designed to resist the horizontal pressures due to wind in any direction, both inwardly and outwardly, allowing for suction on the leeward side, as provided in 714 to 718. 713.1 Torsional resistance- The structural frame shall be designed to resist the torsional moment due to eccentricity of the resultant load.	

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
					C304-5 Overturning Force and Moment Due to Wind	a- The overturning force shall be the wind load. The wind load shall be the load in Table C304-4a [Annex B3], and shall be applied only to the windward vertical surface above the horizontal plane under consideration, and to the rise of the roof. The resisting force shall be the dead load of the structure above the horizontal plane under consideration, plus the strength of material and fastenings establishing continuity with the structure below. b- The moments of stability and overturning shall be computed about the leeward edge of the horizontal plane under consideration. c- The moment of stability of the structure above the horizontal plane under consideration shall be not less than 1.5 times the overturning moment due to wind.
					C304-6 Sliding Force Due to Wind	The sliding force due to wind load, equal to the overturning force, determined in conformity with C304-5, shall be resisted by the dead load of the structure above the horizontal plane under consideration, by anchors, and where applicable, by soil friction, providing a total resisting force equal to not less than 1.5 times the sliding force. Anchors used to resist overturning may also provide resistance to sliding.

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			714.0	Wind on Vertical Surfaces	714.1 Primary framing members.- Height not more than 50 ft: 15 psf. Height not more than 100 ft: 20 psf for the surface above the 50 ft level. Height more than 100 ft: increase by 0.025 psf for each foot in excess of 100 ft above the 100 ft level. 714.2 Distribution of wind force: The wind pressure shall be distributed between opposite walls, 2/3 as normal pressure on the windward side and 1/3 as normal outward suction on the leeward side. 714.3 Secondary wall framing and wall panels.- In buildings provided with 1/3 or more wall openings, internal wind forces of 10 psf shall be assumed to occur simultaneously with the above external forces both in pressure and suction. 714.3.1 External pressures.- External pressure to be considered in the design of secondary wall framing and wall panels and sheathing and their connections shall be 1.5 times those determined in accordance with 714.2. 714.3.2 Internal pressures.- If having 1/3 or more wall surface open, 10 psf internal pressure or 5 psf internal suction, whichever is critical, shall be considered in the design of secondary members. If having less than 1/3 wall surface open, half of the foregoing values apply. 714.4 Design wind load for glass.- Appendix K-12 [Annex A5].	Minimum design wind loads required in various codes on a vertical surface up to a height of 1200 ft are illustrated in Figure 2. NYC Building Code, Chicago Code, and BOCA also provide provisions for secondary elements such as wall elements, roof elements, and other building elements such as chimney, etc. NY State Code, Chicago Code, and BOCA include provisions for overturning, sliding and uplifting forces caused by wind.
			715.0	Wind Load on Roofs	Primary roof framing and truss: 715.1 and 715.2. Secondary roof framing etc.: 1.5 times those determined in 715.1 and 715.2 for external pressure; provisions in 714.3 for internal pressure. 715.1 Pitched roofs. Provisions for the external wind force on primary roof members are given in Exhibit B5-1[Annex B5]. 715.2 Curved roofs. Provisions for curved roofs are given. 715.3 Test determination. The effect of shape of irregular or unusual roofs may be determined by wind tunnel or equivalent tests. 715.4 Anchorage. Roof framing shall be anchored to resist wind uplift and sliding in excess of 75 % of the dead load resistance.	

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
					C304-7 Uplift Force	Uplift force due to wind or hydrostatic head shall be resisted by dead load, acting directly or through anchors or fastening, of not less than 1.25 times the uplift force.
				Article 5 Wind Loads and Earthquake Loads (b) Earthquake loads.- Every building, structure and portion thereof shall, at a minimum, be designed and constructed to resist the effects of seismic ground motions as prescribed in RS 9-6 [Annex A2], which adopted UBC Section 2312 from the 1988 UBC, including the 1990 Accumulative Supplement.		

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			718.0	Overturning and Sliding	718.0 The overturning moment due to wind load shall not exceed 75 % of the moment resulting from the dead load from the building, unless the building is anchored to resist the excess overturning moment and the excess horizontal shear over sliding friction.	
			716.0	Wind Loads on Signs, Tanks and Radio Towers and Chimneys	716.1 Ground signs and towers.- 15 psf for structures up to 50 ft in height, and 20 psf for structures over 50 ft in height. 716.2 Roof Structures.- Roof signs, tank towers, stacks, chimney, etc.: 30 psf. 716.3 Shielding effect.- No shielding effect of one element by another shall be considered when the distance between them exceeds 4 times of the projected smallest dimension of the windward element. 716.4 Effect of shape: Wind pressure on circular structures: 2/3 of the projected area. For hexagonal or octagonal structures: 7/8 of the projected area. 716.5 Radio towers: Shall conform to the provisions in Section 427 and 428 unless smaller or greater loads are approved by test.	
			717.0	Unusual Wind Exposures	717.0 The design load for buildings subject to higher wind loads than herein specified shall be determined by the prevailing conditions.	
			719.0	Earthquake Load	In regions where loss of life or damage of buildings resulting from EQs occur, buildings and structures shall be designed to withstand lateral forces as in Appendix K-11 [Annex A5], except as exempted in section 719.1. 719.1 Exemptions.- In zone "0", and where no loss of life or damage to property were recorded, regardless of zone, or when the building complies with any one or more of the following conditions, no EQ loading shall be required: (a) is a 1- or 2- family dwelling; (b) is a minor accessory building; (c) is not >3 stories or 35 ft in height; (d) is of skeleton frame construction with wind and sway bracing as required by approved engineering practice for the type of frame used, and the least dimension of the building is not less than 35 % of the height.	NYC 2001 code added EQ provisions; BOCA includes EQ provisions.

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 905.0 Other Loads			***Article 6 Other Loads***			
905.1	Earth Pressure and Foundation Loads	The provisions of Sub-article 1102.0 shall apply. 1102.3- Foundation wall and retaining wall shall be designed to resist, in addition to the vertical loads acting thereon, the incident lateral earth pressures and surcharges, plus hydrostatic pressures corresponding to the max probable ground water level.	27-570	Same	C304-8	Soil pressure and hydrostatic head loads 1. General. Retaining walls and parts of the building below ground shall be designed to withstand the following load, if applicable, in addition to other loads: lateral loads due to adjacent soil; from hydrostatic head; from surcharge of fixed or moving loads; or uplift from hydrostatic head. 2. Freestanding retaining walls. The moment of stability and overturning shall be computed about the bottom base edge on the low earth side. The moment of stability shall not be less than 1.5 times the overturning moment. The resistance force due to soil friction shall not be less than 1.5 times the sliding force.
905.2	Bins and Bunkers	Loads on component parts of bins and bunkers may be reduced for friction on sidewalls, provided that sidewalls and supports are proportioned for the increased vertical loads.	27-571	Same		
905.3	Pre-stressing Forces	Prestressing forces shall be considered in the design of prestressed concrete structures, cable structures, guyed structures, and multiple intersecting truss webs utilizing tension members.	27-572	Same		
					C304-9	Horizontal impact loads a- Nonbearing partitions shall be designed to resist w/o displacement at top or bottom a minimum linear load of 10 plf applied at mid height. b- Parapet walls and railings shall be designed to resist minimum 50 plf at top. c- Provisions for parapet walls or barriers at parking deck where vehicles are parked by a driver are given. d- Provisions for barriers at parking deck, where vehicles are parked mechanically, are given. e- Provisions for grandstands are given. f - Provisions for craneways are given.

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
68-5	Soil and Hydrostatic Pressure	Provisions for basement walls and basement floors are given.	871.5	Lateral Stability	Foundation walls which serve as retaining walls shall be able to resist lateral soil and hydrostatic pressure when subjected thereto.	The provisions in the various codes are similar.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
68-2.5	Impact Loads	The live load assumed in this chapter may be assumed to include a sufficient allowance to cover the effects of ordinary impact. For unusual impacts, suitable increase shall be made in the assumed live load.	709.0	Impact Loads	The unit live loads specified in Section 707 shall be assumed to include adequate allowance for ordinary impact conditions. Provisions shall be made for special uses and loads which involve vibration and impact forces. Provisions for elevators, heavy machinery, craneways, and outdoor assembly structures are given.	NYC Building Codes do not have provisions for impact loads. In Chicago and BOCA codes, ordinary impact loads are assumed covered in the prescribed live loads. NY State Code gives provisions for horizontal impact loads.

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
905.4	Construction Loads	Provisions of Article 19- Safety of Public and Property During Construction Operations- shall apply.	27-573	Same	C304-12	Loads imposed during construction: All flooring, structural members, walls, bracing, scaffolding, sidewalk sheds or bridges, hoists and temporary supports of any kind incidental to the erection, alteration or repair of any bldg shall be of such strength as to suffer no structural damage when subject to the temporary loads and wind load imposed during construction.
					C304-11	Elevator machine loads: Shall conform to generally accepted standards.
905.5	Fluid Pressures	The design of building components shall consider pressures, both positive and negative, of confined fluids and gases.	27-574	Same		
905.6	Ice	The weight of 1/2 in. radial thickness of ice on all surfaces shall be considered as part of the live load in the design of open framed or guyed towers.	27-575	Same		
905.7	Thermal Forces	Enclosed buildings > 250 ft in plan shall be designed for 40 ^{o}F temperature change. Exterior exposed structures regardless of plan dimensions shall be designed for 40 ^{o}F temperature change for concrete and masonry construction and 60 ^{o}F for metal construction. Provisions for piping are also given.	27-576	Same		
905.8	Shrinkage	RC components shall be designed for shrinkage of 0.0002 (standard weight concrete) or 0.0003 (light weight concrete) times the length between contraction joints.	27-577	Same		
Sub-Article 906.0 Distribution of Loads			***Article 7 Distribution of Loads***			
906.1	Distribution of Vertical Loads	Distribution of vertical loads to supporting members shall be determined on the basis of a recognized method of elastic analysis or system of coefficients of approximation. Elastic or inelastic displacements of supports shall be considered and, for the distribution of dead loads, the modulus of elasticity of concrete or composite sections shall be reduced to consider plastic flow. Secondary effects, due to warping of the floors shall be considered.	27-578	Same		

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			710.4	Construction Loads and Erection Stress	Provisions shall be made for temporary construction and wind loads which may occur during the erection of the building, to prevent overstressing.	
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.

Table 7–2. Loads (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
906.2	Distribution of Horizontal Loads	The following provisions shall apply to superstructure framing only, and shall not apply to structures wherein horizontal loads are transmitted to the foundation by stay-cables, arches, non-rectangular frames, or by frames, trusses, or shear walls not oriented in the vertical planes. (a) Distribution of horizontal loads to vertical frames, trusses and shear walls. Load should be assumed to be distributed by floor and roof systems acting as horizontal diaphragms. Proportion of total load to be resisted by any given vertical member shall be determined based on relative rigidity, considering the eccentricity of the applied load with respect to the center of resistance. For vertical trusses, web deformations shall be considered in evaluating the rigidity. (b) Distribution of horizontal loads within rigid frames of tier buildings.- (1) Assumptions: Load distribution can be determined based on elastic analysis or, subject to limitations in (2) below, the following simplifying assumptions: Points of deflection in beams and columns are at their midspan and midheight, respectively. The story shear is distributed to the columns in proportion to their stiffness. The change of length of columns due to axial effects of the horizontal loads may be neglected. Vertical column loads due to horizontal forces are taken by the exterior columns only, or are resisted by the columns in proportion to the column distances from the neutral axis of the bent. (2) Limitations: For buildings over 300 ft in height, change in length of the columns due to the horizontal load shall be evaluated. Simplifying assumptions shall be subject to the approval by the commissioner for the following circumstances: For buildings over 300 ft or with a height-width ratio greater than 5; At two-story entrances or intermediate floors; Where offsets in the building occur; Where transfer columns occur; In any similar circumstances of irregularity or discontinuities in the framing. (c) Distribution of load in self-relieving construction.- Assume connections are fully rigid in resisting moments due to lateral load, and that any larger moment due to gravity or a combination of gravity and lateral load will be relieved by deformation of the connection material. (d) Structural walls and partitions.- If specifically designed to resist the applied forces, they may be considered as contributing to the resistance or rigidity of the structure with regard to horizontal load.	27-579	Same		

Table 7–2. Loads (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only NYC Building Codes have provisions.

Table 7–3. Structural Work

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Article 10 Structural Work			*Subchapter 10 Structural Work*			
Sub-Article 1000.0 Scope and General Requirements			*Article 1 Scope and General Requirements*			
1000.1	Scope	The provisions of this article, supplemented by the additional requirements of Article 11, shall establish minimum requirements for materials, design, and construction to be used for all structural elements in buildings.	27-580	Same; In addition, within special flood hazard areas and below the regulatory flood datum, as described in Article 10 of Subchapter 4 of this chapter, materials, designs and construction required for structural elements by Reference Standard RS 4-5 shall be applicable.	C301	General Requirements c- Wherever structural material or assemblies are subjected to deterioration and might become structurally unsound if unprotected, protection in conformity with generally accepted standards for the material involved shall be provided. Causes of such deterioration include, among others, action of freezing and thawing, dampness, corrosion, wetting and drying, and termites and other destructive insects.
1000.2	Standards	The provisions of Reference Standard RS 10 [Annex A1] shall be a part of this article.	27-581	Same. Reference standards have been updated.	Foreword	The State Building Code Council publishes a list of Generally Accepted Standards. The list of Generally Accepted Standards for the 1968 State Building Construction Code (the oldest version the state has available) is listed in Annex A3.

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
69-1	Scope	The provisions of this section shall govern the quality and strength of materials and methods of design and construction hereafter used in the construction of buildings and structures. Materials and methods of design and construction shall conform to the requirements of accepted engineering practice and the recognized standards consistent therewith.	800.0	Scope	The provisions of this article shall govern the quality, workmanship and requirements for all materials and methods and the minimum specifications for enclosure walls and wall thickness hereafter used in the construction of buildings and structures. All materials and methods of construction shall conform to the approved rules and standards for materials and tests of accredited authoritative agencies and the requirements of accepted engineering practice as listed in Appendix A through I [Annex A5].	Provisions in all the codes are similar. The NY State Code discusses protection of structural material or assembles against deterioration.
41.1-6	Standards and Tests of Materials	All building materials shall be of a quality to meet the intent of the building provisions of this code, and shall conform to requirements promulgated as rules by the commissioner. Except as hereinafter specified for particular materials, every material permitted to be used in the buildings or structures in the city shall meet the standards performance expectations for that material as prepared by the ASTM and as adopted by that society in 1958. Where such standards require acceptance tests for the determination of the performance and properties of material, proper evidence of the making of such acceptance tests shall be submitted. Where in this code some other standard of performance is set up for any particular type of construction, the same shall take precedence over ASTM, but any standard requirement in ASTM not in conflict with the same shall remain in full force and effect.			All structural units and assemblies shall be tested in accordance with the standards listed in Appendixes D, E and F [Annex A5]. In the absence of a testing procedure, the building official shall accept authenticated reports which meet the requirements of the Basic Code. Material Standards, Structural Unit Test Standards, Structural Assembly Test Standards, Durability Test Standards are listed in Appendixes C, D, E, and F [Annex A5], respectively.	The NYC Building Code uses the system of Reference Standards (RS). An RS may be a referenced standard (e.g. ACI 318-63), a document that is not a standard (e.g. an ACI Committee Report), a section of a code, or may consist of a set of requirements that are spelt out. The NY State Code is a performance code. The Building Code Counsel of the State publishes a list of generally accepted standards. These standards are deemed to comply with the performance of the code. The Chicago Municipal Code adopts reference standards listed in Section 69-4 of the code. The BOCA-BBC adopts reference standards listed in the appendixes to the code.
69-4	Accepted Engineering Practice	The regulations, specifications, standards and tests of the technical organizations which are referred to in this code are hereby incorporated by such reference with the same effect as though set forth. The standards [Annex A4] for (a) Foundations; (b) Masonry; (c) Wood; (d) Reinforced concrete; (e) Reinforced Gypsum; (f) Steel and metals; (g) Plastering; (h) Single family dwellings; and (i) Abbreviations, shall be deemed to represent accepted engineering practice with respect to the materials, equipment, systems and methods of construction respectively specified therein.				

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1000.3	Definitions	See Article 2.	27-582	Same		
1000.6	General Requirements	For purposes of this code, the structural elements of a building shall normally include all floor, roof, and wall framing members and slabs (but not including slabs-on-grade); all piers, walls, footings, piles, and similar elements of the foundation; and all other elements of both foundation and superstructure which, in engineering practice, are proportioned on the basis of calculated stress. Where doubt exists as to the structural nature of an element, the provisions of this article, and of Article 11, shall be deemed to apply only to an element in which the materials are stressed in excess of 33.3 % of the allowable stress values (without increase for infrequent stress conditions) for such material in its proposed use, or to an element wherein public safety would be involved in the event of excessive distortion under the applied loads.	27-585	Same		
103	Alteration of Existing Buildings	103.1 Alterations exceeding 60 % of building value.- If the cost of making alterations in any 12-month period shall exceed 60 % of the value of the building, the entire building shall be made to comply with the requirement of this code. 103.2 Alterations between 30 % and 60 % of building value.- Only those portions of the building altered shall be made to comply with the requirements of this code. 103.3 Alteration under 30 % of building value.- Those portions altered may, at the option of the owner, be altered in accordance with the requirement of this code, or altered in compliance with their previously required condition and with the same or equivalent materials and equipment, provided the general safety and public welfare are not thereby endangered.	27-114	Alteration of existing buildings.- In addition to the same requirements as in the 1968 code, specifications are given for alterations that shall conform with the requirements of this code regardless of the magnitude or cost. The provisions in the rest of this section are the same as the 1968 code provisions.	C105-2 Existing Building	2.1 General: Definition for the term "existing buildings" is given. 2.2 Roof Covering: Whenever more than 25 % of the roof covering of a building is replaced in any 12-month period, all roof covering shall be made to comply with applicable regulations of this code. 2.3 Addition or alteration: Any addition or alteration, regardless of cost, made to a building shall be made in conformity with applicable regulations of this code. 2.4 Existing uses continued: Except as otherwise herein provided, nothing in this code shall require removal, alteration, or abandonment of, nor prevent continued occupancy or use of, an existing building.

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only NYC Building Codes try to clearly define the applicability of the structural provisions.
Chap. 78	Existing buildings	78-8 Alterations and repairs. 78-8.2 Change of occupancy, height or area: (a) When the occupancy of an existing building is changed from one classification to another, the higher provisions for the new occupancy shall be complied with. (b) When a building is increased in height or area, the building shall comply with the applicable requirements of this code. 78-8.5 More than 50 %: Such buildings and structures shall be made to conform to all requirements of this code applicable to new buildings and structures. 78-8.6 25 % to 50 %: All new constructions shall conform to the requirements of this code for new buildings or structures of like area, height and occupancy. 78-8.7 25 % or less: Certain exceptions can be made that allow the use of materials that conform to the strength and fire resistance for the materials with which the building is constructed. Otherwise, all new construction shall conform to the requirements of this code for a new building. 78-8.8 Repairs to roof coverings: Not more than 25 % of the roof covering shall be replaced in any 12-month period unless the entire roof covering is made to conform to requirements for new buildings.	706.0	Existing building	In the reconstruction, repair, extension or alteration of existing buildings, the allowable working stresses used in design shall be as follows: 1. Building extended: If altered by an extension in height or area, all existing structural parts affected by the addition shall be strengthened where necessary and all new structural parts shall be designed to meet the requirements for buildings hereafter erected. 2. Building repaired: When the uncovered structural parts are found unsound, such parts shall be made to conform to the requirements for buildings hereafter erected. 3. Existing live load: When an existing bldg heretofore approved is altered or repaired within the limitation prescribed in Section 106.3 (alteration under 50 %) and 106.4 (alteration under 25 %), the structure may be designed for the loads and stresses applicable at the time of erection, provided that public safety is not endangered. 4. Posted live load: May be posted for original approved live loads.	The provisions of all codes other than the NY State Building Code are broadly similar. The NY State Code requires that any addition or alteration shall be made in conformity with that code. It is silent as to the structure being altered.

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1000.7	Materials and Methods of Construction	Materials and methods of construction used in the manufacture and/or placement of structural elements in a building shall be subject to the requirements of Sub-article 106.0 (Materials, Assemblies, Forms, and Methods of Construction), the inspection provisions established in Tables 10-1 and 10-2 [Annex B1] and the detailed requirements of Sub-articles 1003.0 through 1011.0 and Sub-article 1112.0.	27-586	Same	C309	C309 Material requirements: All structural units of natural or manufactured materials shall comply with applicable specifications of authoritative agencies, or shall be subjected to test in conformity with generally accepted standards in order to determine their characteristics.
					C303 Allowable stresses of materials	C303 Allowable Stresses of Materials C303-1 General requirements: Safe working stresses shall be assigned to materials in accordance with their classification either as controlled materials or ordinary materials, and these stresses shall not be exceeded unless specifically permitted in C304-10. C303-2 Controlled materials: The safe working stresses of materials which have been identified and certified for quality and strength shall conform to the specifications and stresses for such materials. When a material is formed and cast in the field, tests prior to and during the construction shall be made, and the composition and strength of the material shall be certified. C303-3 Ordinary materials: Materials which do not conform to the requirements for controlled materials shall be considered ordinary materials, and their quality and safe working stresses shall conform to the specifications and stresses for ordinary materials in generally accepted standards. When quality and safe working stresses are not so specified, they shall be determined by test in conformity with C305-1. When a material is formed and cast in field, tests shall be made during the construction and its composition and strength certified.

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
69-3	Classification of Construction Materials	All materials and methods used in the design and construction of buildings and structures shall be classified as "controlled materials" and "ordinary materials" as defined herein. 69-3.1 Controlled materials: Means all materials shall be selected and tested to meet the special strength, durability and fire resistance requirements. Design, shop and field details and inspection of construction shall be under supervision. 69-3.2 Ordinary materials: Materials meeting the requirements for minimum strength, durability and fire resistance for average materials without special selection, testing and supervision.	701.0	Definitions	701.0 Definitions. Controlled Materials. Materials which are certified by an accredited authoritative agency as meeting accepted engineering standards for quality and as provided in Sections 722 and 800. Ordinary Materials. Materials which do not conform to the requirements of the Basic Code for controlled materials.	The NYC has broad requirements. The other codes primarily address allowable stresses and make a distinction between controlled and ordinary materials.
			722.0	Allowable Working Stress	722.1 Controlled materials.- The design and working stress of all controlled materials shall conform to the specifications and methods of design for accepted engineering practice or to the approved rules. 722.2 Ordinary materials.- Shall be limited to the average unit working stresses in Appendix K [Annex A5]. 722.3 New materials.- For materials which are not specifically provided for in the Basic Code, the working stresses shall be established by tests.	
			800.1	General	800.1 The quality, use and installation of all materials and methods of building construction shall be controlled by the standards for accepted engineering practice as listed in Appendix B [Annex A5] except where otherwise specifically provided in the Basic Code.	
			800.2	Material Standards	800.2 All building units used in wall, partition and floor construction and for fireproofing or other insulation purposes shall comply with the applicable standards listed in Appendix C [Annex A5].	
			800.3	New Materials	800.3 All new building materials, equipment, appliances, systems or methods of construction not provided for in the Basic Code, and any material of questioned suitability proposed for use in the construction of a building or structure, shall be subjected to the tests prescribed in this article and in the approved rules to determine its character, quality and limitations of use.	
			800.5	Alternate Test Procedure	800.5 In the absence of approved rules or other accepted standards, the building officials shall make or cause to be made the necessary tests and investigations, or he shall accept duly authenticated reports from recognized testing authorities in respect to the quality and manner of use of new materials.	

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1000.9	Use of Used and Unidentified Materials	The utilization of used materials and unidentified or ungraded materials shall be limited to non-structural elements, except: (a) such materials (or elements) may be reused, or continued in use, at stress levels to which the materials or elements were subjected in the previous construction, or at load capacity as demonstrated by load test procedures as described in 1002.4. (b) Unidentified materials may be graded by the recovery and test of representative samples, or by other means satisfactory to the commissioner. (c) Used materials shall be considered to be graded where the grade is clearly indicated on the approved plans for the existing construction and may be used at the allowable stress levels for that grade of like materials as established in the building code in force at the time the plans for the existing construction were approved.	27-588	Same		
1000.10	Equivalent Systems of Design	Nothing in this article shall be construed to prohibit the use of any system of design, alternate to those indicated, provided that it can be demonstrated to the satisfaction of the commissioner that such system of design will provide a factor of safety against structural failure consistent with the requirements of Sub-article 1003.0 through 1011.0, fire safety in consonance with the requirements of Articles 3 through 8, and such other characteristics pertinent to the safety of life, health, and property as prescribed in this article or as may be required by the commissioner. Alternate or equivalent materials or methods of construction shall be subject to the provisions of C26-106.4.	27-589	Same	C107 Accepta-bility	a- Compliance with applicable provisions of generally accepted standards, except as otherwise prescribed in this code, shall constitute compliance with this code. b- Deviations from applicable provisions of generally accepted standards, when it shall have been conclusively proved that such deviations meet the performance requirements of this code, shall constitute compliance with the code.

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
69-2	Used Materials	Used materials which meet the minimum requirements for new materials and all other special requirements of the code shall be permitted.	800.4	Used Materials	The use of all second-hand materials which meet the minimum requirements of the Basic Code for new materials shall be permitted.	The NYC Building Codes have more specific requirements than the Chicago and the BOCA Codes. The NY State Building Code has no explicit requirement.
41.1	Building Standards and Tests	41.1-1 For the purpose of insuring public safety and for the purpose of ascertaining the suitability of materials, methods, or systems of construction, or arrangements of materials, not permitted by, or varying from, the performance requirements in this code, but which are claimed to be equally as good as or superior to those permitted hereunder, the mayor shall appoint a committee on standards and tests.	109.2	Accepted Engineer-ing Practice	In the absence of approved rules, the regulations, specifications and standards listed in Appendix A [Annex A5] - Accredited Authoritative Agencies, Appendix B [Annex A5]- Accepted Engineering Practice, and Appendix C [Annex A5] - Accredited Material Standards, shall be deemed to represent accepted engineering practice in respect to the material, equipment, system or method of construction therein specified.	The various codes investigated here all permit designs that do not conform to the codes, if the design can provide equivalent or superior performance as required in the said code.

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1000.11	Deferred detailing	Where structural elements are normally detailed on shop or working drawings, the application for the permit shall so state, and insurance of the permit shall be conditioned upon future submission of such shop or working drawings showing the approval of an architect or engineer. In cases where the detailing is based on information in manufacturer's catalogue, the application for approval of the plans shall so state and issuance of such acceptance shall be conditional upon submission of statement by manufacturer, attesting the accuracy of the data and that such data were derived in conformance with this code. Where the detailing is based on data published in technical documents of recognized authority issued by, or accredited by, the agency or association promulgating the applicable reference standard cited in this code, such statements will not be required.	27-590	Same		
Sub-Article 1001.0 Structural Design - General Requirements			***Article 2 Structural Design - General Requirements***			
1001.1	Stability	Except as provided in 1111.0 with regard to foundation elements, a building, or any element thereof shall be proportioned to provide a minimum factor of safety of 1.50 against failure by sliding or overturning. The required stability shall be provided solely by the dead load plus any permanent anchorages which may be provided.	27-591	Same		
1001.2	Bracing	Unless otherwise specified in the reference standards, members used to brace compression members shall be proportioned to resist an axial load of at least 2 % of the total compressive design stress in the member braced, plus any transverse shear therein.	27-592	Same		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965			Comments
						Only the NYC Building Codes have a specific provision concerning issuance of permit conditional upon future submission of shop or working drawings.
						Only NYC Building Codes have an explicit statement concerning stability against sliding and overturning.
						Only the NYC Building Codes have this structurally important requirement.

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only the NYC Building Codes have a requirement concerning secondary stresses in trusses.

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1001.5	Deflection Limitations	The applicable provisions of the several reference standards cited in this article shall apply. In addition, the total of the dead plus live load vertical deflections (including effects of creep and shrinkage) of members supporting walls, veneered walls, or partitions constructed of or containing panels of masonry, glass, or other frangible materials shall not exceed 1/360 of the span.	27-595	Same	C306-2	Performance criteria under test.- Under imposed load, the deflection shall not exceed 1/360 of the span when the inside is to be plastered, and 1/240 if it is not. When a roof is not to be used as a promenade, and the underside is not to be plastered, the deflection shall not exceed 1/180 of the span.
Sub-Article 1002.0 Adequacy of the Structural Design			***Article 3 Adequacy of the Structural Design***		***C305 Analysis and test of structural assemblies***	
1002.1	General	The structural design of a member or assembly shall be deemed to be adequate if the design computations demonstrate conformance with the applicable standards noted in 1003.0 through 1011.0. Where, because of practical difficulties, such computations cannot be executed, the structural design may be deemed adequate if the member or assembly is subjected to , and satisfactorily performs under, load tests in accordance with the provisions of 1002.4 (a). Where there is a question as to the adequacy of a completed or partly completed construction, the provisions of 1002.2, 1002.3 and 1002.4(b) shall apply.	27-596	Same	C305-1 General	The capacity of an assembly to sustain dead and imposed loads w/o exceeding the allowable stresses shall be determined by any one of the procedures described in this section, or by an approved combination thereof. a- Design analysis. Stress shall not exceed safe working stress defined in generally accepted standards or established by tests considering the reliability, durability, and uniformity of the material and its behavior under stress. In no case shall the assigned safe working stress exceed 2/3 of the yield strength nor 1/2 of the ultimate strength of the material unless specified in C304-10. b- Test.- Shall be made in conformity with generally accepted standards of assemblies truly representative of the construction to be used, in order to establish that such assemblies conform to the performance criteria set forth in C306. c- Comparison with an approved assembly of known characteristics and behavior under load, which assembly is directly comparable in all essential characteristics to the assembly under consideration.

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
69-5.4		(a) Floor, wall and roof transverse tests- (2) Deflection: Under design live load, the deflection shall be not greater than 1/360 of the span for plastered construction and 1/240 of the span for unplastered construction.	804.2	Working Load Deflection	The deflection of floor and roof assemblies shall not be greater than 1/360 of the span for plastered construction; 1/240 of the span for unplastered floor construction; and 1/180 of the span for unplastered roof construction.	The provisions in various codes are similar.
69-5.3	Test of Structural Assemblies	When a structural assembly is not capable of design by accepted engineering analysis, or when there is reasonable doubt as to its strength or stability, the safe load-bearing capacity of such structural assemblies shall be determined by tests acceptable to the commissioner of buildings. Such tests shall simulate the loads and conditions of application to which the complete structure will be subjected in normal use.	803.0	Tests	All structural units and assemblies shall be tested in accordance with the standards listed in appendixes D, E and F [Annex A5]. In the absence of a testing procedure, the building official shall accept authenticated reports which meet the requirements of the Basic Code. 803.1 Strength tests.- Strength tests prescribed in this code, or acceptable alternative tests, shall be made to determine the safe uniformly distributed working load, when a structure is not capable of design by accepted engineering analysis, or there is reasonable doubt as to the strength or stability of an assembly. Structural load determinations shall include transverse floor and roof, wall compression and racking, concentrated load, plaster bond, puncture penetration and soil tests. 803.1.1 Strength tests for Glass.- Shall comply with Appendix K-12-B [Annex A5]. 803.2 Durability and endurance tests.- Whenever required, the material or construction shall be subjected to sustained and repetitive loading to determine its resistance to fatigue, and to tests for durability and weather resistance. 803.3 Maintenance test.- Tests of all materials shall be made to assure the maintenance of the standards of approved materials when reasonable doubt exists. 803.5 Tests of service equipment and devices.- Provisions are given for service equipment and accessories that shall be included in the tests. 803.8 Test specimens.- Test procedures shall conform to those listed in the appendixes.	

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1002.2	Questionable Construction	If a construction shows open cracks, spallings, other signs of distress; or should inspection records show some significant deficiency of construction; or tests of concrete or other materials that have been incorporated into the work indicate deficiency of strength; or should there be a reasonable doubt as to the strength, stability, or adequacy of the construction, such construction may be checked by computation, or by core or load tests. Should the adequacy not be verified within a reasonable time, such construction shall be demolished or reinforced or rebuilt to be made safe in conformance with the requirements of this code.	27-597	Same		
1002.3	Core Tests of Concrete Construction	The adequacy of the concrete may be ascertained by the recovery and testing of cores. The compressive strength so determined shall meet the requirements for strength tests as described in RS 10-3 [Annex A1].	27-598	Same		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
69-5.5	Workman-ship Tests	(a) Whenever there is reasonable doubt as to the stability or structural safety of a completed building, the commissioner of buildings may require a load test of the building unit or portion of the structure. (b) Unless otherwise provided for in this code, the structure under consideration shall be subjected to a superimposed load equal to 2 times the design live load which shall be left in position for a period of 24 hrs. If during the test or upon removal of the test load, the structure shows evidences of failure, he shall order reinforcement or modifications necessary to ensure adequacy of the structure for the rated capacity; or he may determine the safe load capacity to which the structure shall be limited. (c) The structure shall be considered to have successfully passed the test if the total deflection does not exceed the theoretical deflection computed by accepted engineering formulae, or if the total deflection exceeds the theoretical value, the structure shall be considered safe for the design load if it recovers 75 % of the maximum deflection within 24 hrs after removal of the test load.	803.4	Workman ship Test	Whenever there is reasonable doubt as to the stability or safety of a completed building, the building official may require a load test of the building unit in question. Such existing structure shall be subjected to two times the design live load for 24 hrs. If the structure shows evidence of failure, reinforcement or modifications shall be made, or a reduced working load limit shall be specified. The structure shall be considered to have met the requirements if the total deflection does not exceed the computed theoretical deflection. When the total deflection is greater than such theoretical value, the structure shall be considered safe for the design load if it recovers 75 % of the maximum deflection within 24 hrs after removal of the test load.	
						Only NYC Building Codes have provisions.

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1002.4	Load Tests	(a) Prequalifying load tests: For structural members before they are incorporated into work. (1) Test specimens: Shall be a true representation of the units to be used in work. (2) Support conditions and interaction: Shall simulate the conditions of support in building, except partial fixity may be approximated by conditions of full or zero restraint, whichever produces a more severe stress condition. (3) Strength requirements: The member or assembly shall be capable of supporting a. Without visible damage (other than hairline cracks) its own weight plus 150 % of the design live load plus 150 % of any dead load that will be added on the site. b. Without collapse, its own weight plus 50 % of its own weight plus 250 % of the design live load plus 250 % of the dead load that will be added on the site. The latter loading shall remain in place for a minimum period of one week. All loading conditions described in Article 9 shall be considered. The design live load shall be the nominal value reduced for contributory area as described in Article 9. Except as permitted under (5) below, units to be tested shall be full size. Load bearing wall and partition assemblies shall be tested both with and without window and door framing where such framing will be included in the final assemblies. Test load may be reduced if the load tests are conducted and the results promulgated in a manner that will permit clear differentiation between the dead and live load components added at the site. (4) Deflection requirement: The percentage of recovery of deflection caused by the superimposed load should be at least 75 %. The deflection under the design live load shall not exceed that permitted in this article. (5) Model tests. Tests on models less than full size may be used to determine the relative intensity, direction, and distribution of stresses and applied loads, but shall not be considered as a proper method for evaluating stresses in, nor the strength of, individual members unless approved by the commissioner for this purpose.	27-599	(a) Same	C306	**Performance Criteria under Test** C306-1 General requirements: Buildings and their components subjected to this code shall meet the performance criteria prescribed for each test. Failure to meet the criteria shall be evidence of noncompliance of this code. C306-2 Under imposed load: When the assembly reacts by bending under the uniformly distributed imposed load, excluding impact, the deflection shall not exceed 1/360 of the span when the inside is to be plastered. When it's not plastered, 1/240 of the span is the limit. When a roof is not to be used as a Promenade, and the underside is not to be plastered, 1/180 of the span is the deflection limit. C306-3 Under 1.5 times imposed load: a- Under its DL, and 1.5 times the uniformly distributed imposed load, excluding impact, the assembly shall sustain the load w/o structural damage. In testing floor assemblies and assemblies in compression, the load shall be applied twice. b- For floor assemblies, the residual deflection from the first load application shall not exceed 25 % of the maximum deflection under the load. After the 2nd application of the load, the total residual deflection shall not exceed 1.1 times the residual deflection from the 1st load. C306-4 Under 2 times imposed load: Under its DL and 2 times the uniformly distributed imposed load, excluding impact, the floor, roof, and wall assembly shall sustain load w/o structural failure for a minimum of 24 hrs. C306-5 Impact loads: Under an impact load of 60 lbs falling 4 ft for floors, 1.5 ft for walls, roofs and nonbearing partitions, on an area 10 in. in diameter, applied perpendicular to the assembly at its center, the assembly shall sustain no structural damage. C306-6 Racking loads: Where exterior walls and partitions react by racking, the racking deformation, while the assembly is sustaining the imposed load, shall not exceed 1/400 of the height of the wall. Under 1.5 times the load there shall be no structural damage, and under 2 times the load there shall be no structural failure. C306-7 Transmitted loads: Fastening and connections shall be capable of transmitting, w/o failure, twice the loads for which they are designed.

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code – Basic Code (1965)			Comments
69-5	Tests	69-5.1 Test specimens: The selection and construction of all test specimens and the details of test procedures herein shall conform to the applicable standards of authoritative testing agencies and laboratories. 69-5.2 Test of materials: (a) When the strength, durability, weather-resistance and other qualities of a material necessary to the conditions of its use have not been established by accepted engineering practice, or are in reasonable doubt, tests shall be made as hereafter provided. (b) Tests of materials shall also be made where specifically required by the provisions of this code. (c) Materials, when required, shall be subjected to sustained and repetitive loading to determine resistance to fatigue, and to tests for durability and weather-resistance when applicable to the use of the material. (d) When not otherwise required in this code, the applicable standards and specifications of ASTM shall be deemed accepted practice in the conduct of tests of materials, assemblies and systems. 69-5.4 In evaluating the physical properties of structural assemblies, the structural requirements shall be based on the following conditions of acceptance: (a) Floor, wall and roof transverse tests: (1) Test load: Shall sustain superimposed load equal to 2.5 times the design live load. (2) Deflection: Under design live load, the deflection shall not be greater than 1/360 of the span for plastered construction, and 1/240 of the span for unplastered construction. (3) Residual deflection: If the deflection is greater than the computed theoretical deflection after 24 hrs under the total static test load, upon removal of the load the construction shall recover not less than 3/4 of the total test load deflection. (b) Wall and partition compression tests: (1) Test load: The assembly, both with and without window framing, shall sustain without failure, superimposed loads equal to 2.5 times the vertical design live load. (2) Recovery: After 24 hrs under the static test load, and after removal of the superimposed load, the specimen shall recover not less than 1/2 of all vertical and horizontal distortion and strain. (c) Wall racking tests:(1) Test load: The assembly shall sustain the design live load without excessive distortion and not less than 2.5 times the design live load without failure. (2) Recovery: After 24 hrs under the total static load, upon removal of the load, the construction shall recover not less than 1/2 of the total deflection. (3) Comparative tests: When not available from existing authoritative test data, the building official may require comparative tests of standard traditional form of construction assemblies of similar dimensions and sizes, to assist in determining the adequacy of the new construction. (d) Concentrated load test: Where design for concentrated loads is required in Section 62-8, floor constructions not capable of design shall be subjected to a concentrated load test when such loading exceeds in stress effect the prescribed uniformly distributed load.	804.0	Conditions of Acceptance	In evaluating the physical properties of materials and methods of construction when not subject to design by accepted engineering analysis, the structural requirements shall be based on the criteria established by the following provisions.	
			804.1	Test Load Factor	The test assembly shall sustain without failure, superimposed loads equal to 2.5 times the design live load.	
			804.2	Working Load Deflection	The deflection of floor and roof assemblies shall not be greater than 1/360 of the span for plastered construction; 1/240 of the span for unplastered floor construction; and 1/180 of the span for unplastered roof construction.	
			804.3	Wall and Partition Assemblies	Bearing wall and partition assemblies shall sustain the load test both with and without window framing.	
			804.4	Comparative Tests	May require comparative tests of assemblies of standard traditional forms of construction to assist in determining the adequacy of the new construction.	
			804.5	Concentrated Load Tests	All floor constructions specified in Table 14 [Annex B5] shall be subjected to the concentrated loads therein prescribed when such loading exceeds in stress effect the uniformly distributed load specified for such uses in Table 13 [Annex B5].	
			804.6	Puncture Penetration Tests	All finished floor constructions in which light gage metal or other thin materials are used as the structural floor shall withstand the application of a 200 lb concentrated load applied to the top surface on an area of 1 $in.^2$ at any point.	

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1002.4	Load Tests	(b) Load tests of completed construction (1) Strength.- The construction shall be loaded in two stages: (a) With all dead load to which it will be subjected in service plus a superimposed load equal to the design live load reduced as described in Article 9; and (b) with a total load, including its own weight, equal to 150 % of the total dead load to be supported in service plus 180 % of the design live load, reduced for contributory area, which load shall remain in place for a minimum of 24 hrs. (2) Deflection requirement.- Under the first stage of loading, the deflection shall nor exceed that permitted in the applicable reference standard. The residual deflection after removal of the second stage loading shall not exceed 25 % of the calculated elastic deflection under the superimposed test load. The structure, after recovery of the deflection, shall not show any evidence of serious distress. (3) Interaction. -The loaded area shall be extended to include the loading of all framing and elements that contribute to the strength of the element by way of interaction. (4) Lateral loads.- The applied live load and lateral load components may be adjusted as in 1001.4, provided that the stress condition under the load increments described in (1) above is not more critical. (5) Reloading.- Not permitted. (6) Limitation on use of load tests of concrete structures.- Where the strength tests of the concrete that initiated the requirement for load tests show strengths less than 2/3 of the strength required by the design of the specific element, the use of load tests to show the adequacy of the structure will not be permitted.	27-599	(b) Same, except for the following changes: The following paragraph is added after the title "Load tests of completed construction": "The provisions of this subdivision shall apply to any type of construction where the appropriate reference standard does not provide for load test of completed construction and the construction is questionable. When the appropriate reference standard provides for such load testing, the provisions of reference standard shall be used." Sub-item (6) "Limitation on use of load tests of concrete structures" is deleted.	C305-2	Load test on completed work a- Safe performance under load tests shall be evidence of the acceptability of the construction. b- The assembly shall be able to sustain the dead load and two times the uniformly distributed imposed load, excluding impact, without structural failure for a min 24 hrs.
					C307	**Exterior Protection** C307-1 General requirement: Whenever structural material or assemblies are subject to deterioration and may become structurally unsound under the proposed condition of use, adequate protection shall be provided. C307-2 Exterior material: Exterior facing or covering shall be resistant to causes of deterioration as set forth in C301c w/o loss of strength or loss of attachment which will render it unfit for use. The material shall be treated if necessary. C307-3 Flashing C307-4 Waterproofing C307-5 Grade protection

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only NYC Building Codes have provisions.

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 1003.0 Masonry			***Article 4 Masonry***			
1003.1	General Require-ments	(a) Unreinforced masonry. -Shall meet the requirements of RS 10-1 [Annex A1]. (b) Reinforced masonry. - Shall meet the requirements of RS 10-2 [Annex A1].	27-6	Same	C309 Material Require-ments	All structural units of natural or manufactured materials shall comply with applicable specifications of authoritative agencies, or shall be subjected to test in conformity with generally accepted standards in order to determine their characteristics.

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
69-6	Prefabricated Construction	(a) Definition: A prefabricated assembly is a building unit, the parts of which have been built up or assembled prior to incorporation in the building. (b) Performance standards: All requirements of this code and accepted engineering practice. (c) Tests: As in Section 69-5. Commissioner may require comparative tests.	803.7	Prefabricated Construction Tests	Shall meet all the requirements and tests for at-site construction. The floor panels shall be assembled to form an integrated specimen of not less than 3 units in width with 2 longitudinal joints.	
69-8	Welded Construction	Shall be done under certified inspection.				Only Chicago Code has explicit provisions.
Chapter 71	***Masonry Construction***		***Masonry Construction***			
71-1	General	71-1 Design and construction shall be in accordance with the provisions of the American Standard Building Code Requirements for Masonry (1954).	835.0	Masonry Wall Construction	All masonry construction shall comply with the provisions of this article governing quality of materials and manner of construction; and shall be of adequate strength and proportions to support all superimposed loads within working stresses prescribed in the Basic Code and the standards of accepted engineering practice. Provisions are also given concerning wetting of brick and precautions against freezing.	NYC Building Code and Chicago Code give general provisions for masonry construction. NY State code has provisions only for general construction, not specifically for Masonry construction. BOCA gives specific provisions for various masonry elements.
71-2	Grouted Brick Masonry	71-2 Provisions for allowable compressive stresses are given.				
71-3	Reinforced Brick Masonry	71-3 Provisions are given for reinforcement and allowable stresses.				
			836.0	Bonding of Walls	Walls of solid, composite and hollow masonry and cavity and other hollow walls shall be bonded in accordance with accepted engineering practice. Specific provisions are given on rubble stonewalls, buttresses and piers, intersecting walls and partitions, and erecting precautions.	
			837.0	Lateral Bracing of Bearing Walls	All masonry bearing walls shall be laterally supported by horizontal bracing of floor and roof framing or vertical bracing of columns, buttresses or cross-walls at vertical or horizontal intervals as specified in Appendix B [Annex A5]; and provisions shall be made in the structure to transfer wind pressures and other lateral forces to the foundations.	
			838.0	Chases and Recesses in Bearing Walls	Chases and recesses are prohibited in many situations. Provisions on maximum size of chases and recesses are prescribed.	
			839.0	Corbelled & Projected Masonry	Limitations on the use of corbels and other projections are given.	
			840.0	Bearing on Hollowed Unit Walls	Provisions on bearing area and closure tile are given.	

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1003.2	Identification	(a) Masonry units. - Shall show the grade of the unit and the compressive strength. (b) Metal reinforcement. - Shall be able to identify the grade and size.	27-601	Same		
1003.3	Inspection	Shall conform to Tables 10-1 and 10-2 [Annex B1].	27-602	Same		
Sub-Article 1004.0 Concrete			***Article 5 Concrete***			
1004.1	General Requirements	Concrete materials, design, and construction shall meet the requirements of Reference Standard RS 10-3 [Annex A1]. Precast concrete construction utilizing a thin skin or slab stiffened or supported by a system of ribs shall conform to the requirements of Reference Standard RS 10-4 [Annex A1].	27-603	Concrete materials, design, construction, *quality, inspection and testing* shall meet the requirements of Reference Standard RS 10-3 [Annex A2]. The rest is the same as in the 1968 Code.		All structural units of natural or manufactured materials shall comply with applicable specifications of authoritative agencies, or shall be subjected to test in conformity with generally accepted standards in order to determine their characteristics.
1004.2	Identification of Metal-Reinforcement	Shall be able to identify type, grade and size.	27-604	Same		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			806.1	Identification	All masonry units shall bear the identification mark of the manufacturer consisting of a cast impression, embossing or painting.	NYC Building Codes and BOCA have similar provisions. NY State and Chicago Codes do not have provisions on Identification.
						Only NYC Building Codes have provisions.
Chap 73 Reinforced Concrete Construction						
73-1	Portland Cement Concrete	The design and construction of reinforced concrete shall be in accordance with ACI 318-63. 73-1.1 Composite beams: Detailed provisions for composite beams are given.				
			830.0	Reinforcing Steel	Shall comply with Appendix B [Annex A5]. 1. Identification. Shall be rolled with symbols or letter, or for wires, tagged, to identify the manufacturer and the grade of steel. 2. High yield steel. If yield point is 50,000 psi or more, tension stress in bending or compression stress in vertical column reinforcement shall not be more than 40 % of the yield point; but shall not be more than 30,000 psi except in one-way slab or prestressed reinforcement.	
			817.0	Concrete Aggregates	Provisions are given for Aggregate quality, Fire resistance, Grade 1 Concrete, Grade 2 Concrete, Size of Aggregates, and Special aggregates.	

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1004.3	Mixes	Concrete may be proportioned, batched, and mixed by any of the following methods: (a) Method I. Mixes with Minimum Cement Factor. (1) Minimum cement factor: The cement factor used in the work shall not be less than the factor given in Table 10-3 [Annex B1] for the corresponding strength of concrete. (2) Water-cement ratio. - The concrete used in the work, whether proportioned on the basis of preliminary tests or of prequalified mix designs, shall be produced by using a water-cement ratio corresponding to a point on the strength vs. water-cement ratio curve representing (at a slump of 5 +/- 1 in. for concrete with gravel or stone aggregate and at a slump of 4 +/- 1 in. for concrete with lightweight aggregate) a strength of concrete at least 25 % higher than the specified strength called for on the plans. The cement factor shall not be less than the factor shown in Table 10-3 [Annex B1]. (3) Preliminary tests.- Except as provided in C26-1004.3 (a)(4), preliminary tests of concrete shall be made in advance of the beginning of any concreting operation and shall be subject to controlled inspection. Preliminary tests shall consist of compressive strength test of molded concrete cylinders made in accordance with RS 10-17 [Annex A1] and RS 10-21 [Annex A1]. A curve representing the relation between the average strength of the concrete at 28 days, or at earlier periods, and the water-cement ratio shall be established. The tests shall include at least 4 different water-cement ratios and at least 4 cylinder specimens for each water-cement ratio. The cylinder strength tests shall be supplemented by tests to confirm that the cement and aggregates conform to the provisions of RS 10-3 [Annex A1]. (4) Prequalified mixes. - In lieu of the making of preliminary tests for individual buildings or groups of buildings, a concrete producer may provide concrete proportioned on the basis of prequalified or previously accepted mix designs, which designs, including the applicable batching weights, the results of applicable preliminary tests and of tests to confirm that the cement and aggregates conform to the provisions of RS 10-3 [Annex A1], shall be submitted not less often than once a year to the commissioner for review and prequalification. The preliminary tests shall be made under the supervision of an architect or engineer engaged by the producer. Concrete proportioned according to prequalified mixes shall be produced only from batch plants satisfactory to the commissioner. Separate prequalification shall be required for mixes utilizing different combinations of aggregates and admixtures from all sources which are to be utilized. (5) Quality control and inspection of materials and of batching. - Shall meet the requirements in Table 10-1 [Annex B1].	27-605	Some terminologies are different, e.g. the term "cement content" is used in the 2001 code, rather than "cement factor" in the 1968 code. "Water-cement ratio" is also referred to as "strength-cement ratio" in the 2001 code. The wordings of some provisions are also different. In the provisions for water-cement ratio, the 2001 code specifically gives provisions for lightweight and heavyweight concrete.		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			818.0	Ready-Mix Concrete	818.1 Control. Shall conform to Section 842 for reinforced concrete.	

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1004.3	Mixes (Cont'd)	(b) Method II - Performance concrete. (1) Preliminary tests: Shall be in accordance with 1004.3 (a)(3). Mixes with performance data from previous projects, similarly proportioned, may be accepted, provided that acceptable performance data from such previous projects are provided and the conditions of paragraph (4) below are met. (2) Performance cement factor: Shall be determined in (3) below. (3) Strength. a. Concrete manufactured with stone and gravel aggregate: the water-cement ratio shall correspond to a concrete strength, at design slump, at least 25 % higher than the specified strength called for on the plan. The 25 % factor can be changed if satisfactory coefficient of variation can be provided by the plant, but in no case shall the water-cement ratio be larger than that corresponding to a concrete strength 15 % higher than the specified strength. b. Concrete manufactured with lightweight aggregate.- The concrete shall be proportioned on a strength vs. cement content basis in accordance with RS 10-65 [Annex A1] for a strength at least 25 % higher than the specified strength. The provisions of a. above relating to reduction in the strength requirement for demonstrable quality control shall apply. (4) Materials. Ingredients of the concrete for the buildings shall be the same as those in the preliminary tests. (5) Batching. Provisions for batching plant are given. (6) Quality control and inspection of materials and of batching. Provisions of 1004.3(a)(5) shall apply.		Method II is defined as "proportioning on the basis of field experience". Similar provisions are given as those in the 1968 code. Provisions are added for Method III -"Average Concrete. In lieu of making preliminary tests, provisions are given for the cement and water content for average concrete of 2000, 2500, or 3000 psi. Each load of concrete shall be certified by the producer.		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1004.7	Licensed concrete testing laboratories	All tests shall be performed by licensed testing laboratory.	27-609	Much more detailed provisions are given for the responsibilities of licensed concrete testing laboratory.		
1004.8	Short-span Concrete Floor and Roof Construc-tion Supported on Steel Beams	The empirical equations in (c) and (d) below shall apply only where the steel beams are placed or encased in a manner that will provide section for the transfer of shear from slabs to beams larger or equal to the slab thickness required by the said equations. (a) Concrete.-Concrete shall have a minimum compressive strength at 28 days of 700 psi. (b) Reinforcement.- Reinforcement shall be or function as continuous. The main reinforcement shall be at least 0.15 % of the gross section where continuous steel fabric is used and at least 0.25 % when other forms of steel are used. All reinforcing shall be draped, with 1in. concrete cover at the center of the span and over the support (between the center of the reinforcing steel and the bottom or top of the slab). (c) Minimum slab thickness.- Shall be determined by the following Eq., but not less than 4 in. : $t=L/2+(w-75)/200$; t=total thickness, L=clear span between steel flanges (ft), w=gross uniform load (dead + reduced live)(psf). (d) Allowable load.- Shall be determined by following Eq.: $w=3CA_s/L^2$; A_s=area of main reinforcement, C=coefficient dependent on conc. and steel properties. (e) Openings in floors and roofs.- Provisions of the size of the openings that require to be framed is given.	27-610	Same		
1004.9	Pneumati-cally Placed Concrete	Shall conform to RS 10-15 [Annex A1].	27-611	Added: 27.611.1 Conveying concrete by pumping methods.- All classes and strengths of concrete may be conveyed by pumping methods. All materials and methods used shall conform to the rules promulgated by the commissioner.		
1004.10	Formwork	Shall conform to Article 19.	27-612	Formwork, slip form construction, lift method construction, precast and prestressed construction. - Shall conform to Sub-Chapter 19.		
1004.11	Concrete Utilizing Preplaced Aggregate	The use of concrete formed by the injection of grout into a mass of preplaced coarse aggregate will be permitted where it can be demonstrated by successful prototype installation that the proposed mix, materials, and methods of placement will produce a concrete of the specified strength and free of areas or inclusions of uncemented aggregate. Detailed provisions are given for prototypes, in-place concrete and inspection.	27-613	Same, except added: 27-613.1 Precast and prestressed concrete. 27-613.2 Thin-section precast concrete construction.		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only NYC Building Codes have provisions.
			848.0	Pneumatic Concrete	Provisions on the placement and mix of pneumatic concrete are given.	Only NYC Building Codes and BOCA Code have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 1005.0 Steel			*Article 6 Steel*			
1005.1	General Requirements	Materials, design, and construction methods shall meet the requirements of the following reference standards: (a) Structural steel- RS 10-5 [Annex A1]. (b) Light gauge cold formed steel - RS 10-6 [Annex A1]. (c) Open web steel. - RS 10-7 [Annex A1].	27-614	Same		All structural units of natural or manufactured materials shall comply with applicable specifications of authoritative agencies, or shall be subjected to test in conformity with generally accepted standards in order to determine their characteristics.

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
Chap. 74	*Steel and Metal Construction*		*Provisions for Steel Construction*			
74-1	Structural Steel Design	Design, fabrication and erection of structural steel shall be in accordance with the following document: Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings, AISC 1963. Exceptions that do not follow this document are given.	827.0	Structural Steel Construction	Structural steel construction used in all buildings and structures shall be fabricated from materials of uniform quality, free from defects that would vitiate the strength or stability of the structure. Workmanship, design, fabrication, transportation and erection shall conform to accepted engineering practice as defined by the standards listed in Appendix B [Annex A5]. Provisions are given for Plans, Temporary and special stresses, Shop drawings, Welding, and Painting.	NYC Building Codes give general provisions for steel construction. Chicago and BOCA Codes give more specific provisions for various steel structural systems. The NY State Code has provisions only for general construction, it has not specific provisions for steel.
74-2	Light Gauge Steel Structural Members	Conform to Light Gage Cold-Formed Steel Design Manual, AISI 1962. Exceptions are also given.				
74-3	Steel Joist Construction	Conform to Open Web Joists-Standard Specifications and Load Tables. SJI-1963.	828.0	Formed Steel Construction	Design: Shall be based on allowable unit stresses and maximum deflections in accordance with Appendix B [Annex A5]. Provisions are also given for: Minimum thickness of metal; Secondary structural systems; Roof decking; Protection; and Tests.	
74-4	Light Weight Metal Alloys	Aluminum, magnesium and other lightweight metals and alloys shall be used only after approval by commissioner.				
74-5	Cast Iron	Conform to Standard Specifications for Gray Iron Castings- ASTM A48-62. Detailed provisions are given for the min thickness requirements for various structural members. Cast iron columns shall not be used where subjected to eccentric load which produce a net tension in the material, nor to resist wind load. Core of superimposed columns shall be of same dimensions above and below a splice. Cast steel shall conform to ASTM A27-62 (for grade 65-30) and A148-60 (grade 80-50).	829.0	Steel Joist Construction	Provisions are given for the design, protection, height and area limitations, and tests of steel joist constructions.	
			831.0	Cast Steel Construction	Provisions are given for materials, higher strength cast steel, and welding cast steel.	
			832.0	Cast Iron Construction	Provisions are given for materials, limitation of use, multi-story columns, and thickness of metal.	
			833.0	Special Steels	Identification: Alloy and high strength steel shall conform to the standards of accepted engineering practice. Shall be clearly marked. 2. Design and workmanship: Shall conform to the requirements of approved rules.	
74-6	Special Steels	Silicon, nickel and other alloy and high strength steels shall conform to the applicable standards of accepted engineering practice and may be used only under a controlled materials procedure. Detailed provisions are given for the stress, identification, and allowable unit stresses in columns.	834.0	Light Weight Metal Alloys	Shall be used in accordance with Appendix B [Annex A5].	
			723.0	Alloy and Special Steel	The use of alloy, high carbon or other special high-strength steels shall be permitted in the design and construction of buildings and structures as controlled materials and as prescribed in Section 833 in accordance with accepted engineering practice.	

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1005.2	Identification	Shall be marked or handled so that they can be positively identified.	27-615	Same		
1005.3	Quality Control	Provisions of Tables 10-1 and 10-2 [Annex B1] shall apply. Detailed provisions for welding and inspection are provided.	27-616	Same		
Sub-Article 1006.0 Wood			***Article 7 Wood***			
1006.1	General Requirements	Materials (other than non-stress grade lumber), design and construction methods shall meet the requirements of the following reference standard: (a) Lumber and timber - RS 10-8 [Annex A1]. (b) Plywood - RS 10-9 [Annex A1]. (c) Structural glued-laminated lumber - RS 10-18 [Annex A1].	27-617	Same		All structural units of natural or manufactured materials shall comply with applicable specifications of authoritative agencies, or shall be subjected to test in conformity with generally accepted standards in order to determine their characteristics.
1006.2	Identification	Provisions for identification requirements are given	27-618	Same		
1006.3	Use of Non-Stress Grade Wood	Conditions to which the use of non-stress grade wood should be limited are given.	27-619	Same		
1006.4	Quality Control	Inspection of the fabrication of glued-laminated assemblies, as stipulated in Table 10-2 [Annex B1], shall include a check of sizes of members of fit, and of gluing operations.	27-620	Same		
1006.5	General Construction Requirements	Provisions for various types of wood members are provided.	27-621	Same		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
Chapter 72		***Wood Construction***				
		Abbreviations: NLMA: National Lumber Manufacturers Association. NDS: National Design Specifications for stress-grade lumber and its fastenings	853.0	Lumber and Timber Construction	Provisions are given for the Design, Minimum dimensions, Fabrication, Trimmer and Header beams, Bearing and anchorage on girders, and Maintenance.	NY State code does not have specific provisions for wood construction.
72-1	General	Wood structural members shall be of sufficient size to carry the dead + live load without exceeding the allowable unit stresses required in this chapter. Adequate bracing and bridging to resist wind and other lateral forces shall be provided. The applicable provisions of NDS shall govern.	854.0	Heavy Timber Type Construction	Provisions are given for Wood, Other structural materials, Columns, Floors, and Beams and girders.	
72-2	Maximum Allowable Unit Stresses	Maximum allowable unit stresses are given in Table 72-2 (a) [Annex B4, for ordinary materials].	855.0	Wood Frame Construction	The exterior walls, interior partitions, floors and roofs of wood frame construction shall be designed and constructed to develop adequate strength to resist all vertical and lateral forces due to both dead and live loads. Standard balloon, braced, platform and post and beam types of construction shall be acceptable framing methods. Detailed provisions are given for Wood-stud frame, Wall sheathing, Exterior weather boarding, veneers and condensation, Foundation anchorage, At-grade protection, Floors, Roofs, Flashing, and Interior finish.	
72-3	Bolted Joints	Provisions for bolted joints are given.				
72-4	Ventilation	Provisions for ventilation are given.				
			856.0	Stress Skin Panels	Provisions are given for Integrated assemblies, Splices, and Molded plywood units.	
			857.0	Glued, Laminated and Built-Up Lumber Construction	Shall comply with Appendix B [Annex A5].	
			853.1		Requirements for identification of lumber and timber are given in Section 853.1.	Only NYC Building Codes and BOCA Code have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1006.6	Empirical Provisions in lieu of Design	Empirical provisions are given for certain buildings. The provisions cover Stud walls and partitions, Bracing of exterior walls, Floor and roof framing, Rafter and ceiling joist, and Built-up members.	27-622	Same		
1006.7	Heavy Timber Construction	Provisions for minimum sizes of members and construction details are given.	27-623	Same		
1006.8	Construction Methods	Provisions for fabrication and erection are provided.	27-624	Same		
Sub-Article 1007.0 Aluminum			***Article 8 Aluminum***			
1007.1	General Requirements	Materials, design and construction methods shall meet the requirements of RS 10-10 [Annex A1], and RS 10-11 [Annex A1].	27-625	Same		
1007.2	Identification		27-626	Same		
1007.3	Quality Control	Provisions of Tables 10-1 and 10-2 [Annex B1] shall apply. Provisions for welding are provided.	27-627	Same		
1007.4	Erection	Provisions for Bracing, Temporary connections, and Alignment are provided.	27-628	Same		
Sub-Article 1008.0 Reinforced Gypsum Concrete			***Article 9 Reinforced Gypsum Concrete***			
1008.1	General Requirements	Materials, design, and construction methods shall meet the requirements of RS 10-12 [Annex A1].	27-629	Same		
1008.2	Identification of Metal-Reinforcement	Bundles or rolls of welded wire fabric shall be securely tagged so as to identify the type and grade of the steel, and the size.	27-630	Same		
1008.3	Limitations of Use	Shall not be used where exposed directly to the weather or where subject to frequent or continuous wetting. Precast units shall be protected from weather and moisture.	27-631	Same		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
			724.0 Light Weight Metals			
			Aluminum and other light weight metals and their alloys may be used in the design and construction of buildings or structures only upon special approval of the building official, subject to the determination of the physical properties by tests as prescribed in Article 8 and in accordance with provisions in section 834.			
73-2 Gypsum Concrete			***850.0 Reinforced Gypsum concrete***			
		The design and construction of reinforced gypsum concrete shall be in accordance with the provisions of the American Standard Specifications for Reinforced Gypsum Concrete.			Shall comply with Appendix B [Annex A5].	NY State code does not have specific provisions for gypsum concrete construction.
						Only NYC Building Codes have provisions.
					Same as in NYC Building Code.	Only NYC Building Codes and BOCA Code have provisions.

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 1009.0 Thin Shell and Folded-Plate Construction			***Article 10 Thin Shell and Folded-Plate Construction***			
1009.1	General Requirements	Applicable reference standards relating to allowable stress and the use of structural material shall apply.	27-632	Same		
1009.2	Analysis	Shall be based on assumptions of elastic behavior. The shell or plate may be assumed to be homogeneous and isotropic. The analysis for stability shall consider large deflections, creep and deviation between the actual and theoretical shell surface.	27-633	Same		
1009.3	Thin Concrete Shells	The provisions of Sections 403, 404 and 405 of RS 10-45 [Annex A1] shall apply with the following modifications. The remaining sections of RS 10-45 shall not apply. (1) The advisory provisions of this standard shall be considered mandatory. (2) Minimum ultimate strength of concrete for thin shells shall be 3000 psi. (3) Change all references to "the Building Code (ACI 318-63)" to "Reference Standard RS 10-4".	27-634	Same		
Sub-Article 1010.0 Suspended Structures			***Article 11 Suspended Structures***			
1010.1	General Requirements	Shall meet applicable requirements of the code and this section.	27-635	Same		
1010.2	Suspenders	Provisions for bridge wire cable and other materials are given.	27-636	Same		
1010.3	Tests of Materials for Bridge Wire Suspenders	Provisions on the minimum quantities of bridge wires to be tested are given.	27-637	Same		
1010.4	Tests of Materials for Other Types of Suspenders	RS 10-3 [Annex A1] and RS 10-5 [Annex A1] shall apply.	27-638	Same		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.

Table 7–3. Structural Work (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1010.5	Design	Supplement design requirements to the applicable provisions for this article are given for the following topics. (a) Flexibility, (b) Elastic stretch, (c) Displacement, (d) Other considerations (effects of temperature, wind load, and vibration) and (e) Allowable working load. The allowable working load in suspenders formed from bridge wire cable shall be computed on the basis of factors equal to (1.5*DL+2.5*LL) or (1.2*DL+2*LL+2*W) applied to the specified, minimum, ultimate strength of the suspender. The allowable working load in suspenders conforming to the material specifications of several reference standards of this code shall be allowable working stress for tension members as prescribed in the applicable reference standard or, for those materials where allowable stresses for tension members are not prescribed, on the basis of factors of (1.5*DL+2.0*LL) or (1.2*DL+1.5*LL +1.5*W), also applied to the specified minimum ultimate strength of the suspender. In no case, however, shall the factor, applied to the yield strength of the material or to the prestretching or prestressing force, exceed (1.1*DL+1.25*LL).	27-639	Same		
1010.6	Fittings for Wire Cable Suspenders	Fittings for wire cable suspenders shall be capable of developing the specified minimum ultimate strength of the attached cable or strand without developing the yield stress.	27-640	Same		
1010.7	Construction	General provisions of RS 10-5 [Annex A1] relating to erection of steel shall apply.	27-641	Same		
1010.8	Protection of Suspenders		27-642	Same		

Table 7–3. Structural Work (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.
						Only NYC Building Codes have provisions.

Table 7–4. Foundations.

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Article 11 Foundations			*Subchapter 11 Foundations*		*Part 3 Structural Requirements C302 Soil Bearing Value*	
Sub-Article 1100.0 General			*Article 1 General*			
1100.1	Scope	The provisions of this article shall establish minimum requirements for the design and construction of the foundations of buildings.	27-652	Added: Flood areas should comply with RS 4-5 [Annex A2]. Otherwise the same.		
1100.2	Standards	RS 11 [Annex A1] shall be part of this article.	27-653	Same	C301	Shall be in conformity with generally accepted standards.
1100.3	Definitions	See Article 2.	27-654	Same		See Section C108-3.
1100.6	General Requirements	Except as otherwise specifically provided herein, the foundations of buildings including retaining walls and other structures shall bear on, or be carried down to, satisfactory bearing materials in such manner that the entire transmitted load will be distributed over the supporting soils at any depth beneath the foundation at unit intensities within the allowable bearing values established in this article. In addition, foundations shall be proportioned to limit settlements to a magnitude that will not cause damage to the proposed construction or to existing adjacent or nearby buildings during or after construction.	27-657	Same	C301 General Requirements	b- Buildings shall be constructed and integrated so that loads are transmitted to the soil without undue differential settlement, unsafe deformation or movement of the bldg or of any structural part. c- Wherever structural material or assemblies are subjected to deterioration and might become structurally unsound if unprotected, protection in conformity with generally accepted standards for the material involved shall be provided. Causes of such deterioration include, among others, action of freezing and thawing, dampness, corrosion, wetting and drying, and termites and other destructive insects. d- Buildings built in soil which is water bearing at any season of the year shall be constructed so that ground and surface water will not penetrate into habitable spaces, basements and cellars.

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
Chapter 70 Foundations			*Article 7 Structural and Foundation Loads and Stresses*			
		See Chapter 47.			See Article 2. Some additional definitions are also given in Section 701.0.	
70-1	General Requirements	(a) Every building or structure shall be supported on footings, piles, foundation columns, piers or caissons complying with the requirements of this section. (b) The encroachment of foundations on public property shall be governed by section 77-2.1.	700.0	Scope	The provisions of this article shall control the structural design of all buildings and structures and their foundations hereafter erected to insure adequate strength of all parts thereof for the safe support of all superimposed live and special loads to which they may be subjected in addition to their own dead load, without exceeding the allowable stresses prescribed in the Basic Code or in accepted engineering practice.	The Chicago Code addresses encroachment of foundations on public property.

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1100.7	Depth of Foundations	The bottom of any footings and pile caps shall be carried down at least 4 ft below the lowest level of the adjoining ground or pavement surface that is exposed to frost. Exceptions to this provision are also given. For grade beams, the bottom of any grade beam shall be carried down at least 18 in. below the lowest level of the adjoining ground or pavement surface that is exposed to frost.	27-658	Same		
1100.8	Foundations at Different Levels	The influence of the pressure under the higher footings on the stability of the lower footings shall be considered.	27-659	Same		
1100.9	Slabs on Grade	Shall be designed to limit the settlement of such slabs.	27-660	Same		
1100.10	Constructions	The provisions of Article 19 relating to safety and of Article 10 relating to concrete, timber, masonry, and steel construction shall apply. For inspection requirements, see Section 1112.0. Provisions for cold weather and seepage are given.	27-661	Same		
Sub-Article 1101.0	***Soil Investigations***		***Article 2***	***Soil Investigation***		
1101.1	General	Borings in earth or rock, recovery of samples, tests of soil samples, load test, or other investigation or exploratory procedures shall be performed as necessary for the design and construction of a safe foundation subject to inspection in accordance with the requirements of 1112.0.	27-662	Same	C302-2 (b)	b- For buildings in which the sum of snow load and those live loads of all floors which are transferred by columns or walls to the soil, divided by grade-floor area, exceeds 200 psf, there shall be a min of 1 test pit or boring for every 2500 sft of grade-floor area, carried sufficiently into acceptable bearing materials to establish its character and thickness. Min depth requirements for at least 1 boring/10000 sft are given. Detailed provisions for boring record requirement are also given.

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
70-3.2	Depth of Footings	All footings shall be carried to a depth of at least 3 ft 6 in. below the adjoining ground surface, except that a reinforced concrete slab foundation extending over the entire area below a one-story building shall be permitted at a lesser depth below the adjoining ground surface when so designed as to eliminate structural damage from frost action.	729.0	Depth of Footings	Except when erected on rock or when otherwise protected from frost, foundation walls, piers and other permanent supports shall extend below the frost line and spread footings of adequate size shall be provided to properly distribute the load within the allowable bearing value of the soil. Or such structures shall be supported on piles or ranging timbers when solid earth or rock is not available. No footings shall be founded on frozen soils unless such frozen condition is permanent. 729.1 Isolated footings. For footings on granular soil of classes 5-10 inclusive in Table 15 [Annex B5], the line drawn between the lower edges of adjoining footings shall not have a steeper slope than 30^{o} with the vertical, unless the material supporting the higher footing is laterally supported. 729.2 Floating mat. Shall be located on permanently undisturbed soil. Detailed provisions are given.	
70-2.2	Soil Investigation	All applications for building permits shall be accompanied by a statement from the architect or engineer as to the character of the soil. Where there is reasonable doubt as to the character and bearing capacity of the soil, the commissioner may require borings, test pits or test loads.	725.0	Bearing Value of Soils	All applications for permits for the construction of new buildings or structures, and for the alteration of a permanent structure which requires changes in foundation loads and distribution, shall be accompanied by a statement describing the soil in the ultimate bearing strata, including sufficient records and data to establish its character, nature and load-bearing capacity.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1101.2	Borings	(a) Number. At least one boring shall be made for every 2500 sft of building area or fraction thereof and, for buildings supported on piling of such type or capacity that load tests are required, one boring shall be made for every 1600 sft of building area except as indicated in (1) through (3) below. Detailed provisions are given for (1) One- and two-family dwellings, (2) Buildings having a plan area in excess of 10,000 sft and where subsurface meets certain conditions, and (3) Where foundations are to rest on rock of certain classes. (b) Location. At least 2/3 of the required number of borings shall be located within the area under the building, those outside shall be within 25 ft from the limits of the building. Borings shall be uniformly distributed or distributed in accordance with the loading pattern. (c) Depth. Provisions for the depth requirements for the borings are given. (d) Types. Provisions are given for soil borings and rock borings. (e) Data to be reported. Provisions are given for data that shall be recorded and reported. (f) Disposition of samples and cores. Soil samples and rock cores shall be retained in an accessible location for one year.	27-663	Same		
1101.3	Test Pits	Test pit may be substituted for borings on a one-for-one basis. All applicable requirements as to depth, number of samples, data to be reported, and disposition of samples shall be observed.	27-664	Added subdivision (b): provisions for buildings not more than one story in height and for one- or two-family residences not more than two stories in height.		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
70-2.3	Borings	All borings shall be made by a procedure that provides info capable of serving as basis for the classification of the subsurface materials as specified in 70-2.1. Detailed requirements for the content of the boring report are given.	726.1	When Required	In the absence of satisfactory data from immediately adjacent areas, the owner or applicant shall make borings, test pits, or other soil investigations at such locations and to sufficient depths of the bearing materials to the satisfaction of the building official. For all buildings, in other than residential use groups, which are more than 3 stories or 40 ft in height, and whenever it is proposed to use float, mat or any type of deep foundation, there shall be at least one exploratory boring to rock or to a depth of >50 ft below the load-bearing strata for every 2500 sft of built-over area, and such additional tests that the building official may direct.	
			726.2	Soil Samples	Samples of strata penetrated in test borings or test pits, representing the natural disposition and conditions at the site, shall be available for examination of the building official. Wash or bucket samples shall not be accepted.	
			726.3	Varying Soil Values	When test borings indicate non-uniformity of bearing materials, a sufficient number of additional borings shall be made to establish strata levels of equal bearing capacity.	
			726.4	Cost of Tests	Tests shall be made by and at the expense of the applicant and under the supervision of the building official.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1101.4	Borings Methods	Borings shall be made by continuous driving and cleaning out of a pipe casing except as permitted in (a) (b) and (c) following. Where casing is used, it shall be cleaned out to undisturbed soil prior to sampling and the sample spoon driven into soil that has not been affected by chopping, washing, or hydrostatic imbalance. Provisions for (a) Uncased borings, (b) Auger borings, and (c) Maximum diameter are given.	27-665			
1101.5	Probings and Geophysical Explorations	Provisions for the use of probings, auger borings or geophysical methods to substitute borings are given for foundations consisting of footings or foundation piers or walls bearing on rock of certain classes or piling bearing on rock of certain classes. Provisions for geophysical investigation are also given.	27-666	Same		
1101.6	Existing Borings	Existing boring data may be utilized subject to the following: (1) Borings, test pits, probings, etc., that have been made in accordance with all requirements of this section, but not necessarily for the investigation of the specific project for which application is being made, may be utilized in fulfillment of these provisions. (2) The logs of borings, test pits, probings, etc., that have been made in accordance with all requirements of this section, but wherein the soil samples and/or rock cores are not available for examination, may be utilized in fulfillment of these provisions to an extent not to exceed 1/2 of the required number of borings. (3) Borings, test pits, probings, etc., or the logs thereof, that do not meet the specific requirements of this article, but which are of suitable type and adequate penetration to provide the data required for the safe design and construction of the proposed foundation, may be utilized in fulfillment of the provisions of this section, subject to the approval of the commissioner.	27-667	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 1102.0 Foundation Loads			*Article 3 Foundation Loads*			
1102.1	Soil Bearing Pressures	The loads to be used in computing the bearing pressures on materials directly underlying footings shall be the total column, pier, or wall reactions determined in accordance with the provisions of Article 9, on the basis of reduced live load; plus the weight of the foundations; plus the weight of any soil, fill, and slabs on grade that is included within vertical planes projected upward from the extreme limits of the footing to the final ground surface. Live load on grade, or on slabs on grade, within these limits shall also be included. Impact loads shall be considered in accordance with 1102.6.	27-668	Same		
1102.2	Pile Reactions	The loads to be used in computing pile reactions shall be determined as provided in 1102.1, except where piles penetrate compressible strata, the pile load shall be increased by the amount of drag exerted by such material during consolidation. Provisions for the computation of the drag are given.	27-669	Same		
1102.3	Lateral Loads	Provisions for (a) Earth and ground water pressure, (b) Wind and other superstructure loads, and (c) Soil movements are given.	27-670	(a) Earth and ground water pressure: Added provisions for earthquake forces acting on the retaining wall.		
1102.4	Eccentricities	Provisions for eccentricity of loading in foundations are given. Soil pressure and pile load due to eccentricity shall be computed on the basis of straight line distribution of foundation reaction, or other modes of distribution with demonstrable evidence.	27-671	Same		
1102.5	Uplift Forces	Uplift and overturning forces due to wind and hydrostatic pressure shall be considered.	27-672	Same	C304-5 C304-7	Overturning Uplifting Overturning and uplifting forces due to wind or hydrostatic head shall be considered. Detailed provisions of these two sections can be found in Table B of this report.
1102.6	Impact Load	May be neglected in the design of foundations, except for foundations on loose soil, or those supporting heavy impact loads.	27-673	Same		
1102.7	Stability	Provisions in 1111.0 shall apply.	27-674	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			710.1	Below Grade	All retaining walls and other walls below grade shall be designed to resist lateral soil pressures with due allowance for hydrostatic pressure and for all superimposed vertical loads.	
			710.2	Hydrostatic Uplift	All foundation slabs and other footings subjected to water pressure shall be designed to resist a uniformly distributed uplift equal to the full hydrostatic pressure.	
						Only NYC Building Code considers impact loads.

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)
1103.4	Allowable Soil Bearing Pressures	The allowable bearing pressures on satisfactory bearing materials shall be those established in Table 11-2 [Annex B1]. The allowable bearing pressures on nominally unsatisfactory bearing materials shall be those established in accordance with C26-1103.5. Allowable bearing pressure shall be considered to be the allowable pressure at a point in the soil mass in excess of the stabilized overburden pressure existing at the same point prior to construction operations. The stabilized overburden pressure existing at a point shall be defined as that portion of the weight of the overlying soil material that is supported by granular interaction rather than pore pressure. In general, the magnitude of the stabilized overburden pressure may be approximated as follows: (a) The overlying soil material shall be in place for an adequate length of time. Where the bearing stratum consists of soils of classes 5-65 through 8-65, the bearing stratum shall be considered to be fully consolidated. (b) The weight of fill material shall not be included in the stabilized overburden pressure unless its magnitude of stabilized pressure is verified by tests. (c) Where the bearing stratum consists of soils of classes 9-65 through 11-65, the stabilized overburden pressure shall be taken as zero unless its magnitude is verified by tests. (d) The stabilized overburden pressure shall not include the weight of any soil removed by excavation and not replaced. For footings, the stabilized overburden pressure shall not exceed the weight of 1 sft column of soil measured from the bottom of the footing to the lowest level of the final grade above the footing. For a boxed foundation, the pressure shall not exceed the weight of 1 sft column of soil measured from the bottom of the box to the lowest level of the adjacent grade. (e) Where the bearing stratum consists of soils of classes 9-65 through 11-65, the allowable bearing pressure shall be adjusted for the effects of rebound due to excavation. (f) Where the bearing stratum consists of rock of classes 1-65 through 3-65, the stabilized overburden pressure shall be neglected.	27-678	Same	C302-1 General Require-met

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)	Comments
70-2.4	Soil Bearing Values	Maximum allowable pressures on the supporting soils at the bottom of the footings shall not exceed the values in Table 70-2.4 (a) [Annex B4] except when determined by tests or analysis. Exceptions to allowable bearing values: (1) Variation in soils. Where portions of the foundations of the same structure rest upon soils which vary substantially in bearing value, special provisions shall be made to prevent serious differential settlements which will impair the safety of the structures. (2) Where the bearing materials directly under a foundation overlie a stratum having smaller allowable bearing values, these smaller values shall not be exceeded at the level of such stratum. Computation of the vertical pressure in the bearing materials at any depth below a foundation shall be made on the assumption that the load is spread uniformly at an angle of sixty degrees with the horizontal. (3) Subject to the approval of the commissioner of buildings, bearing values greater than those required in 70-2.4 may be used if analysis based on laborator1t(be us14 [(fou)5.0.1(a)]TJ T* [(spfieldoad ig va14 [(7.5(sh)4.2(1t oe c4.2(1t pe4.2(tin)5t seTJ 0 -1 psposi-8.6071on. SsT.5(ues ns ow [6h str20.059Tw [6h str9(tionv0.0lx.9Tvaltu)-cpt)4t0017 T7478 0str20.05B5c2 P.(u)-r. 63(2.1		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			725.3	Light Weight Structures	Mud, organic silt, or unprepared fill shall be assumed to have no presumptive bearing capacity unless approved by test, except where the bearing capacity is deemed adequate by the building official for the support of light weight and temporary structures.	
						Only NYC Building Codes have provisions to prevent damage to utility services.
70-2.5	***Field Loading Tests***		***727.0***	***Soil Test Procedure***		
		(a) Whenever the bearing value of soil is in reasonable doubt or when it is desired to use soil bearing values in excess of those established in Table 70-2.4(a) [Annex B1], the allowable load on a bearing material may be determined by test in accordance with the requirements of this section.				

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1104.2	Procedure	Provisions are given for Preparation, Loading of the soil, and Determination of results.	27-682	Same	C302-3 Performance Criteria for Field Loading Soil Test	Under field loading test, the total settlement caused by the proposed load on the soil, measured after a period during which no settlement had occurred for 24 hrs, shall not exceed 3/4 in. The additional settlement caused by a 50 % increase in the proposed load, measured after a period during which no settlement had occurred for 24 hrs, shall not exceed 60 % of the total settlement as previously measured under the proposed load.
					C302-4 Performance Criteria for Pile Test	a- The test load shall be twice the proposed pile load, applied in increments of 1/4 of the proposed pile load, with readings of settlements taken to the nearest 1/32 in. and plotted against load. The test load may be increased to more than twice the proposed pile load value until the gross settlement is approximately 1 in. At each step the load shall remain unchanged until there is no settlement in a 2 hr period, and the test load shall remain in place until there is no settlement in 48 hrs. b- The total test load shall then be removed in decrements not exceeding 1/4 of the total test load at intervals of not less than 1hr, with rebound read after each removal of load and plotted against load and with the final rebound recorded 24 hrs after removal of the last decrement. The allowable pile load shall be the lesser of 1/2 of that load which caused a gross settlement of 1 in. or a net settlement equal to 0.01 in./ton times total test load in tons, with a limit determined by the strength of the pile as a structural member.
Sub-Article 1105.0 Footings, Foundations Piers, and Foundation Walls			***Article 6*** *(Same title as in '68 Code)*			
1105.1	Materials	All structural elements of foundations shall meet the requirements as to type and minimum quality of materials prescribed in Article 10.	27-683	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
		(b) Test procedure. (1) A sufficient number of tests shall be made to determine the bearing value of the soil over the entire building site. (2) Each load test area shall be no less than 4 ft^2, except that for soils of >10,000 psf bearing capacity, the area can be 1 ft^2. (3) Load increments shall not exceed 25 % of the proposed safe load until the load reaches 200 % of it. (4) The load increment shall be applied at uniform intervals such that the proposed safe load is reached in >8 hrs. This load shall remain until no measurable settlements shall occur in 16 hrs period. The total test shall then be completed in >8 hrs. The total load shall remain until no measurable settlement occurs in 16 hrs. (5) Measurements of settlement shall be recorded diagrammatically. (c) Conditions of acceptance. (1) The total settlement under the proposed safe load shall not exceed 3/8 in., and the total settlement under double the design load shall not exceed 1 in. (2) The proposed safe load shall not cause pressure on any underlying soil stratum in excess of maximum pressures established in Table 70-2.4(a). If the above conditions are not satisfied, the allowable safe load shall be determined by selecting a reduced load from the load-settlement diagram such that the above conditions are satisfied.	727.1	Soil Test Method	The test procedure and testing apparatus shall be approved by the building official before they are used; and a complete record of the tests together with a record of the soil profile shall be filed by the licensed engineer or architect who shall have a fully qualified representative on the site during all boring and test operations.	
			727.2	Loaded Area	For spread footings, the soil shall be loaded at one or more places and at the required level or levels. The loaded area shall be approximately 4 sft for all bearing materials; except that when the footing overlies wet clay or other soft materials, the test load shall be applied to an area of not less than 10 sft.	
			727.3	Recorded Settlements	Loads shall be applied in continuous increments of not more than 1/4 of the proposed safe load. When the proposed load has been reached, it shall remain undisturbed and readings shall be recorded to determine the rate of settlement until the settlement in 8 consecutive hrs is less than 0.01 in. A 50 % excess load shall then be applied and allowed to remain in place until the rate of settlement is less than 0.01 in. in 24 hrs.	
			727.4	Accuracy of Loading	Test loads applied by mechanical devices shall be automatically controlled so as to insure not more than 5 % variation in applied load. Such devices shall be calibrated prior to the test.	
			727.5	Test Acceptance	The load settlement shall be represented diagrammatically, and no test shall be deemed satisfactory if the net settlement after removal of the test load exceeds 0.01 in./ton of gross load applied.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1105.2	Footings	(a) Wood footings. May only be used for wood frame structures. Preservative treatment shall be in accordance with RS 11-4 [Annex A1]. (b) Pole buildings. Buildings not more than one story high may be supported on poles embedded in the ground. Shall have protective treatment for wood and steel poles. (c) Grillages. Shall have proper spacers, stiffeners, and diaphragms, or spaces between beams shall be filled with concrete and grout. (d) Design. (1) Concrete footings: per RS 10-3 [Annex A5]. Reinforcement shall extend to within 4 in. of the edges of the footings. (2) Masonry footings: Reinforced masonry footings shall meet the requirements of RS 10-2 [Annex A5] and shall be proportioned similarly to the proportioning of RC footings. Provisions are also given concerning the dimensions of unreinforced masonry footings.		Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
70-3	Footings	Footings shall be provided under walls, piers or columns where required to distribute their loads in accordance with the allowable bearing values of the supporting soils as provided in Section 70-2. 70-3.1 Proportioning. Footings shall be so proportioned as to insure a min. of unequal settlement. 70-3.2 Depth. All footings shall be carried to a depth of at least 3 ft 6 in. below the adjoining ground surface, except that a RC slab foundation below a one-story building shall be permitted at a lesser depth. 70-3.3 Construction. (a) General. Footings shall be constructed of solid masonry or concrete with or w/o reinforcement and shall be so designed that stresses in the material shall not exceed the maximum allowable stresses required in the following chapters: RC footings (Chap 73), plain concrete footings (Chap. 71, 73), masonry footings (Chap. 71). (b) Masonry footings. Footings constructed of solid masonry units shall have a depth at least twice the total projection beyond the wall or column base. When brick work in foundation walls is stepped to form a footing, the maximum offset for each course shall be 1.5 in. (c) Steel grillage footings. When structural steel members are used in footing construction, such members shall be entirely encased by at least 3 in. of concrete, and the space between the members shall be entirely filled with cement grout. Stress in steel members shall not exceed the allowable stress required in Chap. 74.	730.0	Footing Design	730.1 Design loads. The full dead load including the weight of foundations, footings, and overlying fill and reduced LL shall be used. 730.2 Pressure due to lateral loads (W, E).- May be neglected if <1/3 of the DL+LL pressure alone. If >1/3, such increased pressure shall be considered with a 1/3 increase in allowable soil pressure under the combined load. 730.3 EQ loads. Shall comply with Section 719.0. 730.4 Vibratory loads. Consideration shall be given to the design of the footings to prevent detrimental disturbance of the soil.	The BOCA Building Code has the most comprehensive footing design provisions.
			731.0	Timber Footing	731-1 Where permitted. Only for wood frame structures unless otherwise approved by Building Official. Shall be placed entirely below the permanent water level except when treated. 2.- Untreated timber.- The compressive stresses perpendicular to the grain in untreated timber footings shall not exceed 70 % of the allowable stresses of the specified lumber.	
			732.0	Steel Grillages	732.0 Shall be separated with approved steel spacers and shall be entirely encased in at least 3 in. of concrete and the spaces between the beams shall be filled with concrete or cement grout. When used on yielding soils, steel grillages shall rest on approved concrete beds >6 in. thick.	
			733.0	Unreinforced Concrete Footings	733- 1. Concrete strength.- Not less than 2000 psi at 28 days. 2. Deposition.- Shall not be poured through water unless otherwise approved by the building official. When poured under or in the presence of water, the concrete shall be deposited by approved means, which insure minimum segregation of mix and negligible turbulence of the water. 3. Dimensions. Edge thickness shall be not less than 8 in. for footings on soil, and not less than 12 in. above the tops of piles for footings on piles. Except: May be reduced to 6" and 8" respectively for 1-story and basement buildings of wood frame or brick veneered walls. 4. Protection.- Shall be protected from freezing during deposition and not less than 5 days thereafter and no water shall be allowed to flow through the concrete.	
			734.0	Masonry Unit Footings	734- 1 Dimensions: Shall be laid in Type M or S mortar complying with Section 816. Provisions for depth and width of the wall are also given. 2.Offsets: Provisions for maximum offset of each course laid in single or double courses are given.	
			735.0	Reinforced Concrete Footings	735- 1. Design: Shall comply with Sections 841, 842, 843, 844 and applicable standards in Appendix B [Annex A5]. 2. Dimensions: Edge thickness shall be not less than 5 in. above the reinf. if on soil, and not less than 12 in. if on piles. Provisions for dimensions of pile caps are also given. 3. Protection. When concrete is deposited directly against the ground, the reinf. shall have a minimum cover of 3 in. At other surfaces of foundation concrete, the minimum cover shall be 2 in.	
			736.0	Mat, Raft and Float Foundations	736.0 Shall be used only when the loading is uniformly balanced and the soil immediately below the mat is of uniform bearing capacity.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1105.3	Foundation Piers	Shall be designed as columns. RC piers shall conform to RS 10-3 [Annex A5]. Reinforced and unreinforced masonry piers shall conform to RS 10-2 [Annex A5] and RS 10-1 [Annex A5], respectively. Unreinforced concrete piers shall conform to C26-1105.3 (b). (a) Lateral support. May be determined by elastic analysis, or a pier may be assumed to be hinged, but laterally braced at intervals equal to the full height of the pier or eight times the least dimension of the pier, whichever is the lesser value. Provisions in 1105.3 (e) shall apply. (b) Unreinforced concrete piers. Provisions for the allowable compressive stress, the ratio of height to the least lateral dimensions, and maximum eccentricity are given. (c) Metal shells. Where piers are encased by a metal shell, provisions for when the shell can be considered as contributing to the structural strength of the pier are given. (d) Minimum dimensions. Provisions for pier dimensions are given. (e) Filling. The provisions of (a) and (d) shall apply only where the fill is placed around the pier as controlled fill. For uncontrolled fills, provisions are given for the dimensions of the piers.	27-685	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
70 -12	Founda-tion Columns	70-12 Foundation columns: shall consist of steel pipe shells extending to rock and completely filled with concrete with or w/o steel reinforcement or cores. 70-12.1 The pipe shall conform to ASTM specifications for welded and seamless steel pipe piles and shall have a minimum thickness of 0.3 in. The nominal diameter of pipe shall be not less than 22 in. 70-12.2 Foundation column shall extend to solid rock as defined in Section 70-2.1. 70-12.3 Allowable load and stresses. (a) If the base of the foundation column is less than 1ft below the surface of the solid rock, the bearing load on solid rock shall not exceed 100 tsf or the value determined by tests as provided in Section 70-2.5. (b) If the base of foundation column is 1 ft or more below the surface of the solid rock, the allowable bearing value may be increased 20 %/ft for each foot of depth greater than 1 ft, but shall not exceed 200 tsf. (c) When the column extends through a layer of unstable soil, the maximum design load shall be computed as for a column with an unsupported length equal to the depth of the unstable layer of soil, plus 4 times the diameter of the column.	749.0	Foun-dation Piers	1. Unreinforced: when the unsupported height of foundation piers exceeds 6 times the least dimension, the allowable working stress on piers of unit masonry or plain concrete shall be reduced in accordance with accepted engineering practice. 2. Reinforcement: 1) Design- May be reinforced with spiral or vertical reinf in accordance with provisions of column design in Appendix B [Annex A5]. When adequate lateral support is provided, the requirements for long column shall be waived. 2) Minimum percentage: An outer peripheral ring of a thickness of 1/10 of the pier perimeter, but not to exceed 2', shall be considered an envelope. Based on the area of such envelope, the min. vertical reinf. shall be 3/4 of 1 % and 2/10 of 1 % of horizontal reinf throughout its length. Minimum concrete cover shall be 3". 3. Steel shells: When concrete piers are entirely encased with a circular steel shell, the area of the shell steel may be considered as reinforcing provided it is protected per 738.0. All horizontal joints in the shell shall be spliced per Section 737. 4. Dimensions: Minimum dimension for isolated pile: 2', height< 12 times the least dimension unless it's RC or steel or encased in steel shell>1/4" thick. Greater length may be approved if adequate lateral support exists. 5. Belled bottoms: The edge thickness of the bell shall be >12" and the side of the bell shall slope at >60^{o} to the horizontal. 6. Dewatering: Shall insure accurate preparation and inspection of the bottom and the deposition or construction of sound concrete in the dry.	
70 -13	Foundati on Piers and Caissons	Shall be of concrete w/ or w/o steel reinforcement, extending to solid rock or to hardpan. 70-13.1 Piers or caissons bearing on hardpan may be belled to increase load carrying capacity, provided that such bell shall be at least 12 in. thick at its edge and that the sides shall slope at an angle of not less than 60^{o} with the horizontal. 70-13.2 Allowable load and stress. (a) The allowable bearing value shall be the bearing capacity of the hardpan or rock as in section 70-2.4. (b) The load used in determining the areas of the piers and of the belled bottom shall be the load supported at the top of the pier. 70-13.3 Tests. (a) Where piers are to be supported on hardpan, the thickness of the hardpan strata shall be determined by boring extended not less than 6' below the bottom of the pier. (b) When piers extend to bedrock, the thickness of the rock strata shall be determined by borings extended not less than 8 ft into solid rock. The rock bottom of not less than 10 % of the total number of piers evenly distributed over the site shall be so drilled.				

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1105.4	Foundation Walls	(a) Concrete.- Shall be designed according to RS 10-3 [Annex A5]. Provisions for equivalent unbraced height are given. (b) Masonry.- Provisions for the types and wall thickness are given. In addition, provisions in RS 10-1 [Annex A5] and RS 10-2 [Annex A5] should be followed.	27-686	Same		
1105.5	Construction of Footings, Foundation Piers, and Foundation walls	Provisions of 1100.10 and 1112.5 shall apply. In addition, provisions are given for conditions that shall be satisfied for the methods of installation and construction.	27-687	Same		
Sub-Article 1106.0 Pile Foundations-General Requirements			***Article 7*** *(Same title as in '68 Code)*			
1106.1	Administrative Requirements	Requirements concerning Identification of piles and Record of pile driving are given.	27-688	Same		
1106.2	Minimum Pile Penetrations	(a) Required by soil bearing capacity- 1107.1 (b)(1) shall apply. (b) Required for lateral restraint- 1106.7 shall apply. (c) Piles located near a lot line- provisions are given.	27-689	Same		
1106.3	Use of Existing Piles at Demolished Structures	Requirements for piles at demolished sites to be used for the support of new constructions are given.	27-690	Same		
1106.4	Tolerances and Modification of Design due to Field Conditions	Provisions are given for the tolerance in alignment of the pile axis, tolerance in location of the head of the pile, and Bent piles.	27-691	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			871.0	Foundation Walls	Design: Foundation walls shall be designed to resist frost action and to support safely all vertical and lateral loads as provided in Article 7. The maximum stresses due to combined load shall be within the values specified for the materials used in the construction. Unless properly reinforced, tensile stresses shall not exceed those permitted in plain masonry. Provisions for minimum thickness of foundation walls of various materials are also given.	
Pile Foundations - General Requirements			***Pile Foundations***			
			737.0	Pile Foundations	Shall be designed to transmit loads to lower strata of foundation materials. The bearing value of the supporting soil shall be evaluated per Section 739. Piles may be constructed of any approved materials.	
			737.1	Site Investigation	The building site shall be investigated for all conditions which might promote deterioration of the pile foundations, and approved protective measures shall be taken.	
			737.6	Minimum Length and Penetration	Provisions for piles near lot line are given.	
						Only NYC Building Code has this provision.
			737.9	Precautions	During driving, all piles shall be held in their design location and shall be driven plumb. Tolerance to lateral deviation of the pile is given. Driving shall be under inspection.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1106.5	Minimum Spacing of Piles	Provisions for the minimum pile spacing are given.	27-692	Same		
1106.6	Minimum Section	Provisions for the minimum pile sections are given.	27-693	Same		
1106.7	Capping and Bracing of Piles	(a) Capping of piles.- Provisions are given for pile embedment, uplift, reinforcement, and design. (b) Bracing of piles.- Except for short piles, provisions are given for the lateral bracing of piles with caps, brace beams, concrete slab-on-grade, other means (anchors), and floor system. Special requirements for bracing batter piles are also given. (c) Bracing of short piles.- Provisions for bracing of short piles are given.	27-694	(c) Bracing of short piles, (1) Added, at the end of the paragraph, provisions for depth for pile penetration. Otherwise, the same.		
1106.8	Splicing of Piles	Provisions for splicing of piles are given.	27-695	Same		
1106.9	General Requirements for Installation of Piles	(a) Protection of adjacent property. (b) Protection of the pile during installation. (c) Protection of pile materials after installation. Specific provisions are given for untreated timber piles and piles installed in ash or garbage fills etc that need special protection. (d) Equipments for pile installation.	27-696	Same		
1106.10	Use of Uncased Concrete Pile Shafts	Conditions where uncased shafts can be used are given for bored piles and driven piles.	27-697	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
70-4 (a)	Minimum Spacing	Provisions for minimum spacing are given.	737.2	Spacing	The minimum C-C spacing of piles shall not be less than twice the diameter of a round pile, nor less than 1.75 times the diagonal dimension of a rectangular pile. When driven to rock, the spacing shall be not less than 24 in. When other than rock, the spacing shall not be less than 30 in. For piles which cannot be checked for plumbness, the minimum spacing prescribed herein shall be increased not less than 6 in.	
			737.5	Minimum Dimensions	Provisions for tapered piles and uniform circular and non-circular sections are given.	
70-4 (b)	Pile Caps	Provisions for pile caps are given.	737.3 737.4	Wall Piers Isolated Pier Piles	Piles in wall foundations shall be staggered about the C-line at a min. distance of 1/2 the top diameter. Exceptions for single row are given. Not less than 3 piles shall be furnished under isolated piers, unless lateral bracing is provided.	
			737.7	Splices	Shall be avoided if possible. Where used, splices shall be such that the resultant vertical and lateral loads at the splices are adequately transmitted. Detailed provisions are given.	
			738.0	Corrosion Protection	1. Preservative treatment. Shall comply with Section 740.5 and Appendix C [Annex A5]. 2. (Deleted). 3. Protective jackets. When surrounding soil contains destructive chemical elements, protective jacket shall be provided. When the jacket is of concrete, the thickness of the cover shall be not less than 1.5 in. 4. Cinder fill: Shall be considered sufficient reason for protective jacket.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1106.5	Minimum Spacing of Piles	Provisions for the minimum pile spacing are given.	27-692	Same		
1106.6	Minimum Section	Provisions for the minimum pile sections are given.	27-693	Same		
1106.7	Capping and Bracing of Piles	(a) Capping of piles.- Provisions are given for pile embedment, uplift, reinforcement, and design. (b) Bracing of piles.- Except for short piles, provisions are given for the lateral bracing of piles with caps, brace beams, concrete slab-on-grade, other means (anchors), and floor system. Special requirements for bracing batter piles are also given. (c) Bracing of short piles.- Provisions for bracing of short piles are given.	27-694	(c) Bracing of short piles, (1) Added, at the end of the paragraph, provisions for depth for pile penetration. Otherwise, the same.		
1106.8	Splicing of Piles	Provisions for splicing of piles are given.	27-695	Same		
1106.9	General Requirements for Installation of Piles	(a) Protection of adjacent property. (b) Protection of the pile during installation. (c) Protection of pile materials after installation. Specific provisions are given for untreated timber piles and piles installed in ash or garbage fills etc that need special protection. (d) Equipments for pile installation.	27-696	Same		
1106.10	Use of Uncased Concrete Pile Shafts	Conditions where uncased shafts can be used are given for bored piles and driven piles.	27-697	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
70-4 (a)	Minimum Spacing	Provisions for minimum spacing are given.	737.2	Spacing	The minimum C-C spacing of piles shall not be less than twice the diameter of a round pile, nor less than 1.75 times the diagonal dimension of a rectangular pile. When driven to rock, the spacing shall be not less than 24 in. When other than rock, the spacing shall not be less than 30 in. For piles which cannot be checked for plumbness, the minimum spacing prescribed herein shall be increased not less than 6 in.	
			737.5	Minimum Dimensions	Provisions for tapered piles and uniform circular and non-circular sections are given.	
70-4 (b)	Pile Caps	Provisions for pile caps are given.	737.3 737.4	Wall Piers Isolated Pier Piles	Piles in wall foundations shall be staggered about the C-line at a min. distance of 1/2 the top diameter. Exceptions for single row are given. Not less than 3 piles shall be furnished under isolated piers, unless lateral bracing is provided.	
			737.7	Splices	Shall be avoided if possible. Where used, splices shall be such that the resultant vertical and lateral loads at the splices are adequately transmitted. Detailed provisions are given.	
			738.0	Corrosion Protection	1. Preservative treatment. Shall comply with Section 740.5 and Appendix C [Annex A5]. 2. (Deleted). 3. Protective jackets. When surrounding soil contains destructive chemical elements, protective jacket shall be provided. When the jacket is of concrete, the thickness of the cover shall be not less than 1.5 in. 4. Cinder fill: Shall be considered sufficient reason for protective jacket.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1106.11	Where More Than One Pile Type, Pile Capacity, or Method of Pile Installation Is Used	The several parts of the building supported on the different types, capacities, or modes of piling shall be separated by suitable joints providing for differential movement, or a report shall be submitted showing that the proposed construction is adequate and safe.	27-698	Same		
1106.12	Pile Materials	The provisions of C26-1000.1 and 1000.9 relating to "classification of materials, assemblies and methods of construction" and to the use of "used and unidentified materials" shall apply.	27-699	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
			748.0	Lateral Support	1. Surrounding materials: Any soil other than water or fluid soil shall be deemed to afford sufficient lateral support to permit the design of any type of pile as a short column. When piles are driven through soil which will be removed subsequently to the completion of the foundation, the resistance offered by such material shall not be considered to contribute to the lateral supporting capacity. 2. Fixed ends: When not assumed laterally supported by the surrounding soils and when fixed by lateral supports at the upper end only, the unsupported length of pile or other isolated foundation shall be assumed as 3/4 the total length; and when supported at the bottom by drilling or other rigid attachment into the bed rock in addition to top lateral support, the unsupported length shall be assumed as 1/2 the total length.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 1107.0 Pile Foundations - Loads			*Article 8 Pile Foundations - Loads*			
1107.1	Allowable Axial Load	The allowable axial load on a pile shall be the least value permitted by consideration of the following factors: (a) The capacity of the pile as a structural member: Provisions for the embedded portion of the pile, and the portion that is not embedded, and the load distribution along embedded portion of the pile are given. (b) Allowable bearing pressure on soil strata underlying the pile tips: The allowable pile load shall be limited by the provision that the pressures in materials at and below the pile tips shall not exceed the allowable bearing values in 1103.0. Provisions of 1103.4 and 1103.5 shall apply. The transfer of load from piles to soil shall be determined by a recognized method of analysis. Alternative methods to determine load transfer are given for piles in different soil classes. In addition, bearing strata shall be established, to which the piles in the various sections of the building are to be penetrated. (c) Capacity as indicated by resistance to penetration: Where soils that the piles must penetrate consist of materials that present a hazard to the installation of the piles, the selection of types of piles and penetration criteria shall be subjected to approval. But in no case shall the minimum penetration resistance be less than that stipulated in Tables 11-4 and 11-5 [Annex B1]. Detailed provisions are given for (1) piles installed by use of steam-powered, air-powered, diesel-powered or hydraulic impact hammers, (2) piles installed by jacking or other static forces, and (3) piles installed by use of vibration hammer. (d) Capacity as indicated by load test.- Load test requirements are given for piles installed by static forces, by impact hammers, and by use of vibration hammers. Provisions for load test procedures are also given. Foundation piles within the area of influence of a given satisfactory load-tested pile shall be installed under identical conditions. Group load tests up to 150 % of the proposed group load may be required for pile groups. And temporary supporting capacity the soil might provide to the pile during the test shall be obviated by "casing off". (e) Maximum loads.- (1) Basic maximum load: Except as permitted in the provisions of (2) below, the maximum pile load shall not exceed the values in Table 11-6 [Annex B1]. (2) Substantiation of higher allowable loads: load values higher than those in Table 11-6 [Annex B1] can be substantiated on the basis of test and analysis. Detailed provisions are given.	27-700	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
70-5		*Allowable Loads on Piles*	*739.0*		*Allowable Pile Loads*	
		The average compressive stress on any cross-section of a pile under design load shall not exceed the allowable value for the material as provided in Chapters 72, 73, 74. All concrete in piling shall have a min. ultimate compressive strength of 3000 psi. 70-5.1 For pile loads not exceeding 25 tons for timber piles, nor 40 tons for concrete piles, concrete-filled steel pipe piles and rolled structural steel piles, the allowable pile loads may be determined by the value R obtained by one of the following formulas: Formulas for piles whose weight is equal to or less than, and whose is larger than, the weight of the striking part are given, respectively. R is the allowable pile load and is function of weight of the striking part, effective fall height, actual energy delivered by hammer per blow, penetration of pile per blow and weight of pile. 70-5.2 For pile loads exceeding 25 tons for timber or 40 tons for concrete etc, the allowable pile load shall be determined by control load tests as required in Section 70-5.3. 70-5.3 (a) The number of control test piles shall be determined by engineer or architect by the degree of variation in soil conditions. (b) A pile to be tested shall be loaded to double the proposed allowable load. Same as in 70-2.5 (b). (c) Measurement of settlement shall be taken and recorded immediately before and after each increment of load. In determining the settlement, proper deduction shall be made for elastic compression of the pile under test load. (d) The proposed allowable load shall be considered acceptable if the total net settlement under the total test load, after the elastic compression of the pile under the test load has been deducted, does not exceed 0.01 in./ton of total test load. (e) The proposed allowable load, if acceptable, shall be allowable for all piles driven in the same soil conditions if the driving resistance is not less than that of the control test pile. 70-5.4 (a) Where the resistance of a pile is developed in or above a compressible soil layer, the settlement due to compression of this soil shall be considered in the design. (b) Where the piles are jetted into position, allowable loads shall be determined either by Section 70-5.1 or 70-5.3.			Shall be determined by applicable formulas. The maximum load capacity shall be limited by the supporting capacity of the soil as determined by driving resistance or by load test, but shall not exceed the capacity of the pile designed as a short or long column. 739.1 Short column load. Except when extending above permanent ground level, or driven in material of negligible lateral support, or driven through soil which will be later removed, all piles shall be designed as short columns under the provisions of the basic code for the structural material used. The average compressive stress in any section of the pile shall not exceed the allowable column values of the basic code. 739.2 Driving formula load. The allowable load on any pile determined by the application of an approved driven formula shall not be >40 tons. 739.3 Approved test load. When greater loads per pile than permitted in Section 739.2 are desired, control piles shall be tested with the procedure in Section 727.The resulting allowable load shall be <1/2 of the test load which produces a permanent net settlement/ton not more than 0.01 in. All other piles shall have the capacity as that of the control pile, except as provided in Section 739.4. Not less than 3 piles shall be driven in any area of uniform foundation materials and 1 of such shall be test loaded. At least 1 test shall be made for each 15,000 sft of building area. 739.4 Group Pile load. 1. Limiting load. The total load on group of piles shall not exceed the bearing capacity on the gross loaded area of the underlying soil stratum, assuming a uniform load spread within 60^{o} with the horizontal from the area occupied by the pile group + 1 ft surrounding the periphery of the cluster. No overlapping of pressure areas from similar distribution of loads for adjacent pile groups. 2. Load test of pile groups: When driven through materials subjected to displacement or shifts, the immediate surrounding pile groups shall be driven in place before the test load is applied to that group. 739.5 Limiting pile loads: 200 tons when open-ended concrete-filled steel pipe piles are installed to bear on rock; 120 tons on all other types of piles when bearing on rock except timber piles (740.6); 80 tons when bearing on or in materials of classes 3,4,5 in Table 15.; 60 tons when bearing on or in materials classified in Table 15 [Annex B5].	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1107.2	Allowable Lateral Load	Provisions for allowable lateral load are given.	27-701	Same		
1107.3	Uplift Capacity	A minimum safety factor of 2 against withdrawal shall be provided. Shall be greater than 2 if subjected to dynamic uplifting. If factor of 3 or more is used, no need for pull-out test.	27-702	Same		
Sub-Article 1108.0 Pile Driving Operations			***Article 9 Pile Driving Operations***			
The provisions of this article shall not apply to piles driven with a vibration hammer or other equipment wherein the energy of impact cannot be evaluated.						
1108.1	Equipment	General provisions for equipment and specific provisions for cushion or cap block and followers are given.	27-704	Same		
1108.2	Procedure	Provisions for Continuous driving, Jetting, Sequence of installation, Heaved piles, and Penetration measurements are given.	27-705	Same		
Sub-Article 1109.0 Pile Types - Specific Requirements			***Article 10 Pile Types – Specific Requirements***			
1109.1	Scope		27-706	Same		
1109.2	Timber Piles	(a) Materials: Timber piles shall conform in quality to class A or B of RS 11-7 [Annex A5]. Provisions are given for the size of the piles. The limits for stress due to the applied loads are given for various wood types. (b) Limitation on use: Terminate driving directly when the pile reaches bearing on hard materials. (c) Legged and inverted piles: Provisions for double legging and single legging and inverted piles are given. (d) Installation: Damaged materials at the head of the pile shall be removed before capping. Sudden decrease in driving load shall be investigated, and may be adequate cause for rejection of the pile.	27-707	Same		
1109.3	Precast Concrete Piles	(a) Materials: Shall conform to C26-1004.0. (b) Construction: Provisions for handling stress, minimum lateral dimension are given. Structural design shall conform to 1107.0 and additional requirements for reinforcement, etc are given. (c) Tolerances: Tolerances for eccentricity are given. (d) Installation: Precast pile shall not be handled or driven until they have cured sufficiently to develop the necessary strength.	27-708	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
						This is an important provision that is only in the NYC Building Code.
			737.8	Jetting	Piles may be jetted through foundation material listed as Class 6-9 in Table 15 [Annex B1]. Immediately after completion of the jetting, the piles shall be driven to the required load resistance.	
70-6	Timber Piles	70-6.1 Timber piles shall be single pieces of timber of approved species containing no defect. Provisions for shape and diameter of piles are given. 70-6.2 All untreated timber piles shall be cut off at a level not less than 1 ft below the permanent ground water level. 70-6.3 Timber piles above permanent ground water level shall be treated to prevent decay.	740.0	Timber Piles	1. Species.- Approved species are given. All timber piles shall be driven in one piece except for composite piles as provided in Section 746. 2. Timber specifications.-Specification for round timber piles are given. 3. Min dimensions.- Shall comply with Section 737.5 with some specified exceptions. 4. Cut-off.- The tops shall be sawn off in a horizontal plane. If untreated, shall be below water level, except for light frame construction. 5. Untreated piles.- Provisions for creosoted piles are given. 6. Maximum load on piles.- Maximum load on Class A or B piles shall be as in Section 739.0. Piles of smaller sizes shall be as in Sections 739.3 and 740.3.	
70-7	Precast Concrete Piles	70-7.1 Piles shall be reinforced to resist both handling and driving stresses. The diameter of precast pile shall be not less than 8 in, and at the top shall be at least 2 % of the length. Concrete cover of reinforcing shall be not less than 1.5 in. 70-7.2 Precast piles shall not be handled nor driven until the min. ultimate compressive strength of 3000 psi of the concrete has been attained.	741.0	Precast Concrete Piles	1. Concrete strength.- Shall be driven after attaining compressive strength of not less than 3000 psi. 2. Design: Shall be in accordance with Appendix B [Annex A5]. Lateral reinforcement at both ends of the pile shall be spaced in not more than 3 in. 3. Protection: 2 in. cover shall be provided over all reinforcement, except for severe exposure, where 3 in. cover shall be provided.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1109.4	Cast-In-Place Concrete Piles	(a) Description: Shall be cast in shells previously installed in the ground or, with the limitations in 1106.10, may be cast in an uncased hole. They may be tapered or cylindrical, or a combination of tapered and cylindrical shapes. (b) Materials: Provisions for concrete and pile shells are given. (c) Installation: After installation to final depth and immediately before filling with concrete, the inside of the tube, shell, or bore shall be thoroughly cleaned and inspected. Concrete shall be filled so that the entire volume is filled and separation of ingredients shall be precluded. No concrete shall be placed in a cast-in-place pile until all piles within a radius of 15 ft, or within the heave range, have been driven. Rejected shells shall be filled with sand or concrete. The concrete cap shall not be placed until at least 1 hr. after all piles within the cap group are completely filled.	27-709	Same		
1109.5	Compacted Concrete Piles	(a) Description: A concrete pile formed with an enlarged base in which the concrete in the base is placed in small batches that are compacted prior to attaining an initial set. (b) Materials: Provisions for concrete properties are given. (c) Spacing: Minimum spacing between compacted concrete piles is given. (d) Installation: Provisions for the installation of the base concrete and the shaft are given. (e) Bearing materials: Provisions for the bearing materials for the enlarged base are given.	27-710	Same		
1109.6	Steel H Sections	(a) Materials: H sections shall be of any steel permitted by RS 10-5 [Annex A5]. The use of built-up sections or sections other than H will be permitted if the sections are adequately connected or the width/thickness ratios do not exceed those of H shapes. (b) Limitations on use: Driving shall be terminated directly when the pile reaches refusal on the rock surface.	27-711	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
70-8	Cast-In-Place Concrete Piles	70-8.1 Construction. Permanent metal casings shall in all cases be used with cast-in-place concrete piles. Casing shall be inspected before fill, and shall not be buckled or otherwise damaged. 70-8.2 Allowable stresses. The maximum compressive stress shall not exceed 40 % of the ultimate compressive strength of the concrete. Where the metal casing is 1/8 in. or more in thickness, the pile shall be considered a concrete-filled steel pipe pile.	742.0	Cast-In-Place Concrete piles	1. Concrete strength: Shall develop a compressive strength of not less than 2500 psi at 28 days. Shall be deposited continuously and placed in the dry. 2. Design: Reinforcement shall be installed as an assembly. No reinforcement (except dowel) shall be placed within 1 in. of metal casing. Concrete cover shall be not less than 2 in. if no permanent casing is used, and shall be not less than 3 in. if in severe exposure. 3. Installation: Prevent distortion or injury of piles already in use. 4. Inspection: Previous to placing of concrete, the shell and other unfilled space of each pile shall be inspected.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
1109.9	Composite Piles	Composite piles include those consisting of two types of pile joined together. Provisions for the allowable load and the joint between two components are given.	27-714	Same		
Sub-Article 1110.0 Underpinning			***Article 11 Underpinning***			
1110.1	General Requirements	Where support of adjacent structures is required, such support may be provided by underpinning, sheeting, and bracing.	27-715	Same		
1110.2	Use of Rock Support in Lieu of Underpinning	Existing structures founded at a level above the level of adjacent new construction may be supported on hard rock in lieu of underpinning, the use of sheeting and bracing, or the construction of retaining walls provided that the safety of the construction can be substantiated.	27-716	Same		
Sub-Article 1111.0 Stability			***Article 12 Stability***			
1111.1	General	The possibility of overturning and sliding of the building shall be considered.	27-717	Same		
1111.2	Factor of Safety	(a) Overturning: Minimum safety factor against overturning of the structure shall be 1.5. Stability against overturning shall be provided by the dead load of the building, by the allowable uplift capacity of piling, by anchors, by the weight of soil directly overlying footings provided that such soil cannot by excavated without recourse to major modification of the building, or by the combination of these factors. (b) Sliding: Minimum safety factor against sliding shall be 1.5. Resistance to lateral load shall be provided by friction between the foundation and the underlying soil, by passive earth pressure, by batter piles, or by plumb piles. Detailed provisions are given for specific resistance mechanisms.	27-718	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments
70-11	Special Type Piles	The use of types of piles not specifically mentioned in Sections 70-6 to 70-10 including composite piles, and the use of piles under conditions not specifically covered shall be permitted, subject to compliance with the provisions of Chapters 72, 73, 74.	746.0	Composite Piles	1. Design: Composite piles consisting of 2 or more approved pile types shall be designed to meet the conditions of installation. 2. Limitation of load: The maximum load shall be limited by the capacity of the weakest section. 3. Splices: Splices between concrete and steel or wood section shall be designed to prevent separation of the sections both before and after the concrete portion has set, and to insure alignment and transmission of total pile load. Splices shall be designed to resist upheaval during driving of adjacent piles and shall develop the full compressive strength and not less than 50 % of the strength in tension and bending of the weaker section.	
			747.0	Special Piles and Caissons	Types of piles or caissons not covered in the Basic Code shall be permitted provided that sufficient test data, design and construction information is filed.	

Table 7–4. Foundations (continued).

NYC Building Code (1968)			NYC Building Code (2001)		NY State Building Construction Code (1964)	
Sub-Article 1112.0 Inspection			***Article 13 Inspection***			
1112.1	General	The applicable provisions of C26-106.0 shall apply.	27-719	Same		
1112.2	Boring Operation	Boring operations shall be subjected to controlled inspection. Detailed provisions are given for the inspection.	27-720	The section title changed to "Boring and Test pit operations"; In the following text, "boring and test pit" replaced "boring".		
1112.3	Piling	The installation of all piles shall be subjected to controlled inspection. Detailed provisions are given.	27-721	Same		
1112.4	Footings, Foundation Piers, Foundation Walls and Pile Caps	Provisions of 1105.1 shall apply.	27-722	Same		
1112.5	Subgrade for Footings, Foundation Piers, and Foundation Walls	The soil materials directly undrlying footing, foundation piers, and foundation walls shall be inspected by an architect or engineer after excavation and immediately prior to construction of the footings. Detailed provisions are given.	27-723	Same		
1112.6	Construction Required for or Affecting the Support of Adjacent Properties or Buildings	All construction or excavation required for or affecting the support of adjacent properties or buildings shall be subject to controlled inspection.	27-724	Same		

Table 7–4. Foundations (continued).

Municipal Code of Chicago (1967)			BOCA Building Code - Basic Code (1965)			Comments

Annex A1
REFERENCE STANDARDS OF 1968 NEW YORK CITY BUILDING CODE

A1.1 REFERENCE STANDARDS

RS 9 Loads

RS 9-1 Minimum Unit Design Dead Loads for Structural Design Purposes. Unit design dead loads are shown in Exhibit RS 9-1.

RS 9-2 Minimum Requirements for Uniformly Distributed and Concentrated Live Loads. Minimum uniformly distributed and concentrated live loads are shown in Exhibit RS 9-2.

RS 9-3 AASHO 1965, *Standard Specification for Highway Bridges*.

RS 9-4 AREA 1967, *Specification for Steel Railway Bridges*.

RS 9-5 Minimum Design Wind Pressures. Provisions for wind pressures are shown in Exhibit RS 9-5.

RS 10 Structural Work

RS 10-1 Masonry. Requirements for unreinforced masonry are given.

RS 10-2 USASI A-41.2 1960, *Building Code Requirements for Reinforced Masonry.*

RS 10-3 ACI 318 1963, *Building Code Requirements for Reinforced Concrete*.

RS 10-4 ACI 525 1963, *Requirements for Thin-Section Precast Concrete Construction*.

RS 10-5 AISC 1963, *Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings*.

RS 10-6 AISI 1962, *Specification for the Design of Light Gage Cold-Formed Steel Structural Members*.

RS 10-8 NLMA 1962, *National Design Specification for Stress-Graded Lumber and Its Fastenings*.

RS 10-9 Plywood Construction

RS 10-10 ASCE 1963, *Suggested Specifications for Structures of Aluminum Alloy*, 6061-T6 and 6062-T6.

RS 10-11 ASCE 1963, *Suggested Specifications for Structures of Aluminum Alloy*, 6063-T5 and 6063-T6.

RS 10-12 USASI A59.1 1954, *American Standard Specifications for Reinforced Gypsum Concrete*.

RS 10-15 ACI 506 1966, *Recommended Practice for Shotcreting*.

RS 10-17 ASTM-C 39 1966, *Standard Method of Test for Compressive Strength of Molded Concrete Cylinders*.

RS 10-18 CS 253 1963, U.S. *Commercial Standard for Structural Glued-Laminated Lumber*.

RS 10-21 ASTM C 192 1962, *Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory* (tentative).

RS 10-44 ASTM-C 494 1967, *Specifications for Chemical Admixtures for Concrete* (tentative).

RS 10-45 Report of Committee 334, Concrete Shell Design and Construction, of the American Concrete Institute, *ACI Journal*, Proc. V 61, No. 9, Sept. 1964.

RS 10-65 ACI 613A 1959, *Recommended Practice for Selecting Proportions for Structural Lightweight Concrete*.

RS 11 Foundations

RS 11-4 AWPA C4 1965, *Standard for the Preservative Treatment of Poles by Pressure Processes*.

RS 11-7 ASTM D 25 1958, *Standard Specification for Round-Timber Poles*.

RS 11-8 ASTM A 252 1963T, *Specification for Welded and Seamless Steel Pipe Poles*.

A1.2 EXHIBITS

Exhibit RS 9-1 Minimum Design Dead Loads

Exhibit RS 9-1 Minimum Design Dead Loads (Continued)

(Continued on next page)

Exhibit RS 9-1 Minimum Design Dead Loads (Continued)

Earth	100
Masonry, ashlar –	
granite	165
limestone (crystalline)	165
limestone (oolitic)	135
marble	173
sandstone (bluestone)	144
Masonry, rubble w/mortar –	
granite	153
limestone (crystalline)	147
limestone (oolitic)	138
marble	156
sandstone (bluestone)	137
Masonry, dry rubble –	
granite	130
limestone (oolitic)	125
marble	130
sandstone (bluestone)	110
Terra cotta, architectural –	
voids filled	120
voids empty	72
Timber, seasoned –	
pine, Douglas fir, and similar species	35
oak, elm, and similar species	45

Exhibit RS 9-2 Minimum Live Loads

REFERENCE STANDARD RS 9-2

MINIMUM REQUIREMENTS FOR UNIFORMLY DISTRIBUTED AND CONCENTRATED LIVE LOADS

UNIFORMLY DISTRIBUTED LIVE LOADS

Occupancy or Use of Spaces	*Live load (psf)*
Assembly spaces	
Drill rooms	150
Assembly spaces having fixed seats, including auditorium areas in churches, schools, theaters, courthouses, lodges, lecture halls, and similar buildings	60[a]
Dance floors, restaurant serving and dining areas, mess halls, museums, gymnasiums, skating rinks, promenades, and roof gardens	100
Private assembly spaces, including conference rooms and card rooms	50
Stadium, grandstand, and reviewing stand seating areas	100
Other assembly spaces	See note [d]

(Continued on next page)

Exhibit RS 9-2 Minimum Live Loads (Continued)

Balconies	
Exterior	See note [b]
Interior (as required for occupancy or use)	
Mezzanines (as required for occupany or use)	
Catwalks	30
Corridors	
(1) Corridors in schools	100
(2) Corridors, elevators, and stairs in office buildings (other than first floor lobbies)	75
(3) Corridors serving first floor elevator lobbies, auditoriums, and similar areas of public assembly	100
(4) Other (same as that required for the occupancy of the area being served)	
Elevator machine rooms (see Reference Standard RS 18)	
Office areas (not including record storage areas)	50
Parking areas	
For passenger cars, provided that the clear headroom at the entrance does not exceed 8 ft.	50
Penal institutions	
Cell blocks	40
Other (as required for occupancy or use of the area)	
Plaza areas (open) accessible to the public (including landscaped portions)	100
Recreation areas	
Bowling alleys (alleys only)	40
Poolrooms	75
Other (see assembly areas)	

(Continued on next page)

Exhibit RS 9-2 Minimum Live Loads (Continued)

Residential areas	
Dormitories	
Non-partitioned	60
Partitioned	40
Dwellings	
Multi-family units	
Apartments	40
Public rooms (as required for occupancy or use)	
One- and two-family units	
First floor	40
Upper floors and habitable attics	30
Uninhabitable attics	20[c]
Hotels	
Guest rooms	40
Public rooms (as required for occupancy or use)	
Schools	
Classrooms	40
Shops (automotive and press shops)	100
Shops (others)	60
Other (as required for occupancy or use of the area)	
Stairs and exit passages (same as Fire escapes)	
Storage	
Light	100
Warehouse	150

(Continued on next page)

Exhibit RS 9-2 Minimum Live Loads (Continued)

CONCENTRATED LIVE LOADS

Use or Location	*Load (lbs.)*[a]	*Remarks*
Elevator machine room floor		See Reference Standard RS-18
Gratings, checkered plates and similar metal decks	200 (on area of 1.0 sq. in.)	Nonconcurrent with uniform live load.
Floor registers and similar floor insets	250 (on area of 2 ft. x 2 ft.)	Nonconcurrent with uniform live load.
Parking areas – passenger vehicles accommodating nine passengers, or less	2,500 (on area of 20 sq. in.) For slab or deck design	The concentrated load may be assumed to represent the reaction of a jack placed under one end of the vehicle. Omit uniform live load in area (6 ft. x 9 ft.) representing one half the vehicle, adjacent to the point of load concentration.
	1,500 (each wheel)	To be used in lieu of uniform live load in stalls of mechanized garages where there is no slab or deck.
Parking areas – trucks, buses and passenger	150 per cent of maximum wheel load with	Same as for Parking areas – passenger vehicles

(Continued on next page)

Exhibit RS 9-2 Minimum Live Loads (Continued)

Stair and fire escape treads	300 (on area 1 ft. wide by depth of the tread and spaced at 3 ft. center-to-center)	Nonconcurrent with uniform live load.
Boiler rooms	3,000	The concentrated load of 3,000 lbs. may be assumed to represent the weight of minor items of equipment (pumps, etc.) in temporary lo-

Exhibit RS 9-5 Minimum Design Wind Pressures

REFERENCE STANDARD RS 9-5
MINIMUM DESIGN WIND PRESSURES

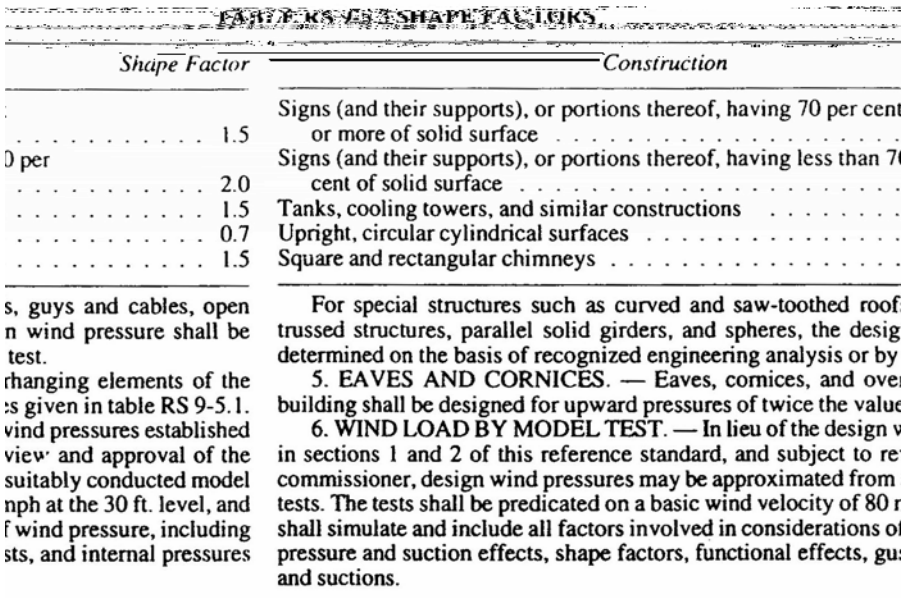
1. DESIGN WIND PRESSURES ON STRUCTURAL FRAMES. – Minimum design pressures due to wind acting on vertical surfaces shall be in accordance with table RS 9-5.1, and minimum design pressures acting normal to horizontal or inclined surfaces shall be in accordance with table RS 9-5.2. The occurrence of the pressures on vertical, horizontal, and inclined surfaces of the building shall be considered as simultaneous.

TABLE RS 9-5.1 DESIGN WIND PRESSURES ON VERTICAL SURFACES

Design Wind Pressure on

(Continued on next page)

Exhibit RS 9-5 Minimum Design Wind Pressures (Continued)



Shape Factor	Construction
. . . . . 1.5	Signs (and their supports), or portions thereof, having 70 per cent or more of solid surface . . . . .
0 per	Signs (and their supports), or portions thereof, having less than 7(cent of solid surface . . . . .
. . . . . 2.0	Tanks, cooling towers, and similar constructions . . . . .
. . . . . 1.5	Upright, circular cylindrical surfaces . . . . .
. . . . . 0.7	Square and rectangular chimneys . . . . .
. . . . . 1.5	

s, guys and cables, open
n wind pressure shall be
test.
rhanging elements of the
:s given in table RS 9-5.1.
vind pressures established
view and approval of the
suitably conducted model
nph at the 30 ft. level, and
f wind pressure, including
sts, and internal pressures

For special structures such as curved and saw-toothed roof
trussed structures, parallel solid girders, and spheres, the desig
determined on the basis of recognized engineering analysis or by

5. EAVES AND CORNICES. — Eaves, cornices, and ove
building shall be designed for upward pressures of twice the value

6. WIND LOAD BY MODEL TEST. — In lieu of the design v
in sections 1 and 2 of this reference standard, and subject to re
commissioner, design wind pressures may be approximated from
tests. The tests shall be predicated on a basic wind velocity of 80 r
shall simulate and include all factors involved in considerations o
pressure and suction effects, shape factors, functional effects, gu
and suctions.

Annex A2
REFERENCE STANDARDS OF 2001 NEW YORK CITY BUILDING CODE

A2.1 REFERENCE STANDARDS

RS 4-5 *Floodproofing Non-Residential Structures and Coastal Construction Manual*

FEMA 55/February 1986 - *Design and Construction Manual for Residential Buildings in Coastal/High Hazard Areas*

FEMA 85/ September 1985 - *Manufactured home installation in flood hazard areas*

FEMA 102/May 1986 - *Floodproofing non-residential structures*

RS 9 Loads

RS 9-1 Same as in 1968 New York City Building Code, which is given in Annex A1.

RS 9-2 Same as in 1968 New York City Building Code, which is given in Annex A1.

RS 9-3 AASHTO 1983, *Standard Specification for Highway Bridges*, 13th Edition and 1984, 1985, 1986 Interim Specifications.

RS 9-4 AREA 1987, *Specification for Steel Railway Bridges*, Chapter 15, Steel Structures, Manual for Railway Engineering.

RS 9-5 Same as in 1968 New York City Building Code, which is given in Annex A1.

RS 9-6 Earthquake Loads. ICBO 1988 with 1990 Accumulative Supplement, *Uniform Building Code*, Section 2312, amended as in Exhibit RS 9-6 of Annex A2.

RS - 10 Structural Work

RS 10-1A Masonry. Requirements for Unreinforced masonry are given.

RS 10-1B Masonry - ACI 530 1992/ASCE 5-92, *Building Code Requirements for Masonry Structures*, as modified. (Modifications are provided in the reference standard.)

- ACI 530.1-92/ASCE 6-92, *Specifications for Masonry Structures*, as modified.

RS 10-2 Reinforced Masonry - ACI 530-92/ASCE 5-92, *Building Code Requirements for Masonry Structures*, as modified. (Modifications are provided in the reference standard.)

- ACI 530.1-92/ASCE 6-92, *Specifications for Masonry Structures*, as modified.

RS 10-3 Reinforced Concrete. ACI 318 1983, *Building Code Requirements for Reinforced Concrete*.

RS 10-3 ACI 318 1989, *Building Code Requirements for Reinforced Concrete.*

RS 10-4 ACI 318, 1963 and applicable sections of ACI 318-83.

RS 10-4 Precast Concrete and Prestressed Concrete - ACI 318 1989; MNL-120-1985.

RS 10-5A AISC-1989, *Specifications for Structural Steel Buildings - ASD and Plastic Design.*

RS 10-5B AISC-LRFD 1993, *Load and Resistance Factor Design Specifications for Structural Steel Buildings.*

RS 10-5C UBC Section 2723, 1990, *Uniform Building Code*.

RS 10-6 AISI 1986, *Specifications for the Design of Cold-Formed Steel Structural Members*.

RS 10-8 AF&PA 1991 and its 1991 Supplement with 1993 Revisions.

RS 10-9 Plywood Construction

RS 10-10 AA SAS 30-1986, *Specifications for Aluminum Structures*.

RS 10-11 ASTM B 209-1988, *Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate.*

ASTM B 308-1988

ASTM B 429-1988

RS 10-12 AF&PA Span Tables for Joists and Rafters 1993 and its Supplement

RS 10-15 Same as in 1968 New York City Building Code.

RS 10-17 ANSI/ASTM C 39-1984

RS 10-18 ANSI/AITC A190.1-1992; AITC 117-1987; AITC 117-1988

RS 10-21 ANSI/ASTM C 192-1981

RS 10-44 ANSI/ASTM C 494-1986

RS 10-45 ACI-ASCE-334

RS 10-65 ACI 211.2-1981

RS-11 Foundations

RS 11-4 AWPA C4 -1988

RS 11-7 ANSI/ASTM D 25; ASTM-D2899-1986

A2.2 EXHIBITS

Exhibit RS 9-6 Earthquake Loads

REFERENCE STANDARD RS 9-6
EARTHQUAKE LOADS

UBC SECTION 2312-1990
Earthquake Regulations with Accumulative Supplement
MODIFICATIONS—The provisions of UBC Section 2312 shall be subject to the following modifications. The subdivisions, paragraphs, subparagraphs and items are from this section.

Subdivision (a) General.

Paragraph 1. Minimum seismic design.

Delete this paragraph and substitute the following:

"The following types of construction shall, at a minimum, be designed and constructed to resist the effects of seismic ground motions as provided in this section:

new structures on new foundations;

new structures on existing foundations; and

enlargements in and of themselves on new foundations. Buildings classified in New York City occupancy group J-3 and not more than three stories in height need not conform to the provisions of this section.

The Commissioner may require that the following types of construction be designed and constructed to incorporate safety measures as necessary to provide safety against the effects of seismic ground motions at least equivalent to that provided in a structure to which the provisions of this section are applicable:

new buildings classified in occupancy group J-3 and which are three stories or less in height; and

enlargements in and of themselves where the costs of such enlargement exceeds sixty percent of the value of the building.

Pursuant to section 27-191 of the code the Commissioner shall have the authority to reject an application for a building permit which fails to comply with the requirements of this section."

Subdivision (b) Definitions.

Delete the definitions of the following terms and substitute the following new definitions:

(Continued on next page)

Exhibit RS 9-6 Earthquake Loads (Continued)

"ECCENTRIC BRACED FRAME (EBF) is a steel-braced frame designed in conformance with reference standard RS 10-5C.

ESSENTIAL FACILITIES are those structures which are necessary for emergency operations subsequent to a natural disaster.

STORY DRIFT is the displacement of one level relative to the level above or below, including translational and torsional deflections."

Add the following definition before "SHEAR WALL":

"REINFORCED MASONRY SHEAR WALL is that form of masonry wall construction in which reinforcement acting in conjunction with masonry is used to resist lateral forces parallel to the wall and which is designed using reinforcement in conformance with Chapter 7 of reference standard RS 10-2."

Delete the definitions of the five frames under the SPACE FRAME paragraph and substitute the following stand-alone definitions:

"INTERMEDIATE MOMENT-RESISTING FRAME (IMRF) is a concrete frame designed in accordance with the requirements of Chapters 1 through 20 and Sections 21.1, 21.2 and 21.9 of reference standard RS 10-3.

MOMENT-RESISTING FRAME is a frame in which members and joints are capable of resisting forces primarily by flexure.

ORDINARY MOMENT-RESISTING FRAME (OMRF) is a moment-resisting frame conforming to the requirements of Chapters 1 through 20 of reference standard RS 10-3 or reference standard RS 10-5A and RS 10-5C but not meeting the special detailing requirements for ductile behavior.

SPECIAL MOMENT-RESISTING FRAME (SMRF) is a moment-resisting frame conforming to reference standards RS 10-3 or RS 10-5A and RS 10-5C and specially detailed to provide ductile behavior by complying with the requirements of Chapters 1 through 20 and Sections 21.1 through 21.8 of reference standard RS 10-3 or reference standards RS 10-5A and RS 10-5C.

VERTICAL LOAD-CARRYING FRAME is a frame designed to carry all vertical gravity loads."

Subdivision (d) Criteria Selection.

Paragraph 1. Basis for design.

Delete the word "zoning" in the first sentence and delete the last sentence.

Paragraph 2. Seismic Zones.

Delete the title and paragraph and substitute the following:

"2. Seismic Zone. The seismic zone factor, Z, for buildings, structures and portions thereof in New York City shall be 0.15. The seismic zone factor is the effective zero period acceleration for S_1 type rock."

Paragraph 3. Site geology and soil characteristics.

Delete the title and paragraph and substitute the following:

"3. Site geology, soil characteristics and foundations.

A. General.

Soil profile type and site coefficient, S, shall be established in accordance with Table No. 23-J.

B. Liquefaction.

(i) Soils of classes 7-65, 8-65, 10-65 and non-cohesive class 11-65 below the ground water table and less than fifty feet below the ground surface shall be considered to have potential for liquefaction.

(ii) The potential for liquefaction of level ground shall be determined on the basis of Standard Penetration Resistance (N) in accordance with Figure No. 4;

Category A: Soil shall be considered liquefiable.

Category B: Liquefaction is possible.

Soil shall be considered liquefiable for structures of Occupancy Categories I, II and III of Table No. 23-K.

Category C: Liquefaction is unlikely and need not be considered in design.

At any site the highest category of liquefaction potential shall apply to the most critical strata or substrata.

(iii) Liquefiable soils shall be considered to have no passive (lateral) resistance or bearing capacity value during an earthquake. An analysis shall be submitted by an engineer which demonstrates, subject to the approval of the Commissioner, that the proposed construction is safe against liquefaction effects on the soil.

(iv) Where liquefiable soils are present in sloped ground or over sloped nonliquefiable substrata and where lateral displacement is possible, a stability analysis shall be submitted by an engineer which demonstrates, subject to the approval of the Commissioner, that the proposed construction is safe against failure of the soil.

C. Foundation Plates and Sills.

Foundation plates or sills shall be bolted to the foundation or foundation wall with not less than one-half inch nominal diameter steel bolts embedded at least seven inches into the concrete or masonry and spaced not more than six feet apart. There shall be a minimum of two bolts per piece with one bolt located within twelve inches of each end of each piece. A properly sized nut and washer shall be tightened on each bolt to the plate.

D. Foundation Interconnection of Pile Caps and Caissons.

Individual pile caps and caissons of every structure subjected to seismic forces shall be interconnected by ties. Such ties shall be capable of resisting, in tension or compression, a minimum horizontal force equal to the product of ZI/4 and the larger column vertical load at the end of each tie.

Exception: Other approved effective methods of foundation interconnection may be used where it can be demonstrated by an analysis that equivalent restraint and relative displacement can be provided."

Paragraph 5, subparagraph C, Irregular structures.

Delete the entire last sentence in item (i).

Paragraph 6, subparagraph E, Dual system.

Delete items (ii) and (iii) and substitute the following:

"Resistance to lateral load is provided by shear walls or braced frames and a moment-resisting frame (SMRF, IMRF or OMRF). The moment-resisting frames shall be designed to independently resist at least 25 percent of the design base shear. The shear walls or braced frames shall be designed to resist at least 75 percent of the cumulative story shear at every level. Overturning effects may be distributed in accordance with item (iii) below.

The two systems shall be designed to resist the total design base shear in proportion to their relative rigidities considering the interaction of the dual system at all levels."

Paragraph 7. Height limits.

Delete this paragraph.

Paragraph 8. Selection of lateral force procedure.

Delete paragraph 8 and substitute the following:

"8. Selection of lateral force procedure. All structures shall be designed using either the static lateral force procedure of Section 2312(e) or using the dynamic lateral force procedure of Section 2312(f). In addition, the dynamic lateral force procedure shall be considered, but is not required, for the design of the following:

A. Structures over 400 feet in height.

B. Irregular structures.

C. Structures located on Soil Profile Type S_4 which have a period greater than 1 second. The analysis should include the effects of soils at the site and should conform to Section 2312(f)2."

Paragraph 9, subparagraph C, Irregular features.

Delete the subparagraph and substitute the following:

"C. Irregular features. Only structures having either vertical irregularities Type D or E as defined in Table No. 23-M or horizontal irregularities Type D or E as defined in Table No. 23-N shall be designed to meet the additional requirements of those sections referenced in the tables."

Paragraph 10. Alternate procedures.

Add at the end of the paragraph the words "when such procedures are consistent with this standard and subject to the approval of the Commissioner."

Subdivision (e) Minimum Design Lateral Forces and Related Effects.

(Continued on next page)

Exhibit RS 9-6 Earthquake Loads (Continued)

Paragraph 1. General, subparagraph A.
Add the words "parking structures" before the word "storage" in the first sentence.
Paragraph 1. General, Subparagraph C.
Delete this subparagraph.
Paragraph 2, subparagraph A, Design base shear.
Change the value for the minimum ratio of C/R_w shown at the end of this subparagraph to "0.050".
Paragraph 2, subparagraph B, Structure period.
Delete the values in item (i) for C_t and substitute the following:
"$C_t = 0.035$ for concrete and steel moment-resisting frames.
$C_t = 0.030$ for eccentric braced frames.
$C_t = 0.030$ for dual systems where the building height exceeds 400 feet or 0.020 for heights less than 160 feet and varies linearly from 0.020 to 0.030 for building heights from 160 to 400 feet.
$C_t = 0.020$ for all other structures."
Delete the sentence immediately after "$C_t = 0.020$ for all other structures" and substitute the following:
"Alternately, the value of T for structures with concrete or masonry shear walls may be taken as $0.1\ (h_n)^{3/4}\sqrt{A_c}$."
Paragraph 3, subparagraph C, Combinations along different axes.
Delete this subparagraph.
Paragraph 6. Horizontal torsional moments.
Delete the fourth paragraph starting with the words "Where torsional irregularity exists" and ending with the words "considered for design."
Paragraph 7, Overturning, subparagraph B.
Delete the words "Seismic Zones 3 and 4" at the beginning of this subparagraph.
Delete item (iii) and substitute the following:
"(iii) Such columns shall meet the detailing or member limitations of reference standard RS 10-3 for concrete and reference standard RS 10-5C for steel structures."
Paragraph 7, subparagraph C.
Delete this subparagraph and substitute the following:
"C. For regular buildings, the force F_t may be omitted when determining the overturning moment to be resisted at the foundation-soil interface."
Paragraph 8. Story drift limitation.
Change the value for the minimum ratio of C/R_w shown at the end of this paragraph to "0.050".
Paragraph 9. P-delta effects.
Delete the last sentence of this paragraph.
Paragraph 10. Vertical component of seismic forces.
Delete this paragraph in its entirety and substitute the following:
"10. Vertical component of seismic forces. Horizontal cantilever components shall be designed for a net upward force of $0.05\ W_p$."
Subdivision (f) Dynamic lateral force procedure.
Paragraph 2. Ground motion.
Add the following at the end of subparagraph A.:
"For soil type S_4 profile, see B. below."
Add the following at the end of subparagraph B.:
"The design of all structures located on a soil type S_4 profile shall be based on properly substantiated site-specific spectra."
Paragraph 5, subparagraph C, Scaling of results.
Add after the word "procedures" in the first sentence, the words "including the appropriate Importance Factor, I,".
Delete item (i) and substitute the following:
"(i) The base shear shall be increased to the following percentage of the value determined from the procedures of Section 2312(e), including consideration of the minimum value of C/R_w, except that the coefficient C, for a period T greater than 3 seconds, may be calculated as 1.80 S/T:
(a) 100 percent for irregular buildings; or
(b) 90 percent for regular buildings, except that the base shear shall not be less than 80 percent of that determined from Section 2312(e) using the period, T, calculated from Method A."
Paragraph 5, subparagraph D, Directional effects.
Delete the words "and prestressed elements" in the second sentence and delete the word "Alternately" at the start of the third sentence.
Paragraph 5, subparagraph F, Dual systems.
Delete this subparagraph and substitute the following:
"F. Dual Systems. Where the lateral forces are resisted by a dual system, as defined in Section 2312(d)6E above, the combined system shall be capable of resisting the base shear determined in accordance with this section. The moment-resisting frame, shear walls and braced frames shall conform to Section 2312(d)6E. The moment-resisting frame may be analyzed using either the procedures of Section 2312(e)4 or those of Section 2312(f)5."
Paragraph 6. Time history analysis.
Add the following words at the end of the sentence: "and the results shall be scaled in accordance with Section 2312(f)5C".
Subdivision (h) Detailed Systems Design Requirements.
Paragraph 1. General.
Delete the words "Chapters 24 through 28" in the fourth sentence of the first paragraph and insert the words "reference standard RS 10".
Delete the words "in Seismic Zones 2, 3 and 4" in the second and fourth paragraphs.
Paragraph 2, subparagraph A, General.
Delete the words "Chapters 24 through 27" at the end of this subparagraph and insert the words "reference standard RS 10".
Paragraph 2, subparagraph C, Connections.
Delete this subparagraph.
Paragraph 2, subparagraph D, Deformation compatibility.
Delete the words "to the reinforcing steel" from the last sentence.
Paragraph 2, subparagraph G, Concrete frames.
Delete this subparagraph and substitute the following:
"G. Concrete frames. Concrete frames required by design to be part of the lateral force resisting system shall, at a minimum, be intermediate moment-resisting frames, except as noted in Table 23-0."
Paragraph 2, subparagraph H, Anchorage of concrete or masonry walls.
Delete the words "Section 2310" in the fifth line and insert the words "reference standards RS 9-6, 10-1B and 10-2".
Paragraph 2, subparagraph I, Diaphragms.
Delete items (iv), (v) and (vi).
Paragraph 2, subparagraph J, Framing below the base.
Delete the words "Chapters 26 and 27" in the third line and insert the words "reference standards RS 10-3 and RS 10-5C".
Paragraph 2, subparagraph K, Building separations.
Delete this subparagraph and substitute the following:
"K. Building Separations. All structures shall be separated from adjoining structures. Separation due to seismic forces shall allow for 1 inch displacement for each 50 feet of total building height. Smaller separation may be permitted when the effects of pounding can be accommodated without collapse of the building."
Subdivision (i) Nonbuilding Structures.
Paragraph 4. Other nonbuilding structures.
Delete in the first sentence of item (iii) the word "national" and insert the word "reference", and delete the words "seismic zones and" in the paragraph following item (iii).
Subdivision (j) Earthquake-recording Instrumentations.
Delete this subdivision.
Table No. 23-I, Seismic Zone Factor Z.
Delete this table and substitute the following new table:

(Continued on next page)

Exhibit RS 9-6 Earthquake Loads (Continued)

TABLE NO. 23-1
SEISMIC ZONE FACTOR Z

ZONE	NEW YORK CITY
Z	0.15

Table No. 23-J. Site Coefficients.
Delete this table and notes and substitute the following new table and notes:

TABLE NO. 23-J
SITE COEFFICIENTS

TYPE	DESCRIPTIONS	FACTOR
S_0	A profile of Rock materials of class 1-65 TO 3-65	0.67
S_1	A soil profile with either: (a) Soft Rock (4-65) or Hardpan (5-65) or similar material characterized by shear-wave velocity greater than 2500 feet per second, or (b) Medium Compact to Compact Sands (7-65) and Gravels (6-65) or Hard Clays (9-65), where the soil depth is less than 100 feet.	1.0
S_2	A soil profile with Medium Compact to Compact Sands (7-65) and Gravels (6-65) or Hard Clays (9-65), where the soil depth exceeds 100 feet.	1.2
S_3	A total depth of overburden of 75 feet or more and containing more than 20 feet of Soft to Medium Clays (9-65) or Loose Sands (7-65, 8-65) and Silts (10-65), but not more than 40 feet of Soft Clay or Loose Sands and Silts.	1.5
S_4	A soil profile containing more than 40 feet of Soft Clays (9-65) or Loose Sands (7-65, 8-65), Silts (10-65) or Uncontrolled Fills (11-65), where the shear-wave velocity is less than 500 feet per second.	2.5

Notes:

1. The site S Type and corresponding S Factor shall be established from properly substantiated geotechnical data with the classes of materials being defined in accordance with Section 27-675 (C26-1103.1) of the administrative code of the City of New York.
2. The soil profile considered in determining the S Type shall be the soil on which the structure foundations bear or in which pile caps are embedded and all underlying soil materials.
3. Soil density/consistency referred to in the table should be based on standard penetration test blow counts (N-values) and taken as: (a) for sands, loose - where N is less than 10 blows per foot, medium compact - where N is between 10 and 30, and compact - where N is greater than 30 blows per foot; and (b) for clays, soft - where N is less than 4 blows per foot, medium - where N is between 4 and 8, stiff to very stiff - where N is between 8 and 30, and hard - where N is greater than 30 blows per foot.
4. When determining the type of soil profile for profile descriptions that fall somewhere in between those provided in the above table, the S Type with the larger S factor shall be used.
5. For Loose Sands, Silts or Uncontrolled Fills below the ground water table, the potential for liquefaction shall be evaluated by the provisions of Section 2312(d)3.

Table No. 23-K, Occupancy Categories.
Add the words "Buildings for schools through secondary or day-care centers - capacity more than 250 students" below the words "Fire and police stations" in the Essential Facilities category, and delete those words from within the Special Occupancy Structure Category.
Add in item III Special Occupancy Structure to the words, "All structures with occupancy > 5000 persons", the words "excluding Occupancy Group E buildings".

Table No. 23-O, Structural Systems.
Delete this table and notes and substitute the following new Table No. 23-O and notes.

TABLE NO. 23-O
STRUCTURAL SYSTEMS

BASIC STRUCTURAL SYSTEM	LATERAL LOAD-RESISTING SYSTEM DESCRIPTION	R_w
A. Bearing Wall System	1. Light-framed walls with shear panels	
	a. Plywood walls for structures three stories or less	8
	b. All other light-framed walls	6
	2. Shear Walls	
	a. Concrete	6
	b. Reinforced masonry	5
	3. Light steel-framed bearing walls with tension-only bracing	4
	4. Braced frames where the bracing carries gravity load	
	a. Steel	6
	b. Concrete	4
	c. Heavy timber	4
B. Building Frame system	1. Steel eccentric braced frame (EBF)	10
	2. Light-framed walls with shear panels	
	a. Plywood walls for structures three stories or less	9
	b. All other light-framed walls	7
	3. Shear Walls	
	a. Concrete	8
	b. Reinforced masonry	6
	4. Concentric braced frames	
	a. Steel	8
	b. Concrete	8
	c. Heavy timber	8
C. Moment-Resisting Frame System	1. Special moment-resisting frames (SMRF)	
	a. Steel	12
	b. Concrete	12
	2. Concrete intermediate moment-resisting frames (IMRF)	8
	3. Ordinary moment-resisting frames (OMRF)	
	a. Steel	6
	b. Concrete[4]	4
D. Dual System	1. Shear Walls	
	a. Concrete with SMRF	12
	b. Concrete with Steel OMRF	6
	c. Concrete with concrete IMRF	9
	d. Concrete with concrete OMRF	5
	e. Reinforced masonry with SMRF	8
	f. Reinforced masonry with steel OMRF	6
	g. Reinforced masonry with concrete IMRF	7
	2. Steel eccentric braced frame	
	a. With steel SMRF	12
	b. With steel OMRF	6
	3. Concentric braced frames	
	a. Steel with steel SMRF	10
	b. Steel with steel OMRF	6
	c. Concrete with concrete SMRF	9
	d. Concrete with concrete IMRF	6

Notes:

1. Basic structural systems are defined in Section 2312(d)6.
2. See Section 2312(e)3 for combinations of structural systems.
3. See Sections 2312(d)8C and 2312(d)9B for undefined systems.
4. Prohibited with S_3 or S_4 soil profiles or where the height exceeds 160 feet.

(Continued on next page)

Exhibit RS 9-6 Earthquake Loads (Continued)

Table No. 23-P, Horizontal Force Factor C_p.
Delete this table and notes and substitute the following new Table No. 23-P and notes:

Table No. 23-P
HORIZONTAL FORCE FACTOR C_p[1]

ELEMENTS AND STRUCTURES, NONSTRUCTURAL COMPONENTS AND EQUIPMENT	VALUE OF C_p
I. Part of Portion of Structure	
1. Walls, including the following:	
a. Unbraced (cantilevered) parapets.	2.00
b. Other exterior walls above street grade[2].	0.75
c. All interior bearing walls.	0.75
d. All interior nonbearing walls and partitions around vertical exits, including offsets and exit passageways.	0.75
e. Nonbearing partitions and masonry walls in areas of public assembly > 300 people.	0.75
f. All interior nonbearing walls and partitions made of masonry in Occupancy I, II and III.	0.75
g. Masonry or concrete fences at grade over 10 feet high.	0.50
2. Penthouses (defined in article 2 of subchapter 2 of chapter 1 of title 27 of the building code) except where framed by an extension of the building frame	0.75
3. Connections for prefabricated structural floor and roof elements other than walls (see above) with force applied at center of gravity.	0.75
4. Diaphragms[3].	
II. Nonstructural Components	
1. a. Exterior ornamentation and appendages including cornices, ornamental statuaries or similar pieces of ornamentation.	2.00
b. Interior ornamentation and appendages in areas of public assembly including cornices, ornamental statuaries or similar pieces of ornamentation.	2.00
2. Chimneys, stacks, trussed towers and tanks on legs.	
a. Supported on or projecting as an unbraced cantilever above the roof more than one-half its total height.	2.00
b. All others, including those supported below the roof with unbraced projection above the roof less than one-half its height, or braced or guyed to the structural frame at or above its center of mass.	0.75
3. Exterior signs and billboards.	2.00
III. Equipment and Machinery[4]	
1. Tanks and vessels (including contents), including support systems and anchorage.	0.75

Notes:
1. See Section 2312(g)[2] for additional requirements for determining C_p for nonrigid equipment or for items supported at or below grade.
2. See Section 2312(h)2D(iii) and Section 2313(g)2.
3. See Section 2312(h)2I.
4. Equipment and machinery include such items as pumps for fire sprinklers, motors and switch gears for sprinkler pumps, transformers and other equipment related to life-safety including control panels, major conduit ducting and piping serving such equipment and machinery.

Figure No. 3, Normalized Response Spectra Shapes.
Delete the Figure No. 3 and insert the New Figure 3 and Table No. 23-R.

TABLE NO. 23-R
SPECTRAL ACCELERATION
IN FRACTION OF G
5% DAMPING

T-SEC	S_0	S_1	S_2	S_3
.01	0.150	0.150	0.150	0.150
.02	0.150	0.150	0.150	0.150
.05	0.375	0.283	0.262	0.244
.075	0.375	0.375	0.336	0.303
.090	0.375	0.375	0.375	0.334
.112	0.375	0.375	0.375	0.375
.267	0.375	0.375	0.375	0.375
.40	0.250	0.375	0.375	0.375
.48	0.208	0.313	0.375	0.375
.60	0.167	0.250	0.300	0.375
1.00	0.100	0.150	0.180	0.225
2.00	0.050	0.075	0.090	0.113
3.00	0.033	0.050	0.060	0.075

Note: This table presents acceleration (g) versus natural period (seconds) to facilitate the presentation of spectra in log-log form.

(Continued on next page)

Exhibit RS 9-6 Earthquake Loads (Continued)

FIGURE NO. 3
NORMALIZED RESPONSE SPECTRA
5% DAMPING

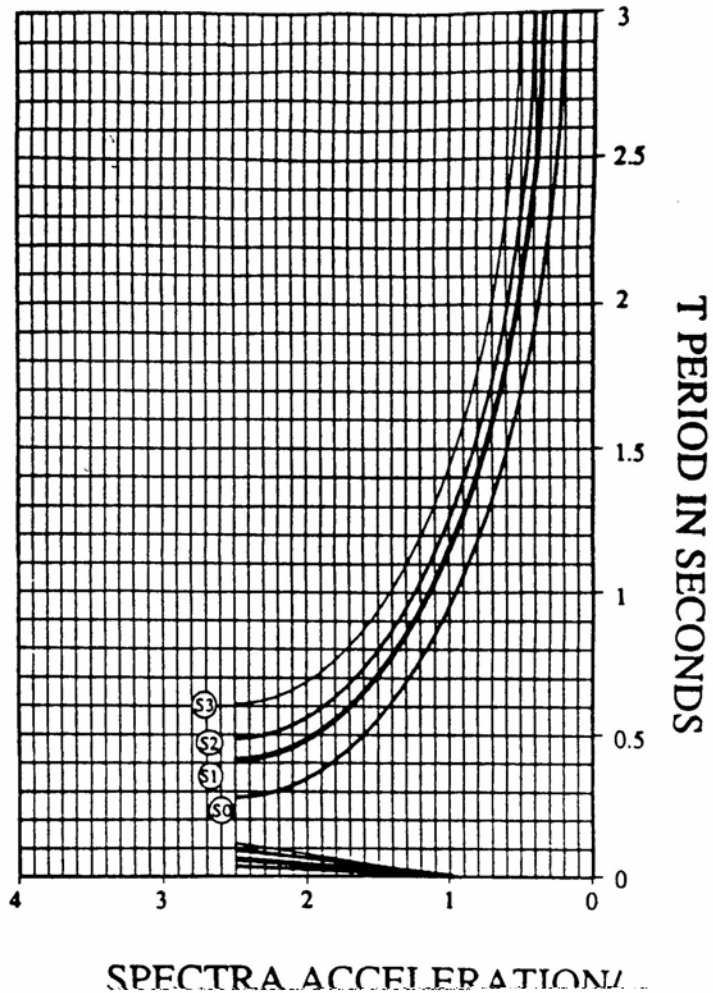
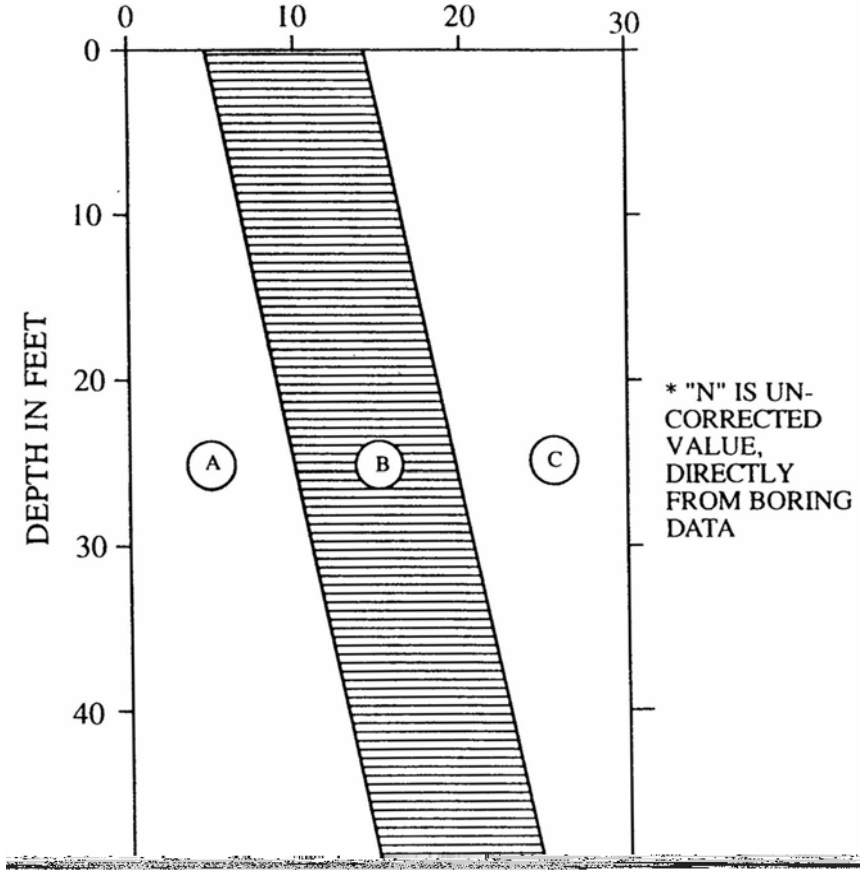


FIGURE NO. 4
"N" IN BLOWS PER FOOT*



Annex A3
REFERENCE STANDARDS OF 1964 NEW YORK STATE BUILDING CONSTRUCTION CODE

A3.1 INTRODUCTION

The *Generally Accepted Standards Applicable to Structural Requirements*, given in A3.2, was published by the New York State Building Code Council for the State Building Construction Code dated January 2, 1968. This is the oldest copy the Department of State Codes Division (NY) has available at this time (November 2003).

A3.2 GENERALLY ACCEPTED STANDARDS

Generally Accepted Standards
applicable to
Structural Requirements

ADHESIVES

FS, Adhesive, Casein-Type, Water-and Mold-Resistant, MMM-A-125b, 1964
FS, Adhesive, Urea-Resin-Type (Liquid and Powder), MMM-A-188b, 1960
MIL, Adhesive, Phenol and Resorcinol Resin Base (for Marine Service Use) MIL-A-22397, 1960 with 1964 amendment

ALUMINUM

AA, Aluminum Construction Manual, Section A, Specifications for Structures of Aluminum Alloys, 1963

CONCRETE AND CONCRETE UNITS

ACI, Building Code Requirements for Reinforced Concrete, ACI 318-63
ACI, Minimum Standard Requirements for Precast Concrete Floor and Roof Units, ACI 711-58
ASTM Various Specifications as listed in Section 410 of Building Code Requirements for Reinforced Concrete ACI 318-63

(Continued on next page)

A3.2 Generally Accepted Standards (Continued)

ASTM, Specifications for Natural Cement, C 10-64
ASTM, Specifications for Gypsum, C 22-50

Reinforcement for Concrete

Reinforcement (ASTM Specifications) as listed in Building Code Requirements for Reinforced Concrete, ACI 318-63, Sections 405 and 410

(Continued on next page)

A3.2 Generally Accepted Standards (Continued)

Structural Steel and Iron

AISC,	Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, adopted April, 1963
AISC,	Specifications for Structural Joints using ASTM-A325 or A 490 Bolts, Approved by the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation, September, 1966
ASTM,	Specification for Gray Iron Castings, A 48-64
ASTM,	Specification for Welded and Seamless Steel Pipe, A 53-67
ASTM,	Specifications for Welded Wrought-Iron Pipe, A 72-66
ASTM,	Specifications for Welded and Seamless Steel Pipe Piles, A 252-63T
SJI,	Standard Specifications and Load Tables-Open Web Steel Joists, 1967

WOOD

APA,	Plywood Design Specifications, Nov. 1966
ASTM,	Methods for Establishing Structural Grades of Lumber, D 245-64T
ASTM,	Methods of Conducting Strength Tests of Panels for Building Construction, E 72-61
CS,	Wood Shingles: Red Cedar, Tidewater Red Cypress, California Redwood, CS 31-52
CS,	Hardwood Plywood, CS 35-61
CS,	Structural Glued Laminated Timber, CS 253-63
NFPAssn.	National Design Specification for Stress-Grade Lumber and Its Fastenings, 1962
NFPAssn.	Working Stresses for Stress-Grade Lumber, Supplement No. 1, 1967, to Wood Structural Design Data, Vol. 1, 1957
NFPAssn.	Plank-and-Beam Framing for Residential Buildings, Wood Construction Data No. 4, 1961
NFPAssn.	Heavy Timber Construction Details, Wood Construction Data No. 5, 1961
PS,	U.S. Product Standard PS-1-66 for Softwood Plywood

Wood Treatment

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Annex A4
REFERENCE STANDARDS OF 1967 CHICAGO MUNICIPAL CODE

A4.1 REFERENCE STANDARDS

Standards that represent Accepted Engineering Practice in the Chicago Municipal Code are listed in the following table.

(a) Foundations.	
Piles—Timber.	ASTM D25-55
Piles—Welded and Seamless. Steel Pipe	ASTM A252-55
Piles—Wood Preservative.	
Treatment Douglas Fir	AWPA-C1-1958
Southern Pine	AWPA-C3-1958
Creosoted Treatment	AWPA-C12-1951
(b) Masonry.	
American Standard Building Code. Requirements for Masonry- Miscellaneous Publication 211	USDC-NBS-July 15, 1954
(c) Wood.	
National Design Specifications for Stress—Grade Lumber and Its Fastenings	NLMA-1957
Glues—For Laminated and Built-up Members	FSMMM-A-188
Plywood—Douglas Fir	NBS-CS45-55
Plywood—Hardwood	NBS-CS-35-56
Plywood—Western Softwood	NBS-CS122-56
(d) Reinforced Concrete.	
Building Regulations for Reinforced Concrete	ACI-318-63
(e) Reinforced Gypsum.	
Reinforced Gypsum Concrete	ASA-A59.1-1954

(g) Plastering.	
Including American Standard Specifications for Gypsum Plastering and Interior Lathing and Furring—	A42.1-1955 and A42.4-1955
Standard Specifications for Portland Cement Stucco and Portland Cement Plastering	ASA-A 42.2-1946 ASA-A42.3-1946
(h) Single Family Dwellings.	
Minimum Property Requirements for Properties of One or Two Family Living Units Located in the State of Illinois, Sections 402, 403, 406, 408 and 410 to 414 inclusive, except 'Note' to, and paragraph 3 of, section 406-G shall not apply. See section 68-5(b) which excepts FHA requirement 406-E.-4a.	FHA-1947

(Continued on next page)

(i) **Abbreviations.**

ACI	American Concrete Institute.
AISC	American Institute of Steel Construction.
AISI	American Iron and Steel Institute.

Annex A5
REFERENCE STANDARDS OF 1965 BOCA BUILDING CODE

A5.1 REFERENCE STANDARDS

Appendix A	Accredited Authoritative Agencies.
Appendix B	Accepted Engineering Practice Standards. The accepted engineering practice standards relevant to Structural provisions are given in Exhibit B of Annex A5.
Appendix C	Material Standards. Relevant standards are given in Exhibit C of Annex A5.
Appendix D	Structural Unit Test Standards. Relevant standards are given in Exhibit D of Annex A5.
Appendix E	Structural Assembly Test Standards. Relevant standards are given in Exhibit E of Annex A5.
Appendix F	Durability Test Standards. Relevant standards are given in Exhibit F of Annex A5.
Appendix G - I	Fire related.
Appendix J	Unit Design Dead Loads for Structural Design Purposes. Minimum Design Dead loads are given in Exhibit J of Annex A5.
Appendix K	Unit Working Stresses for Ordinary Materials. Given in Exhibit K of Annex A5.
Appendix K-11	Earthquake Load Design. Detailed requirements are given in Exhibit K-11 of Annex A5.
Appendix K-12	Glass Design Criteria.

A5.2 EXHIBITS

APPENDIX B

ACCEPTED ENGINEERING PRACTICE STANDARDS

See also appendixes, C, D, E, F, and G for standards on specific materials or tests of units or assemblies, some of which include engineering practice standards for specific applications.

High Hazard materials handling and storage; fire protection devices; heating equipment rules, specifications and standards ..... NFPA
National Fire Codes; Handbook of Fire Protection; standards and reports ..... NFPA
Technical bulletins of building construction data ..... HHFA

CONCRETE

Floor and Roof Units, Precast Concrete—Minimum Standard Requirements for ..... ACI 711—1958
Gypsum Concrete, Reinforced—Specifications for ..... ASA A 59.1—1954
Reinforced Concrete—Building Code Requirements for ..... ACI 318—1963
Reinforced Concrete Structures, Manual of Standard Practice for Detailing ..... ACI 315—1965
Welding Reinforcing Steel, Metal Inserts and Connections in Reinforced Concrete Construction, Recommended Practices for ..... AWS D 12.1—61

MASONRY

Lime-Cement Stucco—Standard Specifications for ..... ASA A 42.5—1960
Marble, Exterior Thin Veneer—Specifications for ..... ASA A 94.2—1961
Marble, Exterior Thin, in Curtain or Panel Walls—Specifications for ..... ASA A 94.3—1961
Marble, Interior—Specifications for ..... (See **INTERIOR FINISHES**)
Masonry—Standard Requirements for ..... ASA A 41.1—1953
Reinforced Masonry—Standard Requirements for ..... ASA A 41.2—1960

METALS

Aluminum Construction, Manual, Section A—Specifications for Structures of Aluminum Alloys ..... AA—1963

STEEL

Cold-Formed Steel ..... (See **Light Gage Cold-Formed Steel**)
Design, Fabrication and Erection of Structural Steel for Buildings
—Specifications for ..... AISC—1963
—Architectural Exposed Structural Steel—Specifications for ..... AISC—1960
—Structural Joints Using ASTM A 325, or A 490 Bolts—Specifications for ..... AISC—1964
Gas Systems for Welding and Cutting ..... (See **FIRE PROTECTION AND SAFETY PRACTICES**)

Light Gage Cold-Formed Steel

—Design Manual ..... AISI—1962
—Structural Members—Specifications for the Design of ..... AISI—1962

Steel Joist, Open Web

Steel Joist Construction, Open Web—Long Span or LA Series—Standard Specifications for ..... AISC-SJI—1961
—J Series and H Series—Specifications and Load Tables for ..... SJI-AISC—1965
—Longspan or LH Series, Standard Specifications ..... SJI—AISC—June 21—1962
Structural Steel ..... (See **Design Fabrication and Erection of**)
Welding in Building Construction, Code for ..... AWS—1963

WOOD AND WOOD PRODUCTS

How to Design a Pole-Type Building ..... AWPI—1965
Lumber, Stress Grade ..... (See Stress Grade Lumber)
Lumber, Structural Glued Laminated—Inspection Manual for ..... AITC—200—63
Plywood, Fir—Technical Data Handbook ..... DFPA—1960
Plywood Beams—Specifications for Design and Fabrication of ..... DFPA Spec. No. BB-8—1963
Plywood Folded Plates—Specifications for Fabrication of ..... DFPA Spec. No. FP-62—1962
Plywood-Lumber Structural Assemblies—Specifications for Design of ..... DFPA Spec. No. 1—1964
Plywood Panels, Curved—Specifications for Design of ..... DFPA Spec. No. CP-8—1963
Plywood Panels—Flat with Stressed Covers—Specifications for Design and Fabrication of ..... DFPA Spec. No. SS-8—1963
Pressure Treated Timber Foundation Piles for Permanent Structures ..... AWPI—1965
Stress Grade Lumber and Its Fastenings—National Design Specifications for ..... NLMA—1962
Structural Design Data—Wood ..... NLMA—1957
Timber Construction Standards ..... AITC—100—1962
Wood Handbook ..... USDA Handbook No. 72—1955

UNCLASSIFIED-MISCELLANEOUS

Building Codes—Administrative Requirements for ..... ASA A 55.1—1948
Building Construction—Safety Code for ..... ASA A 10.2—1944
Building Materials—Coordination of Dimensions of ..... ASA A 62.1—1957
Fibrous Glass Air Duct—Standard for ..... NIMA Feb. 1, 1965
Floor and Wall Openings, Railings, and Toe Boards—Safety Code for ..... ASA A 12—1932
Floors—Waterproofing of ..... NFPA 92—1937
Flue Linings—Sizes of ..... ASA A 62.4—1947
Fuel Oils—Classification of ..... USDC CS 12—1948
Homes—Prefabricated ..... USDC CS 125—1947
Light and Ventilation—Standards for ..... ASA A 53.1—1946
Loads, Minimum Design—Standards for ..... ASA A 58.1—1955
Signs and Outdoor Display Structures—Standards for ..... ASA A 60.1—1949
Welding in Building Construction, Code for ..... (See **METALS—STEEL**)

Exhibit C Material Standards

APPENDIX C
MATERIAL STANDARDS

See also appendix D for standards for tests of specific materials.

CONCRETE

Aggregates, Concrete Specifications for ..... ASTM C 33—64
Aggregates, Lightweight, for Structural Concrete—
Specifications for ..... ASTM C 330—64T
Aggregates, Lightweight, for Concrete Masonry Units—
Specifications for ..... ASTM C 331—64T
Aggregates, Lightweight, for Insulating Concrete—
Specifications for ..... ASTM C 332—61
Bar Supports, Wire, in Reinforced Concrete Construction—
Simplified Practice Recommendation for ..... USDC SP 4687
Floor and Roof Units, Precast Concrete—
Minimum Standard Requirements for ..... ACI 711—58
Forms for Concrete Joist Construction Floors ..... USDC R 87—32
Forms for Two-Way Concrete Joist Floor and Roof Construction ..... USDC R 265—63
Gypsum Concrete—Specifications for ..... ASTM C 317—64
Masonry Units—Concrete ..... (See **MASONRY**)
Natural Cement—Specifications for ..... ASTM C 10—64
Portland Cement, Air-Entraining—Specifications for ..... ASTM C 175—64
Portland Cement—Specifications for ..... ASTM C 150—64
Ready-Mixed Concrete—Specifications for ..... ASTM C 94—64
Reinforcing ..... (See **METALS**)
Roofs and Slabs-On-Grade, Vermiculite Concrete—
Specifications for ..... ASA A 122.1—1965
Waterproof Paper for Curing Concrete—Specifications for ..... ASTM C 171—63

FIRE PROTECTION

Fire Retardant Properties of Treated Textile Fabrics—
Specifications for ..... ASTM D 626—55T

INTERIOR FINISHES

Adhesive—Water Resistant Organic, for Installation of
Clay Tile ..... USDC CS 181—52
Aggregates, Inorganic, for use in Gypsum Plaster—
Specifications for ..... ASTM C 35—62
Gypsum and Gypsum Products, Chemical Analysis of—
Standard Methods for ..... ASTM C 471—61
Gypsum Board Products and Gypsum Partition Tile or Block,
Physical Testing of—Standard Methods for ..... ASTM C 473—62
Gypsum Lath—Specifications for ..... ASTM C 37—54
Gypsum Plasters—Specifications for ..... ASTM C 28—63
Gypsum Plasters and Gypsum Concrete, Physical Testing of—
Standard Methods for ..... ASTM C 472—64
Gypsum Wallboard—Specifications for ..... ASTM C 36—64
Lime, Hydrated, Normal Finishing—Specifications for ..... ASTM C 6—49
Lime, Hydrated, Special Finishing—Specifications for ..... ASTM C 206—49
Quicklime and Hydrated Lime—Methods of Physical
Testing of ..... ASTM C 110—58
Quicklime for Structural Purposes—Specifications for ..... ASTM C 5—59

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Exhibit C Material Standards (Continued)

MASONRY

Aggregate, Fine—Method of Test for Measuring Mortar-Making Properties of	ASTM C 87—63T
Aggregate for Masonry Grout—Specification for	ASTM C 404—61
Aggregate for Masonry Mortar—Specifications for	ASTM C 144—62T
Brick, Building (Solid Masonry Units Made from Clay or Shale)—Specifications for	ASTM C 62—62
Brick, Concrete Building—Specifications for	ASTM C 55—64T
Brick, Facing (Solid Masonry Units Made from Clay or Shale)—Specification for	ASTM C 216—64
Brick, Sand-Lime Building—Specifications for	ASTM C 73—51
Cement, Masonry—Specifications for	ASTM C 91—64
Clay Facing Tile, Structural—Specification for	ASTM C 212—60
Clay Floor Tile, Structural—Specification for	ASTM C 57—57
Clay Load-Bearing Wall Tile, Structural—Specification for	ASTM C 34—62
Clay Non-Load-Bearing Screen Tile, Structural—Specification for	ASTM C 530—63T
Clay Non-Load-Bearing Wall Tile, Structural—Specification for	ASTM C 56—62
Concrete Masonry Units, Hollow Load Bearing—Specifications for	ASTM C 90—64T
Concrete Masonry Units, Hollow Non-Load Bearing—Specifications for	ASTM C 129—64T
Concrete Masonry Units, Solid Load Bearing—Specifications for	ASTM C 145—64T
Dry-set Portland Cement Mortar	ASA A 118.1—1959
Glazed Units:—Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units—Specifications for	ASTM C 126—62
ASTM C 52—54	Gypsum Partition Tile and Block—Specifications for
ASTM C 207—49	Lime, Hydrated, for Masonry Purposes—Specifications for
OR FINISHES)	Limes (See INTERI
ASTM C 476—63	Mortar and Grout for Reinforced Masonry—Specification for
STM C 270—64T	Mortar for Unit Masonry—Specification for
ee CONCRETE)	Portland Cement—Specification for (S

METAL

ASTM A 490—65	Alloy Steel Bolts, Quenched and Tempered, for Structural Steel Joints—Standard Specifications for
ASTM A 490—65	Alloy Steel Bolts, Quenched and Tempered, for Structural Steel Joints—Standard Specifications for
ASTM A 506—64	Alloy Steel Sheets and Strip, Regular Quality Hot-Rolled and Cold-Rolled—Specification for
ASTM B 221—64	Aluminum-Alloy Bars, Rods, Shapes and Tubes—Standard Specification for
ASTM B 211—64	Aluminum-Alloy Bars, Rods and Wire—Standard Specifications for
ASTM B 247—64	Aluminum-Alloy Die and Hand Forgings—Standard Specification for
ASTM B 241—64	Aluminum-Alloy Pipe—Standard Specifications for
ASTM B 209—64	Aluminum-Alloy Sheet and Plate—Standard Specifications for
ASTM B 308—64	Aluminum-Alloy Standard Structural Shapes, Rolled or Extruded—Standard Specifications for
ASTM B 210—64	Aluminum-Alloy Drawn Seamless Tubes—Standard Specifications for
ASTM B 313—63	Aluminum-Alloy Round Welded Tubes—Standard Specifications for
STM B 285—61T	Aluminum and Aluminum-Alloy Welding Rods and Bare Electrodes—Tentative Specifications for
ASTM B 316—64	Aluminum-Alloy Rivet and Cold Heading Wire and Rods—Standard Specifications for
ASTM B 85—60	Aluminum-Base Alloy Die Castings—Standard Specifications for
ASTM B 108—64	Aluminum-Base Alloy Permanent Mold Castings—Standard Specification for
ASTM B 26—64	Aluminum-Base Alloy Sand Castings—Standard Specification for
AMA 402.4—1965	Aluminum Sliding Glass Doors—Specifications for
AMA 302.4—1965	Aluminum Windows—Specifications for

(Continued on next page)

Exhibit C Material Standards (Continued)

METAL *(Continued from previous page)*

Reinforcement, Steel Wire, Cold-Drawn, for Concrete—
Specifications for ..... ASTM A 82—62T

Reinforcement, Deformed Steel Wire for Concrete ..... ASTM A 496—64

Reinforcement, Welded Deformed Steel Wire Fabric for Concrete.... ASTM A 497—64

Reinforcement—Steel Wire, Welded Fabric, for Concrete—
Specifications for ..... ASTM A 185—64

Rivet Steel, Structural—Specifications for ..... ASTM A 141—58

Rivet Steel, Structural, High-Strength—Specifications for ..... ASTM A 195—59

Rods, Gas Welding, for Iron and Steel—Specifications for..... ASTM A 251—46T

Seven-Wire Stress-Relieved Strand, Uncoated, for Prestressed
Concrete—Specification for ..... ASTM A 416—64

Uncoated Stress-Relieved Wire for Prestressed Concrete—
Specification for ..... ASTM A 421—65

Sheet Piling, Steel—Specification for ..... ASTM A 328—65

Steel for Bridges and Buildings—Specifications for ..... ASTM A 7—61T

Steel Plate, Sheet and Strip, Corrosion-Resisting Chromium—
Specification for ..... ASTM A 176—63

Steel Plate, Sheet and Strip, Corrosion-Resisting Chromium-Nickel—
Specification for ..... ASTM A 167—63

Steel Sheets and Strip, High Strength Low Alloy Hot-Rolled ..... ASTM A 375—64

Structural Steel—Specifications for ..... ASTM A 36—63T

Structural Steel, High Strength—Specifications for ..... ASTM A 440—63T

Structural Steel, High Strength Low Alloy—Specifications for ..... ASTM A 242—64T

Structural Steel, High Strength Low Alloy Manganese Vanadium—
Specifications for ..... ASTM A 441—64T

(Continued on next page)

Exhibit D Structural Unit Test Standards

APPENDIX D

STRUCTURAL UNIT TEST STANDARDS

See also appendixes B and C for engineering practice standards and material standards which contain unit test methods.

CONCRETE

Coarse Aggregates, Resistance to Abrasion of Small Size, by use of the Los Angeles Machine—Method of Test for ..... ASTM C 131—64T
Fine and Coarse Aggregates, Sieve or Screen Analysis of—Method of Test for ..... ASTM C 136—63
Graded Coarse Aggregates, Abrasion of, by Use of the

MASONRY

Aggregate for Masonry Mortar—Specifications for ..... ASTM C 144—62T
Brick, Concrete Building—Specifications for ..... ASTM C 55—55
Brick—Methods of Testing and Sampling ..... ASTM C 67—62
Cement, Masonry—Specifications for ..... ASTM C 91—64
Concrete Masonry Units ..... (See CONCRETE)
Glazed Units—Ceramic Glazed Structural Clay Facing Tile, Facing Bricks, and Solid Masonry Units—Specifications for ..... ASTM C 126—62
Lime and Limestone Products—Methods of Sampling, Inspection, Packing and Marking of ..... ASTM C 50—57
Lime, Hydrated and Quick—Methods of Physical Testing of ..... ASTM C 110—58
Lime, Hydraulic Hydrated for Structural Purposes—Specifications for ..... ASTM C 141—61
Mortars, Hydraulic Cement—Method of Test for Compressive Strength of (Using 2 in. cube Specimens) ..... ASTM C 109—64
Mortars, Hydraulic Cement—Method of Test for Tensile Strength of ..... ASTM C 190—63
Stone, Natural Building—Methods of Test for Absorption and Bulk Specific Gravity of ..... ASTM C 97—47
Stone, Natural Building—Method of Test for Compressive Strength of ..... ASTM C 170—50
Stone, Natural Building—Methods of Test for Modulus of Ruptures of ..... ASTM C 99—52
Tile, Structural Clay—Methods of Sampling and Testing ..... ASTM C 112—60

METALS

Cast Iron—Method of Testing Compression of ..... ASTM A 256—46
Metallic Materials—Methods of Tension Testing of ..... ASTM E 8—61T

UNCLASSIFIED MISCELLANEOUS

Cement, Hydraulic—Methods of Sampling ..... ASTM C 183—64T
Cement, Natural—Specifications for ..... ASTM C 10—64
Cement, Portland—Specifications for ..... ASTM C 150—64
Plastics Under Load—Method of Test for Deformation of ..... ASTM D 621—64
Tile, Clay Drain—Specification for ..... ASTM C 4—62

WOOD AND WOOD PRODUCTS

Timber, Small Clear Specimens—Method of Testing ..... ASTM D 143—52
Timbers in Structural Sizes—Methods of Static Tests of ..... ASTM D 198—27
Veneer, Plywood and Other Glazed Veneer Construction—Methods of Testing ..... ASTM D 805—63

Exhibit F Durability Test Standards

APPENDIX F

DURABILITY TEST STANDARDS

See also appendixes C, D and E for tests of individual materials or unit assemblies.

CONCRETE AND CONCRETE AGGREGATE

Concrete, Aggregate—Method of Tests for Voids in ..... ASTM C 30—37
Concrete, Air Content of Freshly Mixed, by the Pressure Method—Method of Test for ..... ASTM C 231—62
Concrete, Weight per Cubic Foot, Yield and Air Content of—Method of Test for ..... ASTM C 138—63
Organic Impurities in Sand for Concrete—Method of Test for..... ASTM C 40—60

MASONRY AND MASONRY PRODUCTS

Ceramic Glazed Structural Clay Facing Tile, Facing Brick and Solid Masonry Units—Specifications for (Autoclave Test) ..... ASTM C 126—62
Freezing and Thawing Tests (See Specifications for Materials)
—Bricks—Methods of Sampling and Testing ..... ASTM C 67—62
—Drain Tile—Specifications for ..... ASTM C 4—62
—Structural Clay Tile—Methods of Sampling and Testing ..... ASTM C 112—60

PLASTICS

Accelerated Weathering Tests of Plastics—Recommended Practice for ..... ASTM D 795—57T
Water Absorption of Plastics—Method of Test for ..... ASTM D 570—63

ROOFING AND SIDING

Asphalt Roll Roofing, Cap Sheets, and Shingles—Methods of Testing ..... ASTM D 228—64
Bituminous Materials, Accelerated Weathering Test of—Recommended Practice for ..... ASTM D 529—62
Felted and Woven Fabrics Saturated with Bituminous Substance for Use in Waterproofing and Roofing—Methods of Sampling and Testing ..... ASTM D 146—59

UNCLASSIFIED MISCELLANEOUS

Fibre Building Boards—Method of Accelerated Aging..... NBS BMS 4—38
Fibre Building Boards—Method of Accelerated Aging ..... ASTM D 1037—63T
Gypsum Products, Wood Fibre Content in—Method of Test for ..... ASTM C 26—59
Textile Fabrics—Method of Test for Water Resistance of ..... ASTM D 583—63

Exhibit J Unit Design Dead Loads for Structural Design Purposes

APPENDIX J

UNIT DESIGN DEAD LOADS FOR STRUCTURAL DESIGN PURPOSES

WALLS AND PARTITIONS (Unplastered)	Pounds per Square Foot
12 inch common brick	120
12 " pressed brick	130
12 " sand-lime brick	105
12 " hollow concrete block—Stone Aggregate	74
Lightweight	55
10 " hollow concrete block—Stone Aggregate	62
Lightweight	46
8 " hollow concrete block—Stone Aggregate	50
Lightweight	36
6 " hollow concrete block—Stone Aggregate	42
Lightweight	36
4 " hollow concrete block—Stone Aggregate	27
Lightweight	20
12 " solid concrete block—Stone Aggregate	108
Lightweight	72
10 " solid concrete block—Stone Aggregate	84
Lightweight	62
8 " solid concrete block—Stone Aggregate	67
Lightweight	48
6 " solid concrete block—Stone Aggregate	50
Lightweight	37
4 " solid concrete block—Stone Aggregate	45
Lightweight	34
12 " combination brick and clay tile	80
8 " " " " " "	60
12 " combination brick and concrete block	90
8 " " " " " "	72
12 inch load-bearing clay tile	60
8 " " " " "	40
6 " " " " "	36
4 " " " " "	24
10 " non-load-bearing clay tile	40
8 " " " " "	36
6 " " " " "	30
4 " " " " "	20
3 " " " " "	18
2 " " " " "	11
8 " non-load-bearing hollow concrete block	40
6 " " " " " "	30
4 " " " " " "	20
T.C. 1½ inch split terra cotta furring	8
2 inch split terra cotta furring	10
3 " " " " "	12
6 " hollow gypsum block	24
5 " " " "	18
4 " " " "	15
3 " " " "	10

(Continued on next page)

Exhibit J Unit Design Dead Loads for Structural Design Purposes (Continued)

	Pounds per Square Foot
4 inch solid gypsum block	24
3 " " " "	18
2 " " " "	12
4 " glass block	18

	Pounds per Cubic Foot
Cast stone solid	144
Granite ashlar	168
Limestone ashlar	168
Marble ashlar	168
Sandstone ashlar	156
Rubble stone masonry	156
Terra cotta architectural (filled)	120
Terra cotta architectural (unfilled)	72
Concrete, stone (plain)	144
Concrete, stone (reinforced)	150
Concrete, cinder	108
Fill, cinder	60
Earth (dry)	96
Earth (damp)	108
Earth (wet)	120
Cork	15
Timber, Ash	40
Timber, Douglas Fir	36
Timber, Cypress	30
Timber, Hemlock	30
Timber, Oak	48
Southern Pine, Short Leaf	36
Southern Pine, Long Leaf	48
Redwood	28
Spruce	30

PLASTER WORK

	Pounds per Square Foot
Gypsum (one side)	5
Cement (one side)	10
Gypsum on wood lath	8
Gypsum on metal lath	8
Gypsum on plaster board or fiber board	8
Cement on wood lath	10
Cement on metal lath	10

SUSPENDED CEILINGS

	Pounds per Square Foot
Cement on wood lath	12
Cement on metal lath	15
Gypsum on wood or metal lath	10

LATH AND PLASTER PARTITIONS

	Pounds per Square Foot
2 inch solid cement on metal lath	25
2 " solid gypsum on metal lath	18
2 " " " on gypsum lath	18
2 " metal studs gypsum & metal lath both sides	18
3 " " " " " " " " "	19
4 " " " " " " " " "	20

(Continued on next page)

Exhibit J Unit Design Dead Loads for Structural Design Purposes (Continued)

	Pounds per Square Foot
6 inch wood studs plaster and wood lath, both sides	18
6 " " " " " metal lath, both sides	18
6 " " " " " plaster boards, both sides	18
6 " " " unplastered gypsum board, both sides (dry wall)	10

FLOOR AND ROOF CONSTRUCTION	Pounds per Square Foot
Cinder fill per inch depth	5
Cinder concrete per inch depth	9
Stone concrete per inch depth	12
Floor finish tile per inch depth	12
Cement finish per inch depth	12
Gypsum slabs per inch depth	4
Precast concrete plank per inch depth (as determined by test)	
Hardwood flooring per inch depth	4
Underflooring per inch depth	3
Linoleum	2
Asphalt tile	2

ROOFS AND ROOFING	Pounds per Square Foot
Metal Skylights	10
3-ply roofing	4
4 " "	5
5 " "	6
Wood sheathing (1")	3
Plywood sheathing (5/16")	1
Corrugated iron roofing	3
Formed steel decking	3
Slate tile roofing	10
Cement tile	16
Spanish tile	20
Shingles, asbestos	6
Shingles, asphalt	6
Shingles, wood	6

Exhibit K Unit Working Stresses for Ordinary Materials

APPENDIX K

UNIT WORKING STRESSES FOR ORDINARY MATERIALS

Unless otherwise specified herein, the allowable working stresses for ordinary materials, as defined in sections 701 and 722, shall be reduced ten (10) per cent below the recommended values of the accepted engineering standards listed in appendix B. When the structural material is identified in regard to manufacture and grade and the identification is accompanied by satisfactory mill tests or the strength and stress grade of the materials are otherwise confirmed to the satisfaction of the building official, the allowable working stresses may be increased to comply with the accepted engineering standards.

K-1. MASONRY STRESSES

K-1-A. Mortar for Unit Masonry.—Mortar for unit masonry shall comply with either the proportion specifications as set out in section 816.2, or shall meet the property specifications of the accepted engineering standard listed in appendix C. Unless laboratory data are presented to show that the mortar meets the requirements of the property specifications, the proportion specifications shall govern.

K-1-B. Compressive Stresses.—Except as permitted in other sections of the Basic Building Code, the compressive stresses in masonry shall not exceed the following values:

Allowable compressive stresses gross cross-sectional area (except as noted)

Type of Masonry and Grade of Masonry Unit (psi gross area)	Type of Mortar			
	M	S	N	O
	psi	psi	psi	psi
Solid masonry of brick and other solid units of clay or shale; sand lime or concrete:				
8000 plus psi	400	350	300	200
from 4500 to 8000 psi	250	225	200	150
from 2500 to 4500 psi	175	160	140	100
from 1500 to 2500 psi	125	115	100	75
Grouted masonry of solid masonry units:				
from 4500 to 8000 psi	350	275	200	.....
from 2500 to 4500 psi	275	215	155	.....
from 1500 to 2500 psi	225	175	125	.....
Solid masonry of solid concrete masonry units:				
1800 plus psi	175	160	140	100
from 1200 to 1800 psi	125	115	100	75
Masonry of hollow units	85	75	70	.....
Hollow walls (cavity or masonry bonded)*				
Solid masonry units				
2500 plus psi	140	130	110	----
from 1500 to 2500 psi	100	90	80	.....
Hollow masonry units	70	60	55	----
Stone ashlar masonry				
Granite	800	720	640	500
Limestone or marble	500	450	400	325
Sandstone or cast stone	400	360	320	250
Rubble stone, coursed, rough or random	140	120	100	80

*On gross cross-sectional area of wall minus area of cavity between wythes. The allowable compressive stresses for cavity walls are based upon the assumption that the floor loads bear upon but one (1) of the two (2) wythes. Where hollow walls are loaded concentrically, the allowable stresses may be increased by twenty-five (25) per cent

Exhibit K Unit Working Stresses for Ordinary Materials (Continued)

K-1-C. Shear and Tensile Stresses.—Except as permitted in other sections of the Basic Building Code, the allowable shear or tensile stresses in unreinforced brick masonry shall not exceed the following values:

Allowable stresses in shear or tension in flexure for unreinforced brick masonry*

Construction	Allowable Working Stresses, psi Gross Cross-Sectional Area, Except as Noted	
	Mortar	
	Type M or S	Type N
Single wythe walls of solid clay masonry units; or walls of grouted brick masonry	36	28
Solid walls, brick and other solid clay masonry units, masonry bonded or metal tied	28	20
Cavity and masonry-bonded hollow walls, brick and brick**	28	20

*Allowable stresses apply to brick and other solid clay masonry units laid in portland cement-lime-sand mortars. If other masonry units or mortars are used, allowable stresses for such masonry construction shall be established by tests specified in section 803.

**Net area.

K-2. REINFORCED CONCRETE STRESSES

The allowable working stresses for ordinary materials shall be based on the following proportions by dry volumetric measurement and maximum water content per sack of cement in accordance with the standard building code requirements for reinforced concrete specified in appendix B subject to the ten (10) per cent reduction prescribed for ordinary materials.

28-day strength of concrete in pounds per square inch	*Concrete proportions*	*Gallons of water per sack of cement*
2000	1:5½	7½
2500	1:4½	6¾
3000	1:3½	6

K-3. REINFORCED GYPSUM CONCRETE STRESSES

When ordinary materials are used, the allowable working stresses shall be based on the following proportions, measured dry by weight with sufficient water to make a plastic mix that will fill the forms: 100 per cent neat calcined gypsum; 97 per cent gypsum and 3 per cent wood chips, shavings or fibers; and 87.5 per cent gypsum and 12.5 per cent wood chips, shavings or fibers; with ultimate compressive strengths of 1,800, 1000 and 500 pounds per square inch respectively.

The working stresses shall not exceed the values prescribed in the standard for reinforced gypsum concrete listed in appendix B subject to the ten (10) per cent reduction prescribed for ordinary materials.

(Continued on next page)

Exhibit K Unit Working Stresses for Ordinary Materials (Continued)

K-4. STEEL REINFORCEMENT STRESSES

The allowable working stresses for reinforcement specified in the standard building code requirements for reinforced concrete listed in appendix B shall be used in all reinforced construction, including reinforced concrete, reinforced gypsum concrete and all forms of reinforced masonry subject to the ten (10) per cent reduction specified for ordinary, unidentified materials except as follows:

Type of Steel Element	*Maximum stress in pounds per square inch*
High Yield Strength Steel (50 per cent of Yield Point)	30,000
Steel Pipe, Concrete-filled (45 per cent of Yield Point)	16,000

K-5. STRUCTURAL STEEL STRESSES

When ordinary materials which are not identified as to manufacture and grade are used, the allowable working stresses specified in the standard for the design, fabrication and erection of structural steel listed in appendix B shall be reduced ten (10) per cent.

K-6. CAST STEEL STRESSES

The allowable working stresses for cast steel in compression and bearing shall be the same as those specified for structural steel and shall not exceed seventy-five (75) per cent of the values specified for all other applicable stresses in the standard.

K-7. CAST IRON STRESSES

	Maximum stress in pounds per square inch
Tension	3,000
Extreme Tension (Fiber Stress in Bending)	3,000
Extreme Compression (Fiber Stress in Bending)	16,000
Shear	3,000
Column Compression	$9{,}000 \text{ minus } 40\frac{l}{r}$

Ratio $\frac{l}{r}$ not to exceed seventy (70)

K-8. OPEN-WEB STEEL JOIST STRESSES

The allowable working stresses specified for open-web steel joists shall be in accordance with the standard specifications for steel joist construction listed in appendix B. For all other steel joists, unless otherwise specifically approved and identified, the allowable working stresses specified by the standard shall be reduced ten (10) per cent.

K-9. FORMED STEEL CONSTRUCTION STRESSES

The allowable working stresses for light gage formed steel structural members shall be based on the following grades of flat rolled carbon steel with yield points of 25,000, 30,000 and 33,000 pounds per square inch as specified in the standard specification for the design of light gage steel structural members listed in appendix B, subject to a reduction of ten (10) per cent on all stress values for ordinary materials.

K-10. LUMBER STRESSES

When the grade of lumber is not identified as provided in section 722 for controlled materials, the maximum allowable working stresses for the species of lumber used shall be determined in accordance with the principles for stress grade lumber as set forth in the National Design Specification for Stress-Grade Lumber and Its Fastenings.

Exhibit K-11 Earthquake Load Design

(Continued on next page)

Exhibit K-11 Earthquake Load Design

K-11-E. Foundation Ties.—Where earthquake loads are applicable in the design of buildings, other than lightly loaded structures of type 2 and 4 construction, where the foundations rest on piles or on soil having a safe bearing value of less than two thousand (2000) pounds per square foot, [illegible] the foundations shall be completely interconnected. In two

[illegible] terconnecting [illegible] compression [illegible] the heavier [illegible] gross size [illegible] (12) inches [illegible] less than the [illegible] Code. If the [illegible] be designed [illegible] A reinforced

proximately at right angles to each other. Each such in member shall be capable of transmitting by both tension and at least ten (10) per cent of the total vertical load carried b only of the footings or foundations connected. The minimu of each such member if of reinforced concrete shall be twelv by twelve (12) inches and shall be reinforced with not minimum reinforcement specified elsewhere in the Basic interconnecting members are of structural steel, they shal as provided elsewhere in the code, and encased in concrete.

concrete slab may be used in lieu of interconnecting tie members, providing the slab thickness is not less than one forty-eighth (1/48) of the clear distance between the connected foundations; also providing the thickness is not less than six (6) inches.

Interconnecting slabs shall be reinforced with not less than eleven-hundredths (.11) square inch of steel per foot of slab in a longitudinal direction and the same amount of steel in a transverse direction. The bottom of such slab shall not be more than twelve (12) inches above the tops of at least eighty (80) per cent of the piers or foundations. The footings and foundations shall be tied to the slab in [illegible]

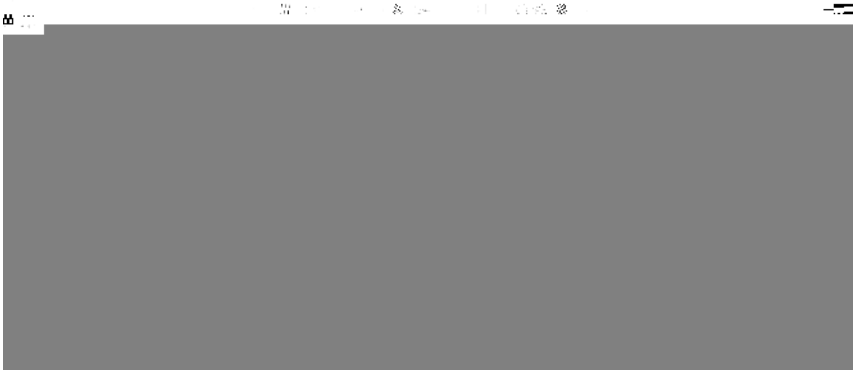
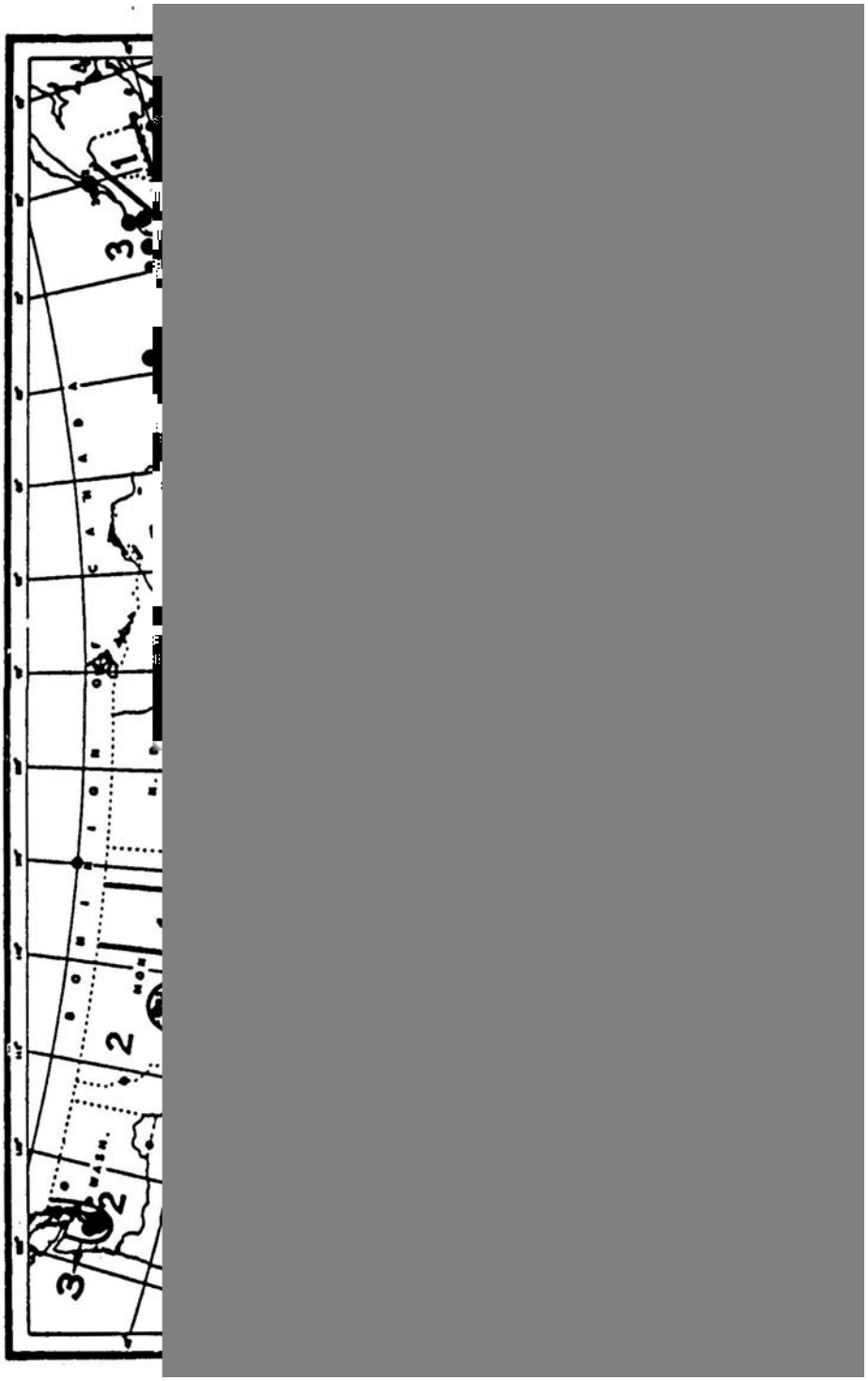


TABLE 14C.—SEISMIC PROBABILITY MAP OF THE UNITED STATES



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Annex B1
TABLES IN 1968 NEW YORK CITY BUILDING CODE

B1.1 EXHIBITS

TABLE 9-1 Percentage of Live Load

Contributory Area (Sq. ft.)	Ratio of Live Load to Dead Load [a]		
	0.625 or less	1	2 or more
149 or less	100	100	100
150-299	80	85	85
300-449	60	70	75
450-599	50	60	70
600 or more	40	55	65

Note:

a. For intermediate values of live load/dead load, the applicable percentages of live load may be interpolated.

TABLE RS 9-5.1 DESIGN WIND PRESSURES ON VERTICAL SURFACES

TABLE RS 9-5.2 DESIGN WIND PRESSURES ON HORIZONTAL AND INCLINED SURFACES

Roof Slope	*Design Wind Pressure Normal to Surface*
30 degrees or less	Either pressure or suction equal to 40 per cent of the values in Table RS 9-5.1 over the entire roof area
More than 30 degrees	Windward slope – pressure equal to 60 per cent of values in Table RS 9-5.1. Leeward slope – suction equal to 40 per cent of values in Table RS 9-5.1.

TABLE RS 9-5.3 SHAPE FACTORS

Construction	*Shape Factor*
Signs (and their supports), or portions thereof, having 70 per cent or more of solid surface	1.5
Signs (and their supports), or portions thereof, having less than 70 per cent of solid surface	2.0
Tanks, cooling towers, and similar constructions	1.5

*** TABLE 10-1 INSPECTION OF MATERIALS AND ASSEMBLIES**

Materials	*Elements That Shall be Subject to Controlled Inspection*[a,b,d]	*Elements That Are Not Subject to Controlled Inspection*[a,c,d]
Steel	None	All structural elments and connections.
Concrete	Materials for all structural elements proportioned on the basis of calculated stresses 70 per cent or greater, of basic allowable values. See Article 5 for specific requirements relating to "quality control of materials and batching."	(1) All materials for structural elements proportioned on the basis of calculated stresses less than 70 per cent of basic allowable values. (2) Concrete materials for: (a) Short span floor and roof construction proportioned as per section 27-610. (b) Walls and footings for buildings in occupancy group J-3. (3) Metal reinforcement.
Aluminum	None	All structural elements and connections.
Wood	None	All structural elements and connections.
Reinforced gypsum concrete	None	All structural elements.
Masonry	None	All structural elements.
Other	Requirements as may be established in other articles of this code or by the commissioner.	

Notes:

[a] For general provisions relating to inspection see section 27-132.

[b] All structural materials and assemblies subject to controlled inspection shall be tested and/or inspected at their place of manufacture and evidence of compliance with the provisions of this subchapter shall be provided as stipulated in articles four through twelve.

[c] Mill, manufacturer's and supplier's inspection and test reports will be accepted as evidence of compliance with the provisions of this code for all structural materials and assemblies not subject to controlled inspection.

[d] Basic allowable stress values as referenced herein shall denote allowable stress value without increase for infrequent stress conditions as established in this code or in the applicable reference standard for the material or element in its proposed use.

***TABLE 10-2 INSPECTION OF METHODS OF CONSTRUCTION**

Materials	*Operations on Structural Elements That Shall be Subject to Controlled Inspection* [a,b,d]	*Operations on Structural Elements That Are Not Subject to Controlled Inspection* [a,c,d]
Steel	(1) Welding operations and the tensioning of high strength bolts in connections where the calculated stresses in the welds or bolts are fifty per cent or more of basic al	(1) Welding operations and the tensioning of high strength bolts in connections where the calculated stresses in the welds or bolts are less than fifty per cent of basic
Wood	Fabrication of glued-laminated assemblies and of plywood components.	All other operations not designated for controlled inspection.
Reinforced	None	All operations incident to the

Table 10-3 Minimum Cement Factor

Specified Comprehensive	Minimum Bags of Cement
[redacted]	

Table 11-1 Unified Soil Clarification

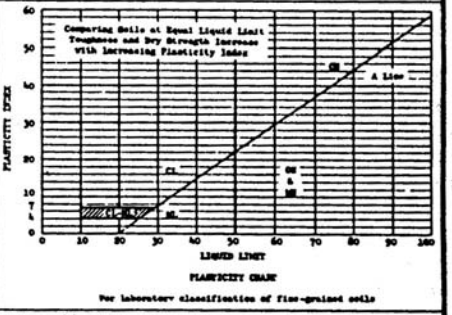
TABLE 11-1—UNIFIED SOIL CLASSIFICATION (Including Identification and Description)

Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 in and basing fractions on estimated weights)			Information Required for Describing Soils	Laboratory Classification Criteria
1	2		3	4	5			6	7
Coarse-grained Soils More than half of material is larger than No. 200 sieve size.	Gravels More than half of coarse fraction is larger than No. 4 sieve size. (For visual classifications, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.				Not meeting all gradation requirements for GW
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).			Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	Atterberg limits below "A" line or PI less than 4 / Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).				Atterberg limits above "A" line with PI greater than 7
	Sands More than half of coarse fraction is smaller than No. 4 sieve size. (For visual classifications, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.				$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3
			SP	Poorly graded sands or gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.			Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).	Not meeting all gradation requirements for SW
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).				Atterberg limits below "A" line or PI less than 4 / Limits plotting in hatched zone with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).				Atterberg limits above "A" line with PI greater than 7
Fine-grained Soils More than half of material is smaller than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.					Identification Procedures on Fraction Smaller than No. 40 Sieve Size				
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)		
	Silts and Clays Liquid limit is less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.	
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium		
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight		
	Silts and Clays Liquid limit is greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium	Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High		
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium	Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).	
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.				

The grain-size curve is identifying the fractions as given under field identification.

Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows:

Less than 5% — GW, GP, SW, SP.
More than 12% — GM, GC, SM, SC.
5% to 12% — Borderline cases requiring use of dual symbols.



PLASTICITY CHART

For laboratory classification of fine-grained soils

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well-graded gravel-sand mixture with clay binder. (2) All sieve sizes on this chart are U. S. Standard.

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air-drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (consistency near plastic limit)

After particles larger than the No. 40 sieve size are removed, a specimen of soil about one-half inch cube in size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line. Highly organic clays have a very weak and spongy feel at the plastic limit.

(over)

Adopted by Corps of Engineers and Bureau of Reclamation, January 1952

Table 11-2 Allowable Soil Bearing Pressures

Class of Material	Description See Note (1)	Basic Allowable Bearing Values (Tons per sq. ft.)—See Notes (10), (11) and (12)	
1-65	Hard Sound Rock	60	See Notes (2) and (8).
2-65	Medium Hard Rock	40	See Notes (2) and (8).
3-65	Intermediate Rock	20	See Notes (2) and (8).
4-65	Soft Rock	8	
5-65	Hardpan	—	See Notes (3) and (8).
6-65	Gravel and Gravel Soils (Soil Groups GW, GP, GM & GC and soils of Soil Groups SW, SP, and SM containing more than 10% of material retained on a No. 4 sieve)	—	See Notes (4) and (8) and (9).
7-65	Sands (other than Fine Sands) (Soil Groups SW, SP & SM but containing not more than 10% of material retained on a No. 4 sieve)	—	See Notes (5), (8) and (9).
8-65	Fine Sand	—	See Notes (6), (8) and (9).
9-65	Clays and Clay Soils (Soil Groups SC, CL & CH)		
	Hard	5	See Note (7).
	Medium	2	See Note (7).
	Soft	See Sec. C26-1103.5.	
10-65	Silts and Silt Soils (Soil Groups ML & MH)		
	Dense	3	
	Medium	1.5	
	Loose	See Sec. C26-1103.5.	
11-65	Nominally Unsatisfactory Bearing Materials	See Sec. C26-1103.5.	

Notes:

(1) Classification.—The soil classifications indicated in this table are those described in section 1103.1. Where there is doubt as to the applicable classification of a soil stratum, the allowable bearing pressure applicable to the lower class of material to which the given stratum might conform shall apply unless the conformance to the higher class of material can be proven by laboratory or field test procedures.

(2) Allowable bearing pressure on rock.—The tabulated values of basic allowable bearing pressures apply only for massive rocks or, for sedimentary or foliated rocks, where the strata are level or nearly so, and, then only if the area has ample lateral support. Tilted strata and their relation to nearby slopes or excavations shall receive special consideration.

(3) Allowable bearing pressure on hardpan.—For hardpan consisting of well cemented material composed of a predominantly granular matrix and free of lenses of fine grained material and inclusions of soft rock, the basic allowable bearing pressure shall be 12 tons per sq. ft. For hardpan consisting of poorly cemented material or containing lenses of fine grained material, inclusions of soft rock, or a fine grained matrix, the basic allowable bearing pressure shall be 8 tons per sq. ft.

(4) Allowable bearing pressure on gravel and gravel soils.—Values of basic allowable bearing pressure shall be as follows:

(a) For soils of Soil Groups GW, GP, GM, and GC:
Compact, well graded material—10 tons per sq. ft.
Loose, poorly graded material—6 tons per sq. ft.
Intermediate conditions—Estimate by interpolation between indicated extremes.

(Continued on next page)

Table 11-2 Allowable Soil Bearing Pressures (Continued)

(b) For soils of Soil Groups SW, SP, and SM, containing more than 10% of material retained on a No. 4 sieve:

, Compact, well graded material—8 tons per sq. ft.

Loose, poorly graded material—4 tons per sq. ft.

Intermediate conditions—Estimate by interpolation between indicated extremes.

(5) Allowable bearing pressure on sands.—The basic allowable bearing pressure shall be determined from the resistance to penetration of the standard sampling spoon. The basic allowable bearing pressure in tons per square foot shall equal 0.10 times N but not greater than 6 tons per square foot, nor less than 3 tons per square foot. The appropriate value for the penetration resistance at various areas of the site shall be made by averaging the measured resistance within a depth of soil below the proposed footing level equal to the width of the footing. Where the average values so obtained do not vary by more than 25 per cent of the minimum of the average values over the site of the proposed building, the lowest average value shall be used for the design of the entire building. Where the variation exceeds 25 per cent, the allowable bearing pressure shall be predicated on the lowest average value unless appropriate measures are taken to avoid detrimental amounts of differential settlements of the footings. Where the design bearing pressure on soils of class 7-65 exceeds 3 tons per square foot, the embedment of the loaded area below the adjacent grade shall not be less than 4 feet and the width of the loaded area not less than 3 feet, unless analysis shall demonstrate the proposed construction to have a minimum factor of safety of 2.0 against shear failure of the soil.

(6) Allowable bearing pressure on fine sand.—The basic allowable bearing pressure shall be determined from the resistance to penetration of the standard sampling spoon. The basic allowable bearing pressure in tons per square foot shall equal 0.10 times N but not greater than 4 tons per square foot nor less than 2 tons per square foot, except that, for loose materials (resistance to penetration of the standard sampling spoon 10 blows per foot or less), where the foundation is subjected to vibratory loads from machinery or similar cause, the indicated basic values shall not apply. The allowable bearing pressure shall be established by analysis applying accepted principles of soil mechanics and a report of such analysis satisfactory to the commissioner shall be submitted as a part of the application for the acceptance of the plans.

(7) Allowable bearing pressure on clays and clay soils.—The bearing capacity of medium and hard clays and clay soils shall be established on the basis of the strength of such soils as determined by field or laboratory tests and shall provide a factor of safety against failure of the soil of not less than 2.0 computed on the basis of a recognized procedure of soils analysis, shall consider probable settlements of the building, and shall not exceed the tabulated maximum values.

(8) Increases in allowable bearing pressure due to embedment of the foundation.—(a) The basic allowable bearing values for rock of classes 1-65, 2-65 and 3-65 shall apply where the loaded area is on the surface of sound rock. Where the loaded area is below the adjacent rock surface and is fully confined by the adjacent rock mass and provided that the rock mass has not been shattered by blasting or otherwise is or has been rendered unsound, these values may be increased 10 per cent of the base value for each foot of embedment below the surface of the adjacent rock surface in excess of one foot, but shall not exceed twice the basic values. (b) The basic allowable bearing values for soils of classes 5-65 through 8-65 determined in accordance with notes (3), (4), and (5) above, shall apply where the loaded area is embedded 4 ft. or less in the bearing stratum. Where the loaded area is embedded more than 4 ft. below the adjacent surface of the bearing stratum, and is fully confined by the weight of the adjacent soil, these values may be increased 5 per cent of the base value for each foot of additional embedment, but shall not exceed twice the basic values. Increases in allowable bearing pressure due to embedment shall not apply to soils of classes 4-65, 9-65, 10-65, or 11-65.

(9) Increase in allowable bearing pressure for limited depth of bearing stratum.—The allowable bearing values for soils of classes 6-65, 7-65 and 8-65 determined in accordance with this table and the notes thereto (including note (8)), may be increased up to one-third where the density of the bearing stratum below the bottom of the footings or the tips of the piles increases with depth provided that: (a) The bearing stratum is not underlain by materials of a lower class. (b) The allowable bearing value of the soil material underlying the bottom of the footings or the tips of the piles increases at least 50 per cent within a depth below the footing or the tips of the piles which is not greater than the width of the footing or the width of the polygon circumscribing the pile group.

Table 11-4—Minimum Driving Resistance and Minimum Hammer Energy for Steel H-Piles, Pipe Piles, Precast and Cast-in-Place Concrete Piles and Composite Piles (other than timber)

Pile Capacity (tons)	Hammer[b] Energy (ft. lbs.)	Friction Piles (blows/ft.)	Minimum Driving Resistance[a, c, e] Piles Bearing on Hardpan (Soil Class 5-65) (blows/ft.)	Non-Displacement Piles Bearing on Decomposed Rock (Soil Class 4-65) (blows/ft.)	Displacement Piles Bearing on Decomposed Rock (Soil Class 4-65) (blows/ft.)	Piles Bearing on Rock (Soil Classes 1-65, 2-65, & 3-65)
Up to 20	15,000	19	19	48	48	
	19,000	15	15	27	27	
	24,000	11	11	16	16	
30	15,000	30	30	72	72	
	19,000	23	23	40	40	
	24,000	18	18	26	26	
40	15,000	44	50	96	96	
	19,000	32	36	53	53	
	24,000	24	30	34	34	
50	15,000	72	96	120	120	5 Blows
	19,000	49	54	80	80	per ¼ inch
	24,000	35	37	60	60	(Minimum
	32,000	24	25	40	40	hammer
60	15,000	96		240	240	energy of
	19,000	63		150	150	15,000 ft. lbs.)
	24,000	44		100	100	
	32,000	30		50	50	
70 & 80	19,000		5 Blows	5 Blows		
	24,000		per ¼ inch	per ¼ inch		
	32,000		(Minimum	(Minimum		
			hammer	hammer		
			energy of	energy of		
			15,000 ft. lbs.)	19,000 ft. lbs.)		
100						
Over 100						

NOTES:

[a] Final driving resistance shall be the sum of tabulated values plus resistance exerted by non-bearing materials. The driving resistance of non-bearing materials shall be taken as the resistance experienced by the pile during driving, but which will be dissipated with time and may be approximated as described in Section C26-1107.1(c)(1)a.

[b] The hammer energy indicated is the rated energy.

[c] Sustained driving resistance—where piles are to bear in soil classes 4-65 and 5-65, the minimum driving resistance shall be maintained for the last 6 inches, unless a higher sustained driving resistance requirement is established by load test. Where piles are to bear in soil classes 6-65 through 10-65, the minimum driving resistance shall be maintained for the last 12 inches unless load testing demonstrates a requirement for higher sustained driving resistance. No pile need be driven to a resistance to penetration (in blows per inch) more than twice the resistance indicated in this table, nor beyond the point at which there is no measurable net penetration under the hammer blow.

[d] The tabulated values assume that the ratio of total weight of pile to weight of striking part of hammer does not exceed 3.5. If [illegible]

Table 11-5 Minimum Driving Resistance and Hammer Energy for Timber Piles

Pile Capacity (tons)	Minimum Driving Resistance (blows-in.) to be added to driving resistance exerted by non-bearing materials [a, c, d]	Hammer Energy (ft.-lbs.)[b]
Up to 20	Formula in Note [d] shall apply	7,500-12,000
Over 20 to 25		9,000-12,000
		14,000-16,000
Over 25 to 30		12,000-16,000 (single-acting hammers)
		15,000-20,000 (double-acting hammers)
Greater than 30*		

NOTES:

[a] The driving resistance exerted by non-bearing materials is the resistance experienced by the pile during driving, but which will be dissipated with time and may be approximated as described in Section C26-1107.1(c)(1)a.

[b] The hammer energy indicated is the rated energy.

[c] Sustained driving resistance.—Where piles are to bear in Soil Classes 4-65 and 5-65, the minimum driving resistance shall be maintained for the last six inches, unless a higher sustained driving resistance requirement is established by load test. Where piles are to bear in Soil Classes 6-65 thru 10-65, the minimum driving resistance measured in blows per inch shall be maintained for the last 12 inches unless

* TABLE 11-6 BASIC MAXIMUM PILE LOADS

Type of pile	*Basic maximum pile load (tons)*
Caisson piles	No upper limit
Open-end pipe (or tube) piles bearing on rock of classes 1-65, 2-65, and 3-65	18 in. O.D. and greater – 250 less than 18 in. O.D. – 200
Closed-end pipe (or tube) piles, H piles, cast-in-place concrete and compacted concrete piles bearing on rock of classes 1-65, 2-65, and 3-65	150
Piles (other than timber piles) bearing on soft rock (class 4-65)	
1) Displacement piles such as pipe, cast-in-place concrete, and compacted concrete piles	60
2) Non-displacement piles such as open-end pipe and H piles	80
Piles (other than timber piles) bearing on hardpan (class 5-65) overlying rock	100
Piles (other than timber piles) that rec[illegible]	

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Annex B2
TABLES IN 2001 NEW YORK CITY BUILDING CODE

B2.1 EXHIBITS

In addition to all the tables listed correspondingly in Annex B1, the following table is added in the 2001 New York City code.

TABLE 10-3.A

Specified compressive strength in twenty-eight days (f 'c) pounds per square inch	*Minimum pounds of cement per cubic yard of concrete*	*Maximum permissible total volume of water, U.S. gallons per cubic yard of concrete*
2000	520	40
2500	560	41
3000	610	42

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Annex B3
TABLES IN 1964 NEW YORK STATE BUILDING CONSTRUCTION CODE

B3.1 EXHIBITS

TABLE C 304-2.2. (I-833)——UNIFORMLY DISTRIBUTED AND CONCENTRATED LIVE LOADS

Occupancy or use	Uniformly distributed loads, psf	Concentrated loads in pounds
C1 Business		
Business machine equipment	100	
Office space	50[1]	
C2 Mercantile		
Stores, shops for display and sale		
Retail		
On ground floor	100	
On upper floors	75	
Wholesale	120	
C3 Industrial		
Bakeries	150	
Laundries	100	
Manufacturing or processing	125	
Light manufacturing, assembly, etc.	75	
[illegible]	[illegible]	[illegible]
C5 Assembly		
Assembly halls, auditoriums, balconies, club rooms, dance halls, exhibition halls, grandstands, gymnasiums, lodge rooms, museums, restaurants, shelters for air raids, stadiums, theaters		
Aisles, crossovers, lobbies, vomitories	100	
Main floors, balconies		
Fixed seats	60[2]	
Movable seats	100	
Dressing rooms	40	
Projection rooms	100	
Stage floors	150	
Colleges, schools (exclusive of dormitories)		
Classrooms	60	
Laboratories	60	
Lecture halls		
Fixed seats	60	
Movable seats	100	
Places of worship		
Fixed seats	60	
Movable seats	100	
C6 Institutional		
Hospitals		
Clinics	60	
Corridors, above first floor	40	
Examination rooms	60	
Laboratories, dark rooms	100	
Operating rooms	60	
Private rooms	40	
Public space	75	
Solariums	60	
Wards	40	
X-ray rooms, treatment rooms, control spaces	100	
Nurseries	40	
Orphanages, infirmaries	40	
Penal institutions, police lockups, reformatories		
Cell blocks	40	
Shops	80	

TABLE C 304-2.2. (I-833)——UNIFORMLY DISTRIBUTED AND CONCENTRATED LIVE LOADS——Continued

Occupancy or use	Uniformly distributed loads, psf	Concentrated loads in pounds
Spaces common to above occupancies		
Air conditioning space	200	2,000
Corridors		
First floor	100	2,000
Other floors	[4]	2,000
Elevator machine rooms	[5]	300
Exitways	100	
Fan rooms	100	
Garages and ramps, open deck parking structures:		
Cars, passenger	50[6]	2,000[10]
Busses, trucks, mixed usage	175	12,000[10]
Incinerator charging floor	100	
Kitchens (other than domestic)	100	
Ladders		250[11]
Laboratories	100	
Libraries		
Reading rooms	60	
Stacks	[7]	
Lobbies	100	2,000[12]
Locker rooms	75	
Marquees	60	
Promenades	60	
Rest rooms	60	
Roofs used as promenades	60	
Other roofs	[8]	200
Sidewalks over vaults	300	12,000[10]
Skylight screens		100[13]
Stairways	100[9]	
Terraces, yards, for pedestrians	60	
Toilet rooms	60	
Vaults, in office space	250	2,000
Workshops	80	

[1] Dead load is to be increased by 20 psf for possible shifting of masonry partitions.

[2] 50 psf per foot of clear story height.

[3] Grandstands, 100 psf; see section C 304-9e for horizontal impact loads.

[4] Unless noted elsewhere in this table, 100 psf; corridors within a tenancy not less than occupancy served.

[5] For loads, see section C 304-11.

[6] Where clear height of garage entrance exceeds 7 feet, load for busses, trucks and mixed usage shall be used.

[7] 20 psf per foot of height, with a minimum of 150 psf.

[8] See section C 304-10c for minimum imposed loads for roofs.

[9] Stringers of stairs need be designed only for uniform load.

[10] Or actual wheel load increased 50 per cent for impact, whichever is larger.

[11] Side rails of ladders need be designed only for 80 pounds at center of every rung, applied simultaneously.

[12] For any building where a floor safe may be brought into building.

[13] Skylight screens to have ¾-inch to 1-inch mesh; upper screen to be 4 to 10 inches above glass and to overhang an identical amount. No uniform load need be figured.

TABLE C 304-3. (II-833)——SNOW LOADS [1]

In pounds per square foot

Zone numbers on snow map	Roof slope from horizontal [2]					
	0°	20°	30°	40°	50°	60° or more
20 [4]	20	18	11	6	2	0
25 [4]	25	22	14	7	3	0
30	30	27	17	9	3	0
35	35	31	20	10	4	0
40	40	35	23	12	4	0
45	45	40	25	13	5	0
50	50	44	28	15	5	0
60	60	53	34	18	6	0
70 [3]						
80 [3]						
90 [3]						

[1] For minimum imposed loads, see section C 304-10c.
[2] For slopes between those tabulated, compute loads by straight-line interpolation.
[3] For snow zones 70, 80, and 90 on snow map, use same tabular values as for zone 60.
[4] For snow zones 20 and 25 on snow map, use same tabular values as for zone 30.

SNOW MAP OF NEW YORK STATE

TABLE C 304-4a. (III-833)——WIND LOADS: WALLS, EAVES, CORNICES, TOWERS, MASTS AND CHIMNEYS

In pounds per square foot

At height above grade, in feet	Walls[1]	Eaves and cornices[2]	Towers, masts and chimneys
501 to 600[3]	34	68	60
401 to 500	33	66	58
301 to 400	32	64	56
201 to 300	30	60	53
101 to 200	28	56	49
61 to 100	24	48	42
41 to 60	21	42	37
26 to 40	18	36	32
16 to 25	15	30	26
0 to 15	12	24	21

[1] Exterior walls shall be capable of withstanding wind load on both the interior and exterior surfaces, acting non-simultaneously. Tabular values are for square or rectangular structures. For structures hexagonal or octagonal in plan, use projected area and multiply tabular values by 0.8; for structures round or elliptical in plan, use projected area and multiply values by 0.6. For tents, the wind pressure shall be 10 psf on the projected area.

[2] Load acting upward.

[3] For heights above grade greater than 600 feet, add 1 psf to load for walls for each interval or part of interval of 200 feet above 600 feet; for eaves and cornices, and towers, masts and chimneys, corresponding loads are in proportion to those for walls.

TABLE C 304-4b. (IV-833)——WIND LOADS: ROOFS

In pounds per square foot

Mean elevation of roof above grade level in feet	Direction of load[1]	Slope from horizontal[2]			
		0° to 20°	20° to 30°	30° to 60°	Over 60°
501 to 600[3]	Downward	8	8	8 to 24	24
	Upward	29	29 to 24	24	24
401 to 500	Downward	8	8	8 to 23	23
	Upward	28	28 to 23	23	23
301 to 400	Downward	7	7	7 to 22	22
	Upward	27	27 to 22	22	22
201 to 300	Downward	7	7	7 to 21	21
	Upward	25	25 to 21	21	21
101 to 200	Downward	6	6	6 to 20	20
	Upward	24	24 to 20	20	20
61 to 100	Downward	5	5	5 to 17	17
	Upward	20	20 to 17	17	17
36 to 60	Downward	5	5	5 to 15	15
	Upward	19	19 to 15	15	15
21 to 35	Downward	5	5	5 to 14	14
	Upward	17	17 to 14	14	14
0 to 20	Downward	5	5	5 to 11	11
	Upward	14	14 to 11	11	11

[1] Downward and upward loads act non-simultaneously.

[2] For slopes between 20° and 30° with wind acting upward, and between 30° and 60° with wind acting downward, compute loads by straight-line interpolation.

[3] For heights above grade greater than 600 feet, add 1 psf to upward load for 0° to 20° slope for each interval or part of interval of 200 feet above 600 feet; for upward loads on other slopes, and downward loads on all slopes, corresponding loads are in proportion to those for upward load for 0° to 20° slope.

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Annex B4
TABLES IN 1967 CHICAGO MUNICIPAL CODE

B4.1 EXHIBITS

TABLE 68-4.1. MINIMUM DESIGN WIND PRESSURES FOR BUILDINGS AND OTHER STRUCTURES.

	Height Zone (feet)	*Wind Pressure (lbs. per sq. ft.)*
Buildings	Less than 300	20
	Above 300	Add 0.025 lb. per foot for each foot above 300
Towers, Tanks and Chimneys	Less than 200	20
	Above 200	Add 0.025 lb. per foot for each foot over 200
Solid Signs	Less than 100	30
	Above 100	Add 0.025 lb. per foot for each foot above 100
Open Signs	For all heights	Increase wind pressure established for solid signs by 1/3

TABLE 70-2.4 (a). BEARING VALUES OF SOILS

Type of Soil	*Maximum Pressure Pounds per Square Foot*
Sand—compact and clean	5,000
Sand—silty and compact	3,000
Inorganic silt—compact	2,500
Clay—very soft	500
Clay—soft	1,500
Clay—stiff	2,500
Clay—tough	3,500
Clay—very tough	4,500
Clay—hard	6,000
Gravel	6,000
Hardpan	12,000
Solid rock	200,000
Organic soil	0
Filled ground or loam	500

TABLE 72-2 (A).

MAXIMUM ALLOWABLE UNIT STRESSES
(POUNDS PER SQUARE INCH)

Species and Commercial Grade	Extreme fiber stress and tension parallel to grain (ft.)	Horizontal Shear (v)	Compression across grain (f'c)	Compression parallel to grain** (fc)	Modulus of Elasticity E
Cypress	1300	120	300	900	1,200,000
Douglas Fir	1300	100	325	1200	1,600,000
Plywood (Fir)					
Built up Section	1500	100 35*	400	1500	1,600,000
Laminated Timber	1100	75	400	1500	1,600,000
Hemlock	1000	90	350	1100	1,400,000
Oak	1300	120	600	1000	1,500,000
Redwood	1100	75	300	1000	1,200,000
Southern Pine					
Longleaf	1300	120	450	1000	1,600,000
Shortleaf	1100	120	400	900	1,600,000
Spruce					
Sitka or Eastern	1000	75	300	800	1,200,000

*Shear in plane of piles. **For L/D of eleven or less.

Annex B5
TABLES IN 1965 BOCA BASIC BUILDING CODE

B5.1 EXHIBITS

TABLE 13.—MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS

Use	Pounds per square foot
Alleys, driveways, yards and terraces	
Pedestrian	100
Vehicular	250
Armories and drill rooms	150
Assembly:	
Fixed seats	60
Removable or no seats	100
Balcony (exterior)	100
Bowling alleys, pool rooms and similar recreational areas	75
Class Rooms	60
Fixed seats	60
Removable seats	100
Cornices	75
Corridors:	
Hotels, hospitals and multi-family dwellings	60
One- and two-family dwellings	40
Serving public rooms in hotels	100
Corridors and entrance hallways other than residential buildings	100
Corridors (other than those specifically designated):	
Private	Same as occupancy served.
Public	100
Court rooms	100
Dance halls and gymnasiums	100
Dwellings:	
Dwelling units (Multi-family dwellings)	40
First floor	40
Second floor and habitable attic	30
Uninhabitable attics	20(c)
Elevator machine rooms	100
Garages and stables, passenger cars not exceeding, 6,000 lbs. wt.	75
Garages, buses and trucks not exceeding 20,000 lbs. wt.: (b)	
Columns, beams and girders	120
Floor slabs	175
Grandstands, reviewing stands and bleachers	100
Hospitals:	
Operating rooms	60
Private rooms	40
Wards	40
Libraries:	
Reading rooms	60
Stack rooms	150(a)
Loft buildings and light manufacturing	125
Manufacturing:	
Heavy	Not less than actual loads.
Light (See Loft buildings . . .)	
Marquees	75
Office buildings:	
Lobbies	100
Rooms	50
Penal institutions: cell blocks	40
Parking structures, passenger cars only:	
Parts of floor accessible to wheel loads	75
Parts of floor not accessible to wheel loads	50
Restaurants and public dining rooms	100
Reviewing stands and bleachers (See Grandstands . . .)	
Sidewalks	250
Skating rinks	75
Stairs, fire escapes and exitways	100
Storage warehouse:	
Heavy	250
Light	125
Stores and shops:	
Retail, and banking rooms	100
Grade floor	75
Upper floors	125
Wholesale	
Theatres:	
Aisles, corridors and lobbies	100
Balconies	60
Orchestra floors	60
Stage floors	150

Note a. Minimum 150 lb./sq. ft. but not less than actual weight of loaded shelves.
Note b. For garages for vehicles exceeding 20,000 lbs. wt.: See sec. 707.2.
Note c. Live load need be applied to joists or to bottom chords of trusses or trussed rafters only in those portions of attic space having a clear height of forty-two (42) inches or more between joist and rafter in conventional rafter construction; and between bottom chord and any other member in trussed or trussed rafter construction. However, joists or the bottom chords or trusses or trussed rafters shall be designed to sustain the imposed dead load or ten pounds per square foot (10 p.s.f.), whichever be greater, uniformly distributed over the entire span.

TABLE 14.—CONCENTRATED LOADS

Location	Pounds
Elevator machine room grating (on area of 4 sq. in.)	300
Finish light floor plate construction (on area of 1 sq. in.)	200
Garages, pleasure cars	2000
Garages, trucks (not less than 150 per cent maximum wheel load)	
Office floors	2000
Scuttles and skylight ribs	200
Sidewalks	8000
Stair treads (on center of tread)	300

Exhibit B5-1 External Wind Pressure on Roofs

EXTERNAL WIND PRESSURE ON ROOFS

Ratio of Side-wall Height to Building Width	Flat Roofs	Windward Slope of Roofs				Leeward Slope
		Less than 1:12	1:12 to 4.05:12	4.05:12 to 6:12	6:12 to 12:12	All Slopes
0.2	—.60	—.60	—.06	.12	.19	—.50
0.4	—.60	—.60	—.33	.01	.09	—.50
0.6	—.60	—.60	—.49	—.20	—.06	—.50
0.8	—.60	—.60	—.57	—.30	—.18	—.50
1.0 or more	—.60	—.60	—.60	—.39	—.28	—.50

For all roof surfaces having a slope greater than 12:12 the same wind forces as for vertical surfaces shall be assumed.

TABLE 15.—PRESUMPTIVE SURFACE BEARING VALUES OF FOUNDATION MATERIALS

Class of material	Tons per square foot
1—Massive crystalline bed rock including granite, diorite, gneiss, trap rock, hard limestone and dolomite	100
2—Foliated rock including bedded limestone, schist and slate in sound condition	40
3—Sedimentary rock including hard shales, sandstones, and thoroughly cemented conglomerates	25
4—Soft or broken bed rock (excluding shale), and soft limestone	10
5—Compacted, partially cemented gravels, and sand and hardpan overlying rock	10
6—Gravel and sand-gravel mixtures	6
7—Loose gravel, hard dry clay, compact coarse sand, and soft shales	4
8—Loose, coarse sand and sand-gravel mixtures and compact fine sand (confined)	3
9—Loose medium sand (confined), stiff clay	2
10—Soft broken shale, soft clay	1.5

NIST NCSTAR 1-1C

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Maintenance and Modifications to Structural Systems

David A. Fanella
Arnaldo T. Derecho
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NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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September 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

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In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

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ABSTRACT

This report documents maintenance and modifications that were made to the structural systems of World Trade Center (WTC) 1, 2, and 7. Included are the Port Authority of New York and New Jersey (PANYNJ or Port Authority) guidelines for inspection, repair, and modifications to the structural systems of WTC 1, 2, and 7. Discussed are the guidelines that governed the inspection and strengthening of existing structural members.

Also contained in this report is a summary of the structural inspection programs that were undertaken during the occupancy of WTC 1, 2, and 7. Included are summaries of the facility condition survey reports that were produced for WTC 1, 2, and 7 and descriptions of the structural integrity inspection programs that were undertaken for WTC 1 and WTC 2.

The significant modifications and repairs that were made to the structural systems of WTC 1, 2, and 7 from initial occupancy to September 11, 2001, are also documented. A discussion on the repairs that were made after the February 1993 bombing of WTC 1 is also included.

Appendixes to this report include copies of referenced documents, including the Tenant Construction Review Manuals; the Standards for Structural Integrity Inspection of the WTC towers; and the Architectural and Structural Design Guidelines, Specifications, and Standard Details, which were all issued by the Port Authority regarding inspection, repair, and modifications to the structural systems of WTC 1, 2, and 7.

Keywords: Bombing, construction, facility condition survey report, guidelines, inspection, modifications, repair, strengthening, structural integrity inspection program, structural systems, World Trade Center.

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LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

AISC	American Institute of Steel Construction
ASTM	American Society for Testing and Materials
BSA	Board of Standards and Appeals, New York City
BOCA	Building Officials & Code Administrators International, Inc.
BPS	Building Performance Study
CMU	concrete masonry unit
EQAD	Engineering Quality Assurance Division
FEMA	Federal Emergency Management Agency
HVAC	heating, ventilation, and air conditioning
LERA	Leslie E. Robertson Associates
MEA	Materials and Equipment Acceptance Division of the Office of the Commissioner of the Buildings Department of New York City
MER	mechanical equipment room
NIST	National Institute of Standards and Technology
NYC	New York City
PANYNJ	Port Authority of New York and New Jersey
PONYA	Port of New York Authority
SHCR	Skilling, Helle, Christiansen, Robertson
SII	Structural Integrity Inspection
WSHJ	Worthington, Skilling, Helle, and Jackson
WTC	World Trade Center
WTC 1	World Trade Center tower 1 (North Tower)
WTC 2	World Trade Center tower 2 (South Tower)
WTC 7	World Trade Center building 7

Abbreviations

ft	feet
g	acceleration due to gravity = 32.2 ft/s^2

Hz	Hertz
in.	inch
lb	pounds
milli	1/1000
min	minute
mph	miles per hour
pcf	pounds per cubic foot
psf	pounds per square foot
s	second
sq ft	square foot

METRIC CONVERSION TABLE

To convert from	to	Multiply by
AREA AND SECOND MOMENT OF AREA		
square foot (ft^2)	square meter (m^2)	9.290 304 E-02
square inch ($in.^2$)	square meter (m^2)	6.4516 E-04
square inch ($in.^2$)	square centimeter (cm^2)	6.4516 E+00
square yard (yd^2)	square meter (m^2)	8.361 274 E-01
ENERGY (includes WORK)		
kilowatt hour (kW · h)	joule (J)	3.6 E+06
quad (1015 BtuIT)	joule (J)	1.055 056 E+18
therm (U.S.)	joule (J)	1.054 804 E+08
ton of TNT (energy equivalent)	joule (J)	4.184 E+09
watt hour (W · h)	joule (J)	3.6 E+03
watt second (W · s)	joule (J)	1.0 E+00
FORCE		
dyne (dyn)	newton (N)	1.0 E-05
kilogram-force (kgf)	newton (N)	9.806 65 E+00
kilopond (kilogram-force) (kp)	newton (N)	9.806 65 E+00
kip (1 kip=1,000 lbf)	newton (N)	4.448 222 E+03
kip (1 kip=1,000 lbf)	kilonewton (kN)	4.448 222 E+00
pound-force (lbf)	newton (N)	4.448 222 E+00
FORCE DIVIDED BY LENGTH		
pound-force per foot (lbf/ft)	newton per meter (N/m)	1.459 390 E+01
pound-force per inch (lbf/in.)	newton per meter (N/m)	1.751 268 E+02
HEAT FLOW RATE		
calorieth per minute (calth/min)	watt (W)	6.973 333 E-02
calorieth per second (calth/s)	watt (W)	4.184 E+00
kilocalorieth per minute (kcalth/min)	watt (W)	6.973 333 E+01
kilocalorieth per second (kcalth/s)	watt (W)	4.184 E+03

To convert from	to	Multiply by
LENGTH		
foot (ft)	meter (m)	3.048 E-01
inch (in)	meter (m)	2.54 E-02
inch (in.)	centimeter (cm)	2.54 E+00
micron (m)	meter (m)	1.0 E-06
yard (yd)	meter (m)	9.144 E-01
MASS and MOMENT OF INERTIA		
kilogram-force second squared per meter ($kgf \cdot s^2/m$)	kilogram (kg)	9.806 65 E+00
pound foot squared ($lb \cdot ft^2$)	kilogram meter squared ($kg \cdot m^2$)	4.214 011 E-02
pound inch squared ($lb \cdot in.^2$)	kilogram meter squared ($kg \cdot m^2$)	2.926 397 E-04
ton, metric (t)	kilogram (kg)	1.0 E+03
ton, short (2,000 lb)	kilogram (kg)	9.071 847 E+02
MASS DIVIDED BY AREA		
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428 E+00
pound per square inch (*not* pound force) ($lb/in.^2$)	kilogram per square meter (kg/m^2)	7.030 696 E+02
MASS DIVIDED BY LENGTH		
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164 E+00
pound per inch (lb/in.)	kilogram per meter (kg/m)	1.785 797 E+01
pound per yard (lb/yd)	kilogram per meter (kg/m)	4.960 546 E-01
PRESSURE or STRESS (FORCE DIVIDED BY AREA)		
kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	9.806 65 E+04
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	9.806 65 E+00
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	9.806 65 E+06
kip per square inch (ksi) ($kip/in.^2$)	pascal (Pa)	6.894 757 E+06
kip per square inch (ksi) ($kip/in.^2$)	kilopascal (kPa)	6.894 757 E+03
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026 E+01
pound-force per square inch (psi) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
pound-force per square inch (psi) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00
psi (pound-force per square inch) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
psi (pound-force per square inch) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00

To convert from	to	Multiply by
TEMPERATURE		
degree Celsius (°C)	kelvin (K)	T/K = t/°C + 273.15
degree centigrade	degree Celsius (°C)	t/°C ≈ t /deg. cent.
degree Fahrenheit (°F)	degree Celsius (°C)	t/°C = (t/°F - 32)/1.8
degree Fahrenheit (°F)	kelvin (K)	T/K = (t/°F + 459.67)/1.8
kelvin (K)	degree Celsius (°C)	t/°C = T/K 2 273.15
TEMPERATURE INTERVAL		
degree Celsius (°C)	kelvin (K)	1.0 E+00
degree centigrade	degree Celsius (°C)	1.0 E+00
degree Fahrenheit (°F)	degree Celsius (°C)	5.555 556 E-01
degree Fahrenheit (°F)	kelvin (K)	5.555 556 E-01
degree Rankine (°R)	kelvin (K)	5.555 556 E-01
VELOCITY (includes SPEED)		
foot per second (ft/s)	meter per second (m/s)	3.048 E-01
inch per second (in./s)	meter per second (m/s)	2.54 E-02
kilometer per hour (km/h)	meter per second (m/s)	2.777 778 E-01
mile per hour (mi/h)	kilometer per hour (km/h)	1.609 344 E+00
mile per minute (mi/min)	meter per second (m/s)	2.682 24 E+01
VOLUME (includes CAPACITY)		
cubic foot (ft^3)	cubic meter (m^3)	2.831 685 E-02
cubic inch ($in.^3$)	cubic meter (m^3)	1.638 706 E-05
cubic yard (yd^3)	cubic meter (m^3)	7.645 549 E-01
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412 E-03
gallon (U.S.) (gal)	liter (L)	3.785 412 E+00
liter (L)	cubic meter (m^3)	1.0 E-03
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353 E-05
ounce (U.S. fluid) (fl oz)	milliliter (mL)	2.957 353 E+01

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PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

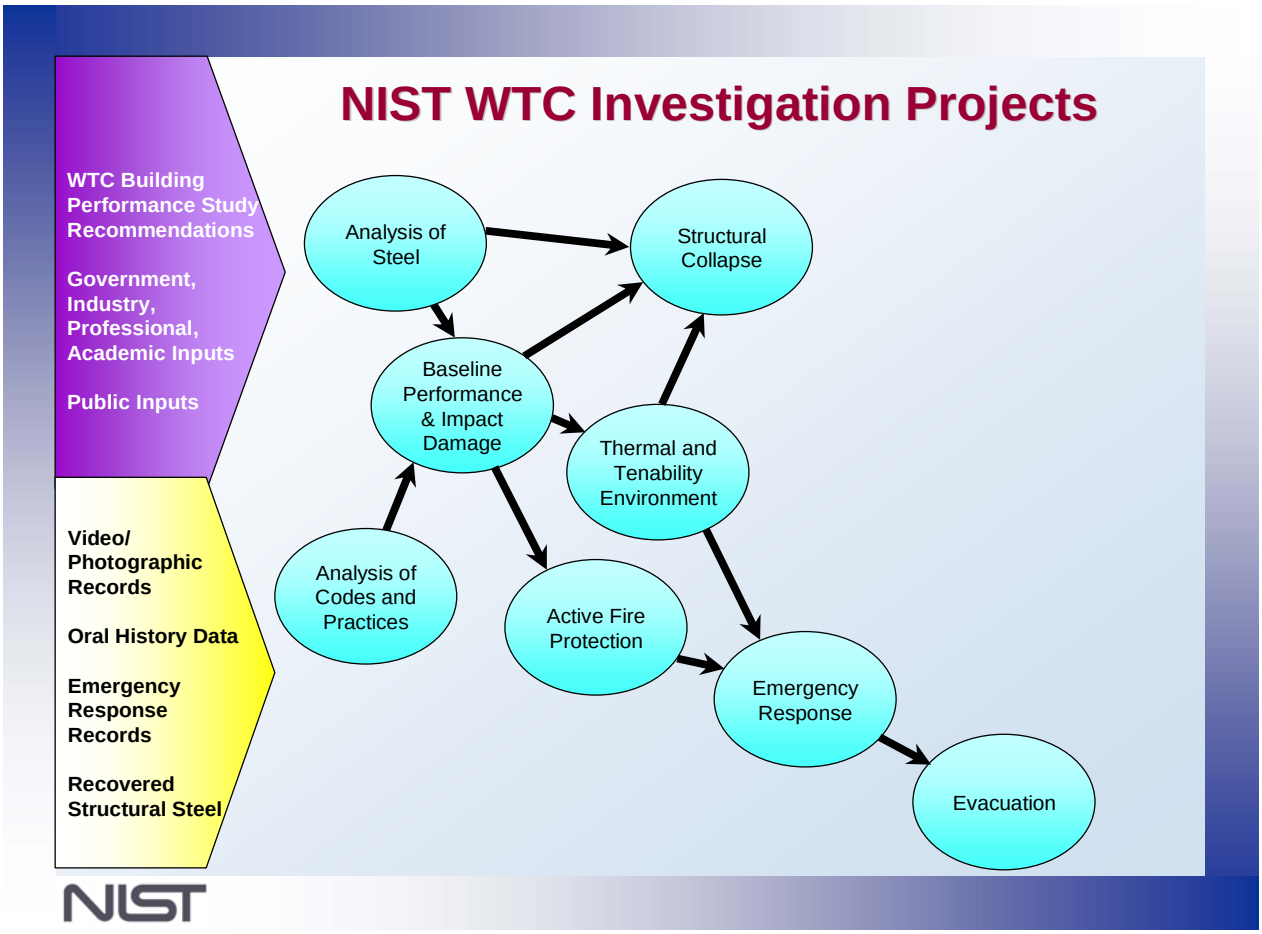

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

NIST (National Institute of Standards and Technology). 2006. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of World Trade Center 7.* NIST NCSTAR 1A. Gaithersburg, MD.

Lew, H. S., R. W. Bukowski, and N. J. Carino. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Design, Construction, and Maintenance of Structural and Life Safety Systems.* NIST NCSTAR 1-1. National Institute of Standards and Technology. Gaithersburg, MD, September.

Fanella, D. A., A. T. Derecho, and S. K. Ghosh. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Design and Construction of Structural Systems.* NIST NCSTAR 1-1A. National Institute of Standards and Technology. Gaithersburg, MD, September.

Ghosh, S. K., and X. Liang. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Comparison of Building Code Structural Requirements.* NIST NCSTAR 1-1B. National Institute of Standards and Technology. Gaithersburg, MD, September.

Fanella, D. A., A. T. Derecho, and S. K. Ghosh. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Maintenance and Modifications to Structural Systems.* NIST NCSTAR 1-1C. National Institute of Standards and Technology. Gaithersburg, MD, September.

Grill, R. A., and D. A. Johnson. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Fire Protection and Life Safety Provisions Applied to the Design and Construction of World Trade Center 1, 2, and 7 and Post-Construction Provisions Applied after Occupancy.* NIST NCSTAR 1-1D. National Institute of Standards and Technology. Gaithersburg, MD, September.

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Grill, R. A., D. A. Johnson, and D. A. Fanella. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Post-Construction Modifications to Fire Protection, Life Safety, and Structural Systems of World Trade Center 7*. NIST NCSTAR 1-1I. National Institute of Standards and Technology. Gaithersburg, MD, September.

Grill, R. A., and D. A. Johnson. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Design, Installation, and Operation of Fuel System for Emergency Power in World Trade Center 7*. NIST NCSTAR 1-1J. National Institute of Standards and Technology. Gaithersburg, MD, September.

Sadek, F. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Baseline Structural Performance and Aircraft Impact Damage Analysis of the World Trade Center Towers.* NIST NCSTAR 1-2. National Institute of Standards and Technology. Gaithersburg, MD, September.

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Kirkpatrick, S. W., R. T. Bocchieri, F. Sadek, R. A. MacNeill, S. Holmes, B. D. Peterson, R. W. Cilke, C. Navarro. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Analysis of Aircraft Impacts into the World Trade Center Towers*, NIST NCSTAR 1-2B. National Institute of Standards and Technology. Gaithersburg, MD, September.

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EXECUTIVE SUMMARY

E.1 OVERVIEW

This report contains a summary of the Port Authority of New York and New Jersey (PANYNJ or Port Authority) guidelines for inspection, repair, and modifications to the structural systems of World Trade Center (WTC) 1, 2, and 7. Included are the guidelines governing the inspection and strengthening of existing structural members and systems for modifications made by tenants of the buildings.

A summary of the (1) structural inspection programs, (2) significant observations, (3) procedures for implementation, and (4) actions taken during the occupancy of WTC 1, 2, and 7 is also documented. In addition to having established guidelines for any type of modifications that were to be made to any of their facilities, including the WTC, the PANYNJ established programs for inspection and repair. Facility condition surveys were commissioned for WTC 1, 2, and 7. These surveys reported on the condition of the buildings, including the structural systems, and contained recommendations for any necessary repairs or upgrading. Periodic inspections of the structural systems were also performed under the Structural Integrity Inspection (SII) Program for WTC 1 and WTC 2.

Also contained in this report is a summary of the significant modifications and repairs that were made to the structural framing systems of WTC 1, 2, and 7 from initial occupancy to September 11, 2001. A discussion is also included on the repairs that were made after the February 1993 bombing of WTC 1.

Apart from the repairs following the 1993 bombing of WTC 1, most of the structural modifications in WTC 1 and WTC 2 were performed to accommodate tenant requirements. Openings were cut in existing floors to construct new stairways linking two or more floors, and floor systems were reconstructed over previously cut openings. In a number of cases, floor trusses outside of the core area and steel beams in the core area had to be reinforced due to heavy loads imposed by tenant requirements.

Similar to WTC 1 and WTC 2, most of the structural modifications in WTC 7 were done to accommodate tenant requirements. Horizontal members of the floor framing system were strengthened due to increased loading from high-density files. Strengthening of these beams and girders was achieved by welding cover plates to the bottom flanges, the underside of the top flanges, or both. In some cases new beams were introduced to carry a portion of the new load. Floor slabs were completely removed on the east side of the building to accommodate trading floors for Salomon Brothers Inc., one of the major tenants of the building. Columns in this area, which had twice the unsupported length after the slab removal, were reinforced. Other openings were cut into a few floor levels to accommodate new stairways connecting adjoining floors. Web openings were cut through some beams and girders to allow passage of ductwork. In some cases, the beams or girders had to be reinforced in order to increase their capacity.

The information contained in this report is based on documents and structural drawings that were primarily acquired from the the offices of the PANYNJ in Newark, New Jersey, and New York City, New York. Paper, microfilm, and electronic versions of these documents were obtained from these sources. Appendixes to this report include copies of referenced documents, including the Tenant Construction Review Manuals, the Standards for Structural Integrity Inspection of the WTC towers, and the

Architectural and Structural Design Guidelines, Specifications, and Standard Details, which were all issued by the Port Authority regarding inspection, repair, and modifications to the structural systems of WTC 1, 2, and 7.

E.2 GUIDELINES FOR INSPECTION, REPAIR, AND MODIFICATIONS TO STRUCTURAL SYSTEMS

E.2.1 Tenant Construction Review Manuals

The first edition of the Tenant Construction Review Manual was issued by Port of New York Authority (PONYA or Port Authority) in 1971. Subsequent editions appeared in 1979, 1984, 1990, and 1997.

The purpose of these manuals was to present the technical criteria, standards, and requirements that were to be followed by tenants that were planning construction work in any Port Authority facility. Included in the manuals were the criteria that were used by the Engineering Department of the Port Authority when reviewing proposed construction or alterations. Requirements were given for alterations and modifications to architectural, structural, geotechnical, civil, mechanical, plumbing, and fire protection systems.

The General Requirements section of the manual required that all tenants submit an application form to the Port Authority outlining the scope of work, the design criteria, and the plans prior to construction. The design was to be performed by a registered architect or licensed professional engineer. Contractors were required to comply with all applicable provisions of federal, state, municipal, local and departmental laws, ordinances, rules, regulations, and orders, except where stricter requirements were contained in the project specifications. Except for some editorial changes, the requirements in this section remained virtually the same in all editions of the manual. In the revised March 1990 edition, requirements were added concerning the role of consultants working on the project who were not the architect or engineer of record.

The scope of structural review of the alterations and/or modifications consisted of compliance with the applicable codes, standards, and design criteria given in the Structural Review section of the manual.

In particular, the provisions of the then applicable New York City Building Code were to be satisfied for work performed in New York City. Structural calculations were to be submitted by the registered design professional for review by the Port Authority. The checklist for structural review included provisions for loads, structural work, various structural materials, and foundations. The requirements in this section of the manual were modified and expanded over the years, most notably the section containing Port Authority design criteria, which was significantly expanded in the revised March 1990 edition of the manual. Included in that edition was a requirement that all structures were to be designed for earthquake zone 2 forces in accordance with the Building Officials Conference of America Basic Building Code.

The Materials, Operations, and Equipment Subject to Controlled Inspection section of the manual contained a comprehensive inspection program that was to be implemented for all construction. The inspection that was required during various phases of construction was mainly to be performed in accordance with the applicable sections of the New York City Building Code that governed at the time. Specific inspection requirements were outlined for concrete and steel. The inspection requirements were significantly reorganized and modified in the revised March 1990 edition of the manual. Requirements for

approval/acceptance of materials and controlled inspections were abstracted from the applicable sections of the New York City Building Code.

E.2.2 Standards for Structural Integrity Inspection of the WTC Towers A & B

The Infrastructure Engineering Design Division of the Engineering Department of PANYNJ issued the *Standards for Structural Integrity Inspection of the World Trade Center Towers A & B* in March of 1986. These standards were to assist the PANYNJ in the evaluation of the structural integrity of WTC 1 and WTC 2.

Three methods were used to evaluate the structural integrity of the towers: (1) statistical inspections, (2) reports, and (3) continued measurements. In the first method, periodic visual inspection of selected structural components in "higher-potential trouble areas" was to be made initially by qualified outside consultants under PANYNJ management. It was anticipated in the future that PANYNJ in-house personnel could perform such inspections. Periodic inspection of the following components was to be performed:

1. TV antenna mast on the top of WTC 1 (every year);
2. Exterior roof and wall elements (every year);
3. Room occupancies (every year);
4. Accessible column envelopes, including fireproofing (every second year);
5. Fireproofing and masonry partitions enclosing the diagonal bracing on exterior column lines in both towers below the Service Level Floor and the transfer trusses below floor 1 in WTC 2 under exterior and core columns (every second year);
6. Hat truss members between floor 107 and the roof (every second year);
7. Exterior box columns and spandrel plates under column trees below Floor 7 (every fourth year);
8. Steel floor framing over mechanical spaces (every fourth year); and,
9. Concrete slabs, partitions, and finishes (every fourth year).

Inspections were also to be made when general repair or remodeling was done that involved removing ceilings, partitions, finishes, or other coverings. Tools and procedures that were to be used to perform the inspections were also included in this method. After inspection was complete, it was required that any spray-on fireproofing that was removed for inspection purposes be properly replaced.

In the second method, various reports were to be examined, which could possibly shed light on underlying structural problems. Maintenance reports of non-structural repairs, water leakage, and tenant complaints about unusual building movements, vibration, or noise are examples of such reports.

In the third method, the performance of systems within the buildings was to be evaluated through measurement of movement or deformation. Measurements of the following were to be performed on a periodic basis:

1. Natural frequency of the towers;
2. Natural frequency of the TV mast on WTC 1;
3. Natural frequency of the floor construction;
4. Viscoelastic dampers; and,
5. Plumbness and level.

This document also contained a list of duties, responsibilities, and minimum qualifications of the inspection supervisor, inspection crew leader, and inspection crewmembers from the PANYNJ. Other requirements were given for outside consultants and suppliers who were to carry out periodic inspections and other special tasks.

During inspections, defects and signs of distress were to be noted and recorded for:

1. Structural steel (rust; cracks; buckles and kinks; connection and joint defects; alignment, excessive deflection, or bowing; and paint); and,
2. Reinforced concrete (scaling, cracking, and spalling).

General requirements were given on how to identify an inspected member, how to describe the defect or distress, and how to categorize the urgency of the required repair.

It was noted in the last section of the document that these standards were applicable to only structural steel and reinforced concrete members in WTC 1 and WTC 2. Glass and glazing, facade panels, ceilings, partitions, elevators, stairs, and mechanical equipment were listed as components outside the scope of the document.

E.2.3 Architectural and Structural Design Guidelines, Specifications and Standard Details

Issued by the Port Authority in February of 1998, this document contained architectural and structural design requirements for tenant alterations that were to be made specifically at WTC 1 and WTC 2.

Prior to any design work, the tenant's consultants were required to perform a field inspection of the area where alterations/modifications were to take place. It was required that all calculations and construction drawings be submitted to the Port Authority for review and approval, and that all documents be sealed by a professional engineer or registered architect licensed to practice in the state of New York.

Proposed floor loads were to be compared with the allowable floor design loads contained in the *Architectural and Structural Design Guidelines, Specifications and Standard Details* document. Existing structural members that would be overstressed by the proposed loads were required to be reinforced to

carry the additional loads. It was required that the weight of any equipment exceeding 500 lbs and the weight of all files and shelves be shown on the construction drawings. Minimum loads to be used in the designs were also specified in the document.

All proposed penetrations or drilling of cores in tower slabs were required to meet the criteria for location, spacing, and repair that were specified in this document. Some areas were denoted as "prohibited" (no penetrations or cores were allowed) and some were denoted as "restricted" (advisable not to locate penetrations or cores).

Additional criteria were provided for (1) supports for hung ceilings in the two-way truss areas of the towers, (2) weight, dimensions, and location of heating, ventilation, and air conditioning equipment, (3) walls over an opening, (4) holes in existing steel, (5) coring at power/telephone cells and under induction units, and (5) concrete anchors that were to be used for any connections made to concrete.

E.3 STRUCTURAL INSPECTION PROGRAMS DURING THE OCCUPANCY OF WTC 1, 2, AND 7

E.3.1 Facility Condition Survey Reports

Port Authority Facility Condition Survey Program – WTC 2

The Engineering Quality Assurance Division of PANYNJ performed a facility condition survey for WTC 2 in 1990. The scope of the survey was based on *Standards for Structural Integrity Inspection of World Trade Center Towers A & B*, which was published by PANYNJ in 1986. This document contained the minimum requirements of periodic and occasional inspection programs that were implemented for WTC 1 and WTC 2.

The scope of work, which was designed to minimize impact on tenant and facility operations, included inspection of the (1) exterior wall system (columns, spandrel plates, and splices), (2) core columns (including column splices and lateral bracing below the 7th floor), (3) space frame (hat truss), (4) floor systems (floor slabs and decks, trusses, rolled beams, bridging, and connections), and (5) damping system. Thirty floors throughout WTC 2 were selected for inspection, including all four of the two-story mechanical equipment rooms (MER).

Exterior Walls (Columns and Spandrels)

Exterior columns and spandrels were inspected at (1) column field splice connections, (2) spandrel field splice connections, and (3) the inside of the spandrel plate face at the column/floor truss seat connections.

According to the report, a total of 59 column splices were inspected and all were found to be in good condition. On two of the floor levels, the columns had only three bolts at the splice location, although the design called for four. According to the report, this had no effect on structural integrity.

Spandrel plates, splice plates, and spandrel bolted connections were also found to be in good condition. Scattered rust stains were observed on the spandrel fireproofing as well as on the inside of some of the steel box columns.

No priority recommendations were made in the report. It was recommended, however, that a long-term maintenance program be developed and implemented to clean and paint the inside surfaces of the exterior box columns to prevent further corrosion of the structural steel.

Core Columns

Core columns were inspected from elevator shafts and from office area floors. Twenty-five elevator shafts were randomly selected for inspection, and the elevator core framing was primarily inspected with fireproofing materials in place. In general, some defects were found in the fireproofing material. In most of the shafts, several small regions and a few large areas of fireproofing were found to be missing from core framing members. In the worst case, 100 percent of the fireproofing was found to be missing from the south face of column 908 between floors 27 and 29 in elevator shaft number 1. Exposed steel members exhibited only isolated locations of light surface corrosion.

Gypsum wallboards surrounding the elevator shafts were also found to be in good condition, although isolated holes were detected at various locations.

Inspection of column splices and eccentric-braced column connections with fireproofing removed showed that all bolts, welds, and structural steel were in good condition.

No priority recommendations for repair were made in the 1990 report. It was recommended that the fireproofing that was missing from the framing members in the elevator shaft be replaced, including those regions where the fireproofing was removed for inspection. It was also recommended that the holes in the gypsum wallboards surrounding the elevators be repaired.

Floor Framing

In the main lobby, beams and connections that were inspected within the core area were found to be in good condition. Fireproofing was missing at various locations, exposing light surface corrosion on these elements.

On floors 9 through 41, the floor framing that was inspected was also found to be in good condition. Light corrosion was observed on all core beams and beam connections, and on floor truss connections. The most significant deficiencies were found at the damping units, where a number of such units were missing from one to four fasteners in the connections to the framing members.

Floor framing on floors 43 though 75 was found to be in good condition. The most significant deficiencies were found on floors 64 and 75. A deformed bottom chord was found on the main truss along column 343 on floor 64; no signs of distress were observed. On the 75th floor, untightened bolts were found at truss seat connections at several locations, which, according to the report, had no significant affect on the structural integrity of the framing, since they served erection purposes.

The floor framing on floors 77 through 107 was found to be in good condition with light surface corrosion observed on all core framing beams and connections. The most significant deficiencies were concrete slabs that had separated from the metal deck at floors 93 and 108. According to the report, structural integrity was not comprised, since the metal deck served as only formwork for the concrete.

Hairline cracks were found in concrete beam encasement at various locations on all four mechanical equipment room levels. Other than that, floor framing and slabs were found to be in good condition. Selected elements of the hat truss were also found to be in good condition, with light surface corrosion on exposed truss elements and connections.

No priority recommendations for repair were made in the report. All of the deficiencies noted above were considered to have no significant effect on structural integrity.

Port Authority Facility Condition Survey Program – WTC 1

The Office of Irwin G. Cantor, Consulting Engineers, performed a condition survey of WTC 1 in 1991 for the Engineering Quality Assurance Division of PANYNJ. The scope of the survey was based on experience gained from the survey of WTC 2 in 1990. As in the case of WTC 2, the scope of work was designed to minimize impact on tenant and facility operations. The floor framing, damping system, exterior wall system, core columns, space frame (hat truss), MER, and roof were inspected.

Exterior Walls (Columns and Spandrels)

A total of 28 exterior column splices were inspected throughout 14 office floors on floors 9 through 106. Nondestructive testing was performed on the plate splice welds, and ultrasonic testing was performed to verify plate thickness at 26 of these locations. All inspected columns splices were found to be in good condition.

The inside faces of the steel box column plates exhibited scattered areas of light to moderate corrosion and peeling paint. Ultrasonic thickness testing on these outer column plates above and below the splice location indicated no cross-section loss.

Spandrel plates, splice plates, and bolted connections were also found to be in good condition. Scattered rust stains were observed on the spandrel fireproofing.

In the floors above 106, only the joints at floor 108 were inspected. No structurally significant deterioration was found.

No priority recommendations for repair were made in the report. It was noted that missing fireproofing should be replaced on the spandrel plates and splices.

Core Columns

Core columns were inspected from 13 elevator shafts with fireproofing left in place. Corner core column splices were inspected from two office area floors. Core floor beam to column connections were also inspected at 25 of 56 locations on 14 floors.

The exterior wall column splices were found to be in good condition. Results from nondestructive testing of the splice plate welds were acceptable, and results from ultrasonic thickness testing showed no significant loss in member thickness.

Several small areas and a few large areas of fireproofing were missing from some of the steel beams and columns in the express elevator shafts. According to the report, the probable cause of missing fireproofing on the columns was the high speed of the elevators moving up and down the shafts. All exposed steel was found to be in good condition with light to medium surface rust.

Gypsum wallboards were found to be in good condition, except for two isolated holes in two elevator shafts at the 58th and 69th floors.

Similar to the case of the express elevator shafts, fireproofing was found to be missing on some of the steel columns and beams, and some isolated holes were found in some of the gypsum wallboards in the local elevator shafts.

Inspection of core corner column splices and floor beam to column connections showed all of the elements to be in good condition.

No priority recommendations were made in the report. It was recommended that missing fireproofing from the framing members in the elevator shafts be replaced, including those regions where the fireproofing was removed for inspection during the condition survey. It was also recommended that the holes in the gypsum wallboards be repaired.

Floor Framing

Two typical conditions were observed during inspection of the floor trusses: (1) small areas of fireproofing were missing at scattered locations throughout the floor framing and (2) the underside of the floor trusses exhibited light rust. Welds were tested at various connections and were found to be in good condition. In some cases, the connection of the truss to the exterior spandrel plate had one bolt and a weld instead of the typical two-bolt connection. These field welds were also tested and were found to be in good condition.

At all of the locations that were inspected, the damping units did not have fireproofing covering them. Light rust was observed on the surfaces of the units. A non-structural bolt was missing on one of the damping units under the 30th floor.

The metal deck and concrete slabs that were inspected were also found to be in good condition, except for the slab in the southeast corner of the 60th floor where cracks were found on the top surface.

No priority recommendations for repair were made in the report. Routine recommendations were made to patch spalls and cracks in the concrete slab.

MER and Space Frame

All four mechanical equipment room floor levels (floors 7–8, 41–42, 75–76, and 108–109) were inspected. Floor slabs at these levels were found to be in good condition with scattered cracks found on the slab surfaces. Scattered patches of fireproofing were found missing from the underside of the metal decks outside the core area.

A concrete encased beam on the 110th floor was subjected to steam from a leaking steam valve. Moderate rusting was found on the member, but no significant section loss was found.

Hangers supporting ducts, piping, etc. were visually inspected, and some were found to be subject to excessive vibration. Loose hanger rods and fatigue of pipe supports were also found at various locations. Beams that supported the duct hangers had fireproofing missing where the hangers were mounted.

A total of 199 members were inspected in the space frame (hat truss). Light rust was found on diagonal braces, beams, and connections where fireproofing was missing.

A priority recommendation was made in the report to replace the leaking valve under the 110th floor that caused the floor beam to rust. Routine recommendations were made to repair cracks in the concrete slabs and to repair hangers that were found to be vibrating, bowed, sagged, and/or deformed.

Roof

No significant structural deficiencies were found at the roof level. Cracking and spalling of the concrete slab was found in localized areas of the roof.

No priority recommendations were made in the report. Routine recommendations included removing and replacing existing patches in the roof slab and patching spalled areas in the concrete slabs.

Port Authority Facility Condition Survey Program – WTC 7

Ammann & Whitney performed a condition survey of WTC 7 in 1997 for the Engineering Quality Assurance Division of PANYNJ. The scope of work was designed to minimize impact on tenant and facility operations and was limited to unoccupied floors and floors which had vacant space. The foundation, column splices, wind bracing system, interior beam connections, floor slabs, and the Con Edison Substation were all inspected.

According to the report, no problems or deterioration were found on the column splices, wind bracing, or the interior beam connections at any of the locations that were inspected. Rust buildup was found between the flanges of members that rested on top of one another at the main roof level where the steel framing was exposed. It was recommended that the steel be cleaned and painted to prevent further deterioration, even though this was not considered to be a structural problem.

Fireproofing was found to be missing from the steel framing at various locations where utility supports were installed on all of the floors that were inspected. Missing fireproofing was most prominent on the 5th floor framing above the main lobby and the 2nd floor framing above the loading dock area. It was recommended in the report that the fireproofing be replaced.

Loose concrete was found on the north face of column 51 on the 46th floor of the cooling tower area. Silverstein Properties personnel immediately removed the loose concrete.

Floor slabs were found to be in good condition. No deficiencies were found, except for some shrinkage cracks on the top of some of the exposed slabs and some damage to the metal deck.

The Con Edison station was found to be in very good condition, and no action was required at that time.

Due Diligence Physical Condition Survey – WTC 1 and WTC 2

Merritt & Harris, Inc., performed a condition survey for WTC 1 and WTC 2 in 2000 for PANYNJ. The on-site evaluations were carried out to assess the general physical condition of the property at that time. WTC 4, WTC 5, the retail mall and plaza, central services, and the subgrade were inspected in addition to WTC 1 and WTC 2.

Observations were limited to those portions of the buildings that were visible during walk-through. No material samples were taken, and no tests were performed on the building materials or systems.

According to the report, the building structure appeared to be in good overall condition, based on observations of the structural members that were not concealed by building finishes. The interior slabs were reported to be in good condition, and no apparent movement or settlement of foundations was observed.

The report notes that Leslie E. Robertson Associates (LERA) and other engineering firms had performed Structural Integrity Inspections of various structural systems and had pointed out the following deficiencies: (1) rusting of steel columns in the elevator shafts, (2) missing fireproofing on structural members, and (3) floor coring damage. The report goes on to discuss the damping units, including LERA's strong recommendation to continue wind acceleration measurements.

E.3.2 Structural Integrity Inspection Program

In 1986, PANYNJ implemented an inspection program to detect, record, and correct any signs of distress, deterioration, or deformation that could signal structural problems. This structural integrity inspection program, which was based on an inspection and testing plan prepared by LERA, contained detailed guidelines on inspection, record-keeping, and follow-up procedures.

In regard to the follow-up procedure, a description was to be provided of the defect or indication of distress. Measurements, sketches, and photographs were to be provided in those cases where a written description was not adequate. The use of a tape recorder was also permitted.

If the Supervisor or the inspection team uncovered defects or indications of distress that appeared to require more than routine attention, a separate report of such findings was to be submitted to the Port Authority's Engineer of Design, Infrastructure. For conditions of a serious nature, immediate notification was to be made to the Engineer of Design, Infrastructure in person.

Inspection findings under this program were to be categorized as "Immediate," "Priority," or "Routine." Repairs falling into the "immediate" category included possible closure of the area and/or structure affected until interim remedial action (such as shoring or removal of a potentially unsafe element or structure) could be implemented. Such action was to be undertaken immediately after discovery, and a description of the action taken and recommendations for permanent repair were to be included in the inspection report. The "priority" category was for those conditions where no immediate action was required, or for which immediate action had been completed, but for which further investigation, design, and implementation of interim or long-term repairs should be undertaken on a priority basis (i.e., taking precedence over all other scheduled work). Repairs falling into the "routine" or "non-priority" category

could be undertaken as part of a scheduled major work program or other scheduled project, or when routine facility maintenance was to be performed, depending on the type of repair that was required.

An important requirement in the inspection program was that where inspection procedures involved the removal of fireproofing, such fireproofing was to be properly replaced on completion of inspection.

LERA submitted a proposal to PANYNJ in 1990 to monitor the structural integrity of the WTC Complex, which included WTC 1, WTC 2, WTC 4, WTC 5, WTC 6, the Vista Hotel, and the subgrade. The proposal called for inspection/monitoring of the following items in WTC 1 and WTC 2:

- TV mast (WTC 1 only)
- Roof water tightness and curtain wall
- Space usage
- Accessible columns, including exterior box columns at locations of spandrel intersections and "tree' junctions below floor 7 and above floor 1 (Plaza Level)
- Bracing at exterior column line below elevation 294 ft-0 in., and in WTC 2 only, the transfer trusses below floor 1 under exterior columns
- Hat truss between floor 107 and the roof
- Floor framing over mechanical spaces
- Concrete slabs, partitions, and finishes
- Steel framing, slabs, and the like where exposed for general repairs or tenant remodeling
- Measurement of natural frequency of tower and TV mast
- Floor natural frequency
- Damping units
- Plaster ceilings in main lobby
- Marble wall panel supports
- Review of maintenance reports
- Fire stairs

Inspection and monitoring of these items were to occur at regular intervals, which were proposed by LERA.

LERA and other engineering firms conducted periodic inspections of the towers under the WTC Structural Integrity Inspection Program, which was based on the proposal originally submitted to

PANYNJ by LERA in 1990. A summary of the structural integrity inspection programs and their corresponding dates is given in Table E–1.

Table E–1. Summary of Structural Integrity Inspection programs for WTC 1 and WTC 2.

Inspection Program	Date(s) of Inspection Reports
Space Usage Survey	1995, 1996, 1997, 1998, 1999
Accessible Columns	1993, 1995, 1996, 1997, 1998
Plaza Level Box Columns	1998
Bracing Below Elevation 294 ft- 0 in.	1991, 1995
Hat Trusses	1992, 1995
Floor Framing Over Mechanical Areas	1992, 1996, 1999
Floor Framing Over Tenant Areas	1992, 1995, 1997, 1999
Natural Frequency Measurements	1993, 1995, 2000
Natural Frequencies of Floors	1995
Viscoelastic Damping Units	1996

Space Usage Surveys

The purpose of the space usage surveys was to identify possible structural overloading of the slabs and floor framing due to changes in occupancies and uses and/or due to additions of heavy equipment or furniture. Surveys were conducted annually over a 5 year period starting in 1995, with two surveys conducted in 1996. The only priority recommendation was made in the 1995 report, which advised PANYNJ to distribute the load of the granite slabs on floor 106 of WTC 1 over a larger area. A summary of the findings from the space usage reports can be found in Table 3–13 of this report.

Accessible Columns

Surveys of the accessible columns (columns in the core area that were not enclosed by an architectural finish, which can be visually inspected) in the elevator shafts of WTC 1 and WTC 2 were performed to:

- Ascertain the condition of the accessible columns with respect to rusting, cracking, bowing, and deviation from plumb;
- Identify specific locations of structural distress or damage;
- Identify locations of damage to the fireproofing;
- Identify lateral displacement or rotation of the column about a vertical axis where the column was directly braced on only one axis by connecting beams or concrete slabs; and
- Identify deformations of the slabs-on-ground surrounding each column at the sublevel.

Accessible column surveys were performed approximately every 2 years, starting in 1993 and ending in 1998. Priority recommendations were made in the 1996 report and the second report in 1998. The later

report recommended that missing fireproofing be replaced on columns at various locations in WTC 1 and WTC 2. A summary of the findings from the accessible columns reports can be found in Table 3–14 of this report.

Plaza Level Box Columns

The purpose of the inspection of the Plaza Level box columns was to assess their overall structural integrity, including the condition of the fireproofing. The proposed inspection interval was 4 years.

Fireproofing was found to be missing from approximately 2 to 3 percent of the Plaza Level box columns and seated beam connections in WTC 1 and about 1 to 2 percent in WTC 2. A summary of the findings from the Plaza Level box columns report is given in Table 3–15 of this report.

Bracing Below Elevation 294 ft 0 in.

Below Elevation 294 ft 0 in. (Sublevel 1) in both WTC 1 and WTC 2, diagonal bracing was used in place of deep spandrels between the exterior columns to resist lateral loads from the towers above.

The purpose of the inspection of the bracing system below elevation 294 ft 0 in. in the perimeter walls of the towers was to:

- Assess the overall performance and structural integrity of the bracing (and, in 1991 only, the transfer trusses below elevation 310 ft 0 in. in WTC 2);
- Identify specific locations of structural distress or damage;
- Identify locations of damage to the structural fireproofing systems; and
- Provide recommendations for remedial work for both structural and fireproofing damage.

Bracing surveys were performed in 1991 and 1995, and a summary of the findings from these reports can be found in Table 3–16 of this report. No priority recommendations were made in these reports.

It is evident from Table 3–16 that the PANYNJ did not act on a number of recommendations priority and routine repairs from earlier reports. In particular, draining of flooded areas due to water leaks was not fully accomplished, and repairs to the connections between the braces and the columns were not made. Fireproofing was not applied to the transfer truss between columns 242 and 248 at the B1 Level in WTC 2. Also, fireproofing was not repaired on some of the bracing members at Level B6 and at other levels. It appears that all of the damaged concrete masonry unit (CMU) walls acting as fireproofing, which were identified in the 1991 Structural Integrity Inspection report, were repaired; many additional CMU walls were noted for repair in the 1995 Structural Integrity Inspection report.

Hat Trusses

The purpose of the inspection of the hat trusses between floor 107 and the roof was to:

- Assess the overall performance and structural integrity of the hat trusses;

- Identify specific locations of structural distress or damage;
- Identify locations of damage to the structural fireproofing systems; and
- Provide recommendations for remedial work for both structural and fireproofing damage.

Hat truss surveys were performed in 1992 and 1995. A summary of the findings from these reports can be found in Table 3–17 of this report. Although no priority recommendations were made in these reports, routine recommendations were made to repair fireproofing and gypsum wallboard at various locations in WTC 1 and WTC 2. No follow-up actions were stated in the report.

Floor Framing over Mechanical Areas

The inspection program for the floor framing supporting the MER consisted of the following:

- Assess the overall performance and structural integrity of the steel and concrete framing.
- Identify locations of defects and signs of distress in slabs, partitions, column enclosures, and concrete supports for mechanical equipment.
- Identify locations of damaged fireproofing.
- Compare the findings with those of previous inspections.
- Provide recommendations and procedures for remedial work for both structural and fireproofing damages and/or inadequacies.

Surveys were conducted in 1992, 1996, and 1999. Priority recommendations were made in the 1996 and 1999 reports. The 1996 recommendation called for reapplication of fireproofing at various locations in WTC 1 and WTC 2. The 1999 recommendation called for repair of a water leak in an overhead pipe on floor 75 of WTC 1. A summary of the findings from these reports can be found in Table 3–18 of this report.

Floor Framing over Tenant Areas

The inspection program for the floor framing supporting the tenant areas consisted of the following:

- Assess the overall performance and integrity of the steel and concrete framing.
- Identify locations and signs of distress in slabs, partitions, column enclosures, and steel framing.
- Identify locations of inadequate fireproofing.
- Provide recommendations and procedures for remedial work for both structural and fireproofing damages and/or inadequacies.

Surveys for floor framing supporting tenant areas occurred in 1992, 1995, 1997, and 1999. Priority recommendations were made in the 1999 report concerning restoration of fireproofing on a truss on floor 89 in WTC 2, repair of spalled concrete on floor 89 of WTC 2 and floors 33 and 91 in WTC 1, and repair of damaged reinforcement on floor 91 of WTC 1. A summary of the findings from these reports can be found in Table 3–19 of this report.

Natural Frequency Measurements

The purpose of this inspection program was to determine the natural frequencies of oscillation of WTC 1 due to wind excitation. Only WTC 1 was instrumented with accelerometers at six locations on floor 108, which measured the accelerations in both principal directions of the building with respect to time due to wind. These natural frequencies were to be compared with corresponding values that were determined in the past. A significant change in the tower's dynamic behavior was considered to be a possible indication of diminishing structural integrity. According to the reports, characteristics that may have been observed or inferred by review of the recorded acceleration data were:

- Integrity of the lateral-load-resisting system;
- Condition of the viscoelastic damping system;
- Condition of other sources of inherent structural damping; and
- Other changes that affect fundamental characteristics of the lateral-load-resisting system.

Reports were prepared by LERA in 1993, 1995, and 2000. The main conclusion from the 1993 and 1995 reports was that the measured and computed first mode frequencies compared well, especially for the large wind speeds. The 1995 report also concluded that the February 1993 bombing had no permanent measurable effect on the dynamic response of WTC 1. Both reports recommended that WTC 2 be instrumented similarly to WTC 1.

The 2000 report pointed out that data acquired since 1998 could not be analyzed due to the dismantling of the PANYNJ facilities that performed the analysis. The report recommended that the capability to assess the data be re-established as soon as possible.

Natural Frequencies of Floors

The purpose of this inspection program was to determine the natural frequencies of the floor systems in WTC 1 and WTC 2. These natural frequencies were to be compared with corresponding values that were determined in the past. A significant change in the vibration characteristics of the floor system was considered to be a possible indication of diminishing structural integrity. Summaries of the natural frequencies of the floors in WTC 1 and WTC 2 are given in Tables 3–22 and 3–23 of this report.

The report produced by LERA in 1995 summarized the analytical and experimental results to date. The report concluded that there was no significant measurable change in the performance of the typical floors systems of WTC 1 and WTC 2.

Viscoelastic Damping Units

A summary of the integrity of the viscoelastic damping units in WTC 1 and WTC 2 was given in a report by LERA in 1996. Also given in the report is a historical review related to the performance of the damping units.

The report concluded that based on the then available studies, the integrity of the damping units was good, and that no action was required at that time beyond the routine testing of the damping units.

Inspections Related to Explosion of February 16, 1993

Six different inspections were performed before and after repairs were made to WTC 1 in the aftermath of the terrorist attack in February of 1993. A summary of these inspections can be found in Table 3–24 of this report. No anomalies were detected in the welds used to repair structural members.

E.3.2 Summary of Structural Inspection Programs

In general, the structural integrity inspections found that the structural systems of WTC 1, 2, and 7 were in good condition. The inspection consultants made numerous routine and some priority recommendations for repairs to the PANYNJ, as outlined in the appropriate sections of this report. Unless there were scheduled maintenance programs, the PANYNJ did not act expeditiously on some of these repair recommendations, including not replacing or repairing fireproofing on structural steel members that was found to be missing from the inspections. According to the PANYNJ, all of the construction records on repairs following the inspections were lost on September 11, 2001. Thus, it cannot be determined whether all of the recommended repairs were performed.

Table 3–25 of this report gives a chronological summary of the locations where fireproofing was reported to be missing, based on the findings from the applicable inspection programs.

E.4 SIGNIFICANT MODIFICATIONS AND REPAIRS MADE TO THE STRUCTURAL FRAMING SYSTEMS OF WTC 1, 2, AND 7

Most of the modifications to the structural systems of WTC 1, 2, and 7 were done to accommodate tenant requirements. These generally involved cutting holes in existing floor slabs to construct new stairways linking two or more floors or reconstructing the floor system over previously cut openings. In other cases floor or column members were reinforced to accommodate new floor loadings imposed by tenant requirements.

Modifications to the structural systems were to follow the guidelines set forth by the PANYNJ, which are summarized in Sec. E.2 and Chapter 2 of this report.

E.4.1 Modifications and Repairs Made to WTC 1

Openings Made in Floor Slabs

Slab openings were made in the floor slabs on the following floors during the following years:

1. Floors 93-95, 1978 (openings were made in floors 93, 94 and 95 between columns 901, 902, 1001, and 1002 in core)

2. Floors 99-101, 1979 (openings were made in floors 100 and 101 between columns 707, 708, 806, and 807 in core, and in floor 99 between columns 701, 702, 801, and 802)

3. Floors 89 and 90, 1985 (opening was made in floors 89 and 90 between columns 901, 902, 1001, and 1002)

4. Floor 107, 1995 (opening was made in floor 107; location could not be determined)

5. Floors 105-roof, 1997 (opening was made in floor 105 near columns 704 and 804A in the core)

6. Floors 93-100, 1999 (openings were made on all floors; location could not be determined)

Most openings were made to accommodate new stairs and elevators.

Openings in Floor Slabs that Were Closed

Openings that had been cut primarily for stairways were subsequently closed on the following floors during the following years:

1. Floor 95, 1972 and 1985 (new beams and floor deck were added near column lines 124 and 239)

2. Floors 91 and 92, 1987 (new beams and floor deck were added between columns 901, 902, 1001, and 1002 in the core)

3. Floors 96 and 100, 1998 (new beams and floor deck were added between columns 119 and 123 on floor 96 outside of the core and near columns 707, 708, 806, and 807 on floor 100)

Structural Members that were Reinforced

Various floor members were reinforced to accommodate floor loads that were greater than the original design loads. Members were reinforced on the following floors during the following years:

1. Floors 98 and 99, 1979 (cover plates were added on existing beams on floor 98 between columns 601 and 602 and between 701 and 702; on floor 98, diagonals were added to existing floor trusses on the east side of the core between columns 218 and 221; on floor 99, floor trusses along lines 309, 311, 313, 315, 317, 319, 321, 323, 325, 327, and 329 were reinforced; and, on floor 99, core perimeter columns were reinforced)

2. Floor 86, 1996 (floor trusses were reinforced in the northwest corner of the building)

3. Floor 85, 1998 (cover plates were added to existing beams and existing floor trusses were reinforced)

4. Floors 47 and 48, 2001 (floor trusses were reinforced)

Repair Work Following the February 26, 1993, Explosion

Damage from the Explosion

The explosion of February 26, 1993, occurred on Level B2 near the center of the south wall of WTC 1 and adjacent to the Vista Hotel. Structural steel columns, diagonal braces, and spandrel beams in the vicinity of the blast were damaged. Concrete floor slabs at Levels B1 and B2 and unreinforced masonry walls were also damaged over a large area.

The explosion tore out the diagonal brace between column 324 at Level B2 and column 327 at Level B1 and severely bent the diagonal brace between column 324 at Level B2 and column 321 at Level B1.

Spandrel beams at Level B1 from column 321 to column 324 and from column 324 to column 327 were also damaged by the blast. Spandrels were bowed and cracked, and some had missing bolts.

The inspection teams observed a crack along the field splice in column 324. Ultrasonic testing determined that the crack extended across the full width of the weld on the south face of the column and at each end of the weld on the north face. Magnetic-particle testing procedures determined that the crack extended across the east face of the column and the majority of the weld on the west face as well.

The explosion also damaged floor beams framing into the tower side of column 324 at Levels B1 and B2. Concrete spandrel beams at Level B3 between columns 318 and 330 also sustained damage. Masonry walls in WTC 1 were breached over distances of approximately 50 ft to the east and 120 ft to the west of the blast origin.

Repair Work

The diagonal bracing members between levels B1 and B2 that were damaged by the explosion were removed and replaced with new members.

New plates were added to the damaged spandrel beam at level B1 between columns 324 and 327 and between columns 321 and 324. Also, the cracked weld on the south face of the spandrel beam at level B1 near column 324 was removed and replaced.

An eight-step procedure was prescribed for repair of the crack in column 324 immediately adjacent to the field weld at the column splice above level B2. No documentation was found to confirm that this crack was repaired according to that procedure.

Repairs were made to the floor beams framing into columns 321, 324, and 327. Repairs were also made to connections between floor beams and columns on Levels B3 and B4. Along the south face of WTC 1, the damaged concrete spandrel beams were demolished and replaced.

Other Modifications

An FM transmitter was installed on the 110th floor in 1997. In June of 2000, structural calculations were submitted by LERA for the WABC Control Room on floor 110. A new transmitter and ductwork were suspended from the existing floor system at this level.

E.4.2 Modifications and Repairs Made to WTC 2

Openings Made in Floor Slabs

Slab openings were made in the floor slabs on the following floors during the following years:

1. Floor 77, 1979 (openings were made at nine locations in the northeast quadrant of the building)
2. Floor 96, 1987 (opening was made near columns 901 and 902 in the southeast quadrant of the building)
3. Floors 94 and 95, 1993 (opening was made between columns 507, 508, 607 and 608)
4. Floors 99-101, 1997 (openings were made; locations could not be determined)
5. Floor 99, 1998 (opening was made between columns 601, 602, 701, and 702 in the core on Floor 99)
6. Floors 25 and 26, 1999 (opening was made near column 901 in the core)
7. Floors 88 and 89, 1999 (openings were made; locations could not be determined)

Most openings were made to accommodate new stairs.

Openings in Floor Slabs that were Closed

Openings that had been cut were subsequently closed on the following floors during the following years:

1. Floors 37 and 38, 1997 (new framing and floor deck was added near column 608)
2. Floors 95 and 96, 2000 (new beams and floor deck were added between columns 901, 902, 1001, and 1002)

Structural Members that were Reinforced

Members were reinforced on the following floors during the following years:

1. Floor 96, 1993 (a number of floor trusses and their connections were reinforced in the northeast quadrant of the building)

2. Floor 81, 1991 (two-way floor trusses were reinforced in area occupied by UPS)

Other Modifications

In 1994, the slab in the elevator lobby on floor 90 (bounded by columns 702, 703, 902, and 903) was repaired for Fiduciary Trust for an unknown reason. The existing slab was demolished and was replaced with a 5 in. thick lightweight aggregate concrete slab.

E.4.3 Modifications and Repairs Made to WTC 7

Modifications Made due to New Loading Requirements

Members were reinforced primarily to accommodate floor loads that were greater than the loads for which these members were originally designed. Members were reinforced on the following floors during the following years:

1. Floor 38, 1988 (cover plates were added to existing beams along column lines 30, 35, 37 and 40)

2. Floor 24, 1989 (cover plates were added to existing beam on column line 45 and to two adjacent beams)

3. Floor 47, 1989 (cover plates were added to existing beams on column line 25 and to the existing girder on column line 56)

4. Floors 11 and 12, 1990 (cover plates were added to eight existing beams and girders in the northwest corner of the building on floor 11, and to three existing beams between lines 48 and 49 and to the girder between columns 70 and 73 on floor 12)

5. Floor 19, 1991 (cover plates were added to existing beams; location could not be determined)

6. Floor 12, 1992 (cover plates were added to eleven existing beams in the northwest corner of the building and a new beam was added between existing beams)

7. Floors 18 and 19, 1992 (cover plates were added to existing beams on lines 31, 32, and 33)

8. Floor 28, 1993 (additional shear studs were added to existing beams located in the mechanical/electrical room)

9. Floors 7 and 8, 1993 (a new beam was added between column lines 7 and 8)

10. Floors 7-29, 1994 (cover plates were added to 22 existing beams between lines 5 and 25 on the south side of the building and on each floor between levels 7 and 29, and to 8 existing beams on the east side of the building between lines 31 and 37)

11. Floor 20, 1995 (cover plates were added to existing beams along lines 23 and 25, and WT sections and cover plates were added to existing beams east of column line 19)

12. Floor 37, 1999 (a new beam was added between two existing beams along column lines 76 and 77)

13. Floor 13, 1999 (additional shear studs were added to an existing beam; location could not be determined)

14. Floor 40, 1999 (four new beams were added near column 76, and WT sections were welded to the bottom of two existing beams)

15. Floor 31, 2000 (cover plates were added to an existing beam between columns 77 and 80)

16. Floor 38, 2000 (cover plates were added on existing beams between columns 76 and 77 and between columns 77 and 78, and to existing girders between columns 76 and 79, 77 and 80, and 78 and 81)

17. Floor 39, 2000 (new beams were added between columns 76 and 77)

Openings Made in Floor Slabs

The floor slabs on floors 41 and 43 were completely removed on the east side of the building to accommodate the trading floors for Salomon Brothers Inc. Also, columns 76, 78, 79, 80, and 81 were reinforced with plates that ran from the top of the 39th floor to the underside of the 49th floor due to the removal of the floor slab at the 39th floor. Similarly, column 74 was reinforced with plates that ran from the top of the 43rd floor to the underside of the of the 44th floor due to the removal of the floor slab at the 43rd floor.

Other slab openings were made in the floor slabs on the following floors during the following years:

1. Floors 3 and 4, 1989 (openings were made on the 3rd floor on the west, north, and east sides of the building; on the 4th floor, openings were made on the north side of the building)

2. Floor 3, 1989 (openings were made near columns 24 and 25)

3. Floor 11, 1990 (opening was made between columns 77, 78, 80, and 81)

4. Floor 43, 1994 (opening was made near column 71 in the core area)

Modifications Made to Beam Webs and Flanges

Modifications were made to beam webs and flanges on the following floors during the following years:

1. Floor 28, 1993 (openings were cut in the web of an existing beam; location could not be determined)

2. Floors 4-7, 16, 21, 29, 38, and 45, 1993 (notches were cut in the bottom flanges of various beams, and plates were welded to the upper side of the bottom flanges)

3. Floor 1, 1998 (notch was cut into the top flange of an existing beam, and two plates were welded under the top flange; location could not be determined)

4. Floors 36-44, 1999 (openings were cut in the web of existing beams framing into column 75 on all floor levels; the beams were reinforced with web plates and a WT section welded to its bottom flange)

5. Floors 42 and 44, 1999 (openings were cut in the webs of numerous beams along the north and east sides of the building)

Other Modifications

A list of structural modifications that were made to WTC 7 prior to April of 1997 is given in Chapter IV, Section A(5) of the Facility Condition Survey Report for WTC 7. The following is a summary of the modifications that are noted in that report:

1. In the Convention Area on the 3rd floor between column numbers 45 and 48A, steel plates were installed around the perimeter of the room between the slab and the floor surface (behind the wall coverings and above the suspended ceiling). According to the PANYNJ report, these plates were installed to protect attendees of the Convention Center from the magnetic field generated from the ConEd Substation beneath the conference rooms. No documentation was located that provides any additional details on this modification.

2. On the north side of the 5th floor generator room, masonry block walls were added to partition the eight transformer vaults installed for Salomon Brothers. The vaults were between columns 46 and 53. No documentation was located that provides any additional details on this modification.

3. A penthouse was constructed on the 47th floor roof to house the chiller plant and the cooling towers for Salomon Brothers. The chiller plant was an enclosed steel-framed structure with corrugated steel walls. It was approximately 25 ft in height and took up about one-third of the square footage of the 47th floor roof. The cooling towers were supported on a steel frame and were enclosed by louvered walls on the north and south sides and by the chiller plant and the bulkhouse on the east and west sides, respectively. No documentation was located that provides any additional details on this modification.

The list of modifications in the PANYNJ report also include the removal of the floor slabs on floors 41 and 43 to accommodate the trading floors for Salomon Brothers, as noted above.

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Chapter 1
INTRODUCTION

This report contains a summary of the maintenance and modifications that were made to the structural systems of World Trade Center (WTC) 1, 2, and 7. Documented in Chapter 2 of this report are the guidelines that were established by the Port Authority of New York and New Jersey (PANYNJ or Port Authority) for inspection, repair, and modifications to the structural systems of WTC 1, 2, and 7. Included are the guidelines governing the inspection and strengthening of the existing structural systems for modifications made by tenants of the buildings.

Chapter 3 of this report contains a summary of the structural inspection programs that were undertaken during the occupancy of WTC 1, 2, and 7. Included are summaries of the facility condition survey reports that were produced for WTC 1, 2, and 7. These surveys reported on the condition of the buildings, including the structural systems, and contained recommendations for any necessary repairs or upgrading. This chapter of the report also contains a description of the structural integrity inspection program that was undertaken for WTC 1 and WTC 2. In addition to the structural integrity inspection programs, significant observations, procedures for implementation, and actions taken are summarized.

The significant modifications and repairs that were made to the structural systems of WTC 1, 2, and 7 from initial occupancy to September 11, 2001 are documented in Chapter 4 of this report. A discussion on the repairs that were made after the February 1993 bombing of WTC 1 is also included. Other than the repairs following the 1993 bombing of WTC 1, most of the structural modifications in WTC 1 and WTC 2 were performed to accommodate tenant requirements. Openings were cut in existing floors to construct new stairways linking two or more floors, and floor systems were reconstructed over previously cut openings. In a number of cases, floor trusses outside of the core area and steel beams in the core area had to be reinforced due to heavy loads imposed by tenant requirements.

As in WTC 1 and WTC 2, most of the structural modifications in WTC 7 were made to accommodate tenant requirements. Horizontal members of the floor framing system were strengthened due to increased loading from high-density files. Strengthening of these beams and girders was achieved by welding cover plates to the bottom flanges, the underside of the top flanges, or both. In some cases new beams were introduced to carry a portion of the new load. Floor slabs were completely removed on the east side of the building to accommodate trading floors for Salomon Brothers Inc., one of the major tenants of the building. Columns in this area, which had twice the unsupported length after the slab removal, were reinforced. Other openings were cut into a few floor levels to accommodate new stairways connecting adjoining floors. Web openings were cut through some beams and girders to allow passage of ductility work. In some cases, the beams or girders had to be reinforced in order to increase their capacity.

The information contained in this report is based on documents and structural drawings that were primarily acquired from the following locations: (1) the offices of the PANYNJ in Newark, New Jersey, and New York City, New York, and (2) the National Institute of Standards and Technology in Gaithersburg, Maryland, where Port Authority documents were sent. Paper, microfilm, and electronic versions of these documents were obtained from these sources.

Appendixes to this report include copies of referenced documents, including the Tenant Construction Review Manuals; the Standards for Structural Integrity Inspection of the World Trade Center Towers; and the Architectural and Structural Design Guidelines, Specifications, and Standard Details, which were all issued by the Port Authority regarding inspection, repair, and modifications to the structural systems of WTC 1, 2, and 7.

Chapter 2
GUIDELINES FOR INSPECTION, REPAIR, AND MODIFICATIONS TO STRUCTURAL SYSTEMS

In 1971, the Port of New York Authority (PONYA or Port Authority), which was later renamed The Port Authority of New York and New Jersey (PANYNJ or Port Authority), established guidelines for all types of modifications that were to be made to any of their facilities, including the World Trade Center (WTC). As shown in Sec. 2.1 of this chapter, these guidelines evolved through the years. Standards for structural integrity inspection and architectural and structural design guidelines and specifications were also issued by PANYNJ and are discussed in Secs. 2.2 and 2.3, respectively. In addition, the PANYNJ commissioned facility condition surveys at regular intervals for WTC 1, 2, and 7. These surveys reported on the condition of the buildings, including the structural systems, and included recommendations for any necessary repairs or upgrading. Discussion on these reports can be found in Chapter 3 of this report. Periodic inspections of the structural systems were also performed under the Structural Integrity Inspection (SII) Program for WTC 1 and WTC 2, the details of which can also be found in Chapter 3. The following discussion focuses on the guidelines for inspection, repair, and modifications to the structural systems for WTC 1, 2, and 7.

2.1 TENANT CONSTRUCTION REVIEW MANUALS

PONYA issued the first edition of the Tenant Construction Review Manual in 1971, shortly after the first tenants occupied WTC 1 in December of 1970 and prior to initial occupancy of WTC 2 in January 1972. Other editions of the manual followed. As stated in its Introduction, the manual was published to present the technical criteria to be used by tenants of Port Authority facilities who were planning construction work in such facilities. In particular, the manuals set forth the applicable standards and requirements to be used by tenants and their agents. The manuals also included the review criteria of the design documents that were used by the Engineering Department of the Port Authority in connection with proposed construction or alterations. Also covered in the manuals were requirements for alterations and modifications to architectural, structural, geotechnical, civil, electrical, mechanical, plumbing, and fire protection systems in any Port Authority facility, including the WTC.

General requirements and specifications evolved over the years. The following discussion summarizes the structural provisions contained in the Tenant Construction Review Manual from the 1971 edition through the 1997 edition.

2.1.1 1971 Edition[1]

General Requirements

Prior to construction, all applicants were required to submit a completed application form to PONYA that included, among other things, the scope of work to be performed, design criteria, and plans. It was required that design was performed by a registered architect or licensed professional engineer and that the drawings produced by the design professionals were consistent with criteria set forth in the manual. At the termination of construction, a complete set of as-built drawings, sealed and signed by the design professional, was to be submitted to PONYA.

Contractors were required to comply with all applicable provisions of federal, state, municipal, local, and departmental laws, ordinances, rules, regulations, and orders, except where stricter requirements were contained in the project specifications based on the criteria in the manual. In such cases, the latter requirements would govern. It was also necessary for contractors to obtain PONYA permits for any welding or hot work, in addition to being licensed by the state or municipality. Finally, contractors were not permitted to apply for any variance, license, waiver, or permit of any kind in the name of or on behalf of the Port Authority.

Structural Requirements

The scope of structural review of the alterations and/or modifications consisted of compliance with the applicable codes, standards, and design criteria set forth in the Structural Requirements section of the manual.

For work performed in New York City, the New York City (NYC) Building Code was to be used. Both the 1938 edition and the December 6, 1968 edition were listed. Also, the laws, rules, and regulations adopted by federal, state, and local municipal agencies were to be satisfied, where applicable.

Structural calculations were to be submitted by the registered design professional for review by PONYA. The PONYA structural reviewer was responsible for the structural integrity of all walls and partitions. Building frames were checked for stability and sidesway, including the effects of these on the columns. Once the review of the superstructure was complete, the structural reviewer was to submit all applicable materials to the Chief Structural Engineer of PONYA for review and comment.

All structural modifications were required to conform to the provisions contained in Table 2–1. This checklist, which was utilized during the review process by PONYA, is based on the 1968 edition of the NYC Building Code.

Controlled Inspection of Materials, Operations, and Equipment

A comprehensive inspection program was implemented for all construction. Inspection was required during various phases of construction, and was mainly to be performed in accordance with NYC Building Code Section C26-106.3 (Materials, Assemblies, Forms and Methods of Construction; Inspection

[1] See Appendix A for the general and structural requirements in the 1971 edition of the Tenant Construction Review Manual (PONYA 1971).

Requirements) and Section C26-107.3 (Service Equipment; Inspection Requirements). Table 2–2 contains a summary of these requirements as they appeared in the 1971 edition of the manual. For brevity, only general requirements and items related to concrete and steel are contained in the table.

According to Chapter 5, Section VIII of the Tenant Construction Review Manual, tests prescribed by the NYC Building Code were to be made under the supervision of an architect, engineer, or testing service acceptable to the PONYA Resident Engineer. Also, inspections during the progress of work could be performed without verification by PONYA department inspectors. The architect, engineer, or other person who supervised the work was required to be present at final inspection by PONYA.

Table 2–1. Checklist for Structural Review in the 1971 Edition of the Tenant Construction Manual.

Provision	Code Reference[a]
General	
Materials, Assemblies, Forms & Methods of Construction	C26-106.0
General Requirements	C26-106.1
Acceptance Requirements	C26-106.2
Inspection Requirements	C26-106.3
Plan Required	C26-110.2
Structural Plans	C26-110.2(b)
Loads	
Dead Loads	901.0
Floor Live Loads	C26-902.2 & RS9-2
Live Loads for Sidewalks, Driveways, and Railings	C26-902.3
Roof Loads	C26-902.6
Moving Loads	C26-902.7
Partial Loading Conditions	C26-902.8
Floor Live Load Reduction	C26-903.2
Contributory Floor Areas	C26-903.3
Wind Loads	904.0 & RS 9-5
Thermal Forces	C26-905.7
Shrinkage	C26-905.8
Distribution of Loads	906.0
Structural Work	
General Requirements	C26-1000.6
Materials and Methods of Construction	C26-1000.7
Inspection of Materials and Assemblies	Table 10-1
Inspection of Methods of Construction	C26-1000.9
Use of Used and Unidentified Materials	C26-1000.10
Equivalent Systems of Design	C26-1000.1
Deferred Detailing	C26-1001.4

Table 2–1. Checklist for Structural Review in the 1971 Edition of the Tenant Construction Manual (continued).

Provision	Code Reference[a]
Structural Work (continued)	
Combination of Loads	C26-1001.4
Load Tests	C26-1002.4
Masonry	1003.0
Unreinforced Masonry	***RS 10-1***
General	Section 1
Definitions	Section 2
Materials	Section 3
Design	Section 4
Lateral Support	Section 5
Thickness and Height of Masonry Empirical Provisions	Section 6
Bonding	Section 7
Grouted and Filled Cell Masonry	Section 8
Anchorage	Section 9
Miscellaneous Requirements	Section 10
Veneer	Section 11
Miscellaneous Structures and Systems	Section 12
Reinforced Masonry	***RS 10-2***
Concrete	***1004.0***
Concrete Mixes	C26-1004.3
Short Span Concrete Floor and Roof Construction Supported on Steel Beams	C26-1004.8
Reinforced Concrete	***RS 10-3***
ACI 318-63, Building Code Requirement; modified as specified in RS 10-3	
Structural Steel	***RS 10-5***
AISC 1969 Specifications for the Design, Fabrication, and Erection of Structural Steel for Buildings; modified as specified in RS 10-5	
Light Gauge Cold Formed Steel	***RS 10-6***
AISI Specification or the Design of Light Gauge Cold Formed Steel; modified as specified in RS 10-6	
Open Web Steel Joists	***RS 10-7***
Wood	***1004.0, Table RS 10-8 and RS 10-9***
Aluminum	***1007.0, Table RS 10-10 and RS 10-11***
Glass	***1011.0***

Table 2–1. Checklist for Structural Review in the 1971 Edition of the Tenant Construction Manual (continued).

Provision	Code Reference[a]
Soil and Foundations	
Depths of Foundations	C26-1100.7
Foundations at Different Levels	C26-1100.8
Borings	C26-1101.2
Probings and Geophysical Explorations	C26-1101.5
Foundation Loads	1102.0
Classification of Soil Materials	C26-1103.1
Allowable Soil Bearing Pressures	C26-1103.4
Bearing Capacity of Nominally Unsatisfactory Bearing Materials	C26-1103.5
Soil Load Bearing Tests	1104.0
Footings	C26-1105.2
Foundation Piers	C26-1105.3
Foundation Walls	C26-1105.4
Pile Foundations	
Administrative Requirements	C26-1106.1
Minimum Pile Penetrations	C26-1106.2
Minimum Spacing of Piles	C26-1106.5
Capping and Bracing of Piles	C26-1106.7
General Requirements for Installation of Piles	C26-1106.9
Allowable Axial Loads on Piles	C26-1107.1
Allowable Lateral Load	C26-1107.2
Pile Driving Operations	
Equipment	C26-1108.1
Procedures	C26-1108.2
Pile Types	
Timber Piles	C26-1109.2
Precast Concrete Piles	C26-1109.3
Cast-in-place Concrete Piles	C26-1109.4
Compacted Concrete Piles	C26-1109.5
Steel “H” Sections	C26-1109.6
Concrete Filled Pipe Piles	C26-1109.7
Caisson Piles	C26-1109.8
Composite Piles	C26-1109.9
Underpinning	1110.0
Stability	1111.0

Table 2–1. Checklist for Structural Review in the 1971 Edition of the Tenant Construction Manual (continued).

Provision	Code Reference[a]
Inspection	
Boring Operations	C26-1112.2
Piling	C26-1112.3
Subgrade for Footings, Foundation Piers, and Walls	C26-1112.5
Support of Adjacent Properties or Building	C26-1112.6

a. 1968 NYC Building Code.

Table 2–2. Inspection requirements in the 1971 edition of the Tenant Construction Manual.

Item		Code Reference
Concrete		
Inspection of materials for all structural elements proportioned on the basis of calculated stresses 70 percent or greater of basic allowable values		Table 10-1, Article 10
Preliminary tests of concrete		C26-1004.3(a)(3)
Quality control and inspection at the batch plant		C26-1004.3(a)(5) except as provided in C26-1004.3(b)(6)
Preparation of cylinders for strength tests		C26-1004.5(a)(1)
Checking of all samples recovered for the purpose of strength tests for slump, air content, unit weight, and temperature		RS 10-3, C26-1004.5(a)(2)
Measurement of forms for size and dimension of members		C26-1004.5(a)(3)
Checking of sizes and position of reinforcement		C26-1004.5(a)(3)
Inspection of placement of concrete and the recording of and compliance with Building Code provisions associated with/to:	Temperature	---
	Protection against excessive temperature	---
	Curing	---
	Erection and connection of precast members	---
	Amount of water added in field	---
	Tensioning of prestressed elements	C26-1004.5(a)(3)
	Pre-placed aggregate	C26-1104.11(c)
Steel		
Inspection of welding operations where stresses in welds are 50 percent or more of basic allowable values		Table 10-2
Check of welders' licenses or qualifications		C26-1005.3(2), C26-1005.3(4)
Inspection of the tensioning of high strength bolts where stresses in bolts are 50 percent or more of basic allowable values		Table 10-2
Inspection of the connection of fittings to wire cables, except where proof-loading to not less than 55 percent ultimate capacity		Table 10-2

Table 2–2. Inspection requirements in the 1971 edition of the Tenant Construction Manual (continued).

Item	Code Reference
Materials, Assemblies, Forms and Methods of Construction	
Code test method – whenever the Building Code prescribes a method of testing, such tests shall be made under the supervision of an architect or an engineer or by a testing service or laboratory acceptable to the PONYA Resident Engineer.	C26-106.2(a)(1)
Inspections During Progress of Work	
The commissioner may accept signed statements by architects and engineers and supporting inspection and test reports without verifying inspection or test by department inspectors.	C26-120.5
Final Inspection	
The architect, engineer, or other person who supervised or superintended the work is required to be present at final inspection by department.	C26-120.6

2.1.2 1979 Edition[2]

General Requirements

Except for some minor editorial changes, the general structural requirements in Section 2 of the 1979 edition of the manual were essentially the same as those outlined in the 1971 edition.

Structural Requirements

As was required in the 1971 edition of the manual, the NYC Building Code was to be used for work performed in New York City. As before, both the 1938 edition and the December 6, 1968 edition of the code were referenced.

Structural requirements were modified and expanded in Section 5 of the 1979 edition of the manual. A list of notable differences between the 1971 and 1979 editions follows.

1. New Section A, Plans Notes, Schedules. This section contained the same requirements as in the 1971 edition, except for the following:

    a. Requirements for signing and sealing the structural plans and the information required on the structural plans were directly referenced to code sections C26-110.2 and C26-110.2(b), respectively.

    b. The requirement that the structural reviewer be responsible for the structural integrity of all walls and partitions was deleted.

    c. New rules and regulations listed in Section C of the Structural chapter that were applicable to construction in New York City were to be considered. The list is as follows:

[2] See Appendix B for the general and structural requirements in the 1979 edition of the Tenant Construction Review Manual (PANYNJ 1979).

(1) Rules and Regulations Relating to Resistance to Progressive Collapse Under Extreme Local Loads (Building Department)

(2) Rules and Regulations for the Design of Composite Construction with Metal Decks or Lightweight Concrete (Building Department)

(3) Rules Related to Structural Design Based on Electronic Computer Computations (Building Department)

(4) Rules and Regulations Relating to the Design and Installation of Curtain Wall Systems (Building Department)

(5) Rules for Application and Protection of Sprayed-on Fireproofing (BSA Cal. #118-68-GR)[3]

(6) Rules and Regulations for Masonry Parapet Walls (Building Department)

(7) Rules for Arc and Gas Welding and Oxygen Cutting of Steel Covering the Specifications for Design, Fabrication, and Inspection of Arc and Gas Welded Steel Structures and the Qualification of Welders and Supervisors (BSA Cal. #1-38-SR)

(8) Rules for Governing the Marking of Transparent Glass Doors and Fixed Adjacent Glass Sidelights (BSA Cal. #501-68-SR)

(9) Rules for the Manufacture, Testing, and Use of Concrete Masonry Units (BSA Cal. #639-40-SR)

d. A new section was introduced requiring that all required schedules for structural and foundation elements be on the plans.

2. Checklist for structural review (Section B in the 1979 manual). Some items in the checklist were modified and some were deleted. Table 2–3 contains the items in the 1979 checklist. References to code sections were no longer provided.

3. New Section C, Additional Port Authority Criteria. This section required that buildings designed and/or constructed by PANYNJ that were being altered needed to be coordinated with the particular PANYNJ facility design group, especially for foundation requirements.

[3] Denotes number of the New York City Board of Standards and Appeals (BSA) document.

Table 2–3. Checklist for structural review in the 1979 edition of the Tenant Construction Manual.

Provision
Loads
Dead Loads
Floor Live Loads
Live Loads for Sidewalks, Driveways, and Railings
Roof Loads
Moving Loads
Partial Loading Conditions
Floor Live Load Reduction
Contributory Floor Areas
Wind Loads
Thermal Forces
Shrinkage
Distribution of Loads
Structural Work
General Requirements
Materials and Methods of Construction
Inspection of Materials and Assemblies
Inspection of Methods of Construction
Use of Used and Unidentified Materials
Equivalent Systems of Design
Deferred Detailing
Combination of Loads
Load Tests
Fire Protection Requirements
Soils and Foundations
Depths of Foundations
Foundations at Different Levels
Slabs on Grades Construction
Borings
Probings and Geophysical Explorations
Foundation Loads
Classification of Soil Materials
Allowable Soil Bearing Pressures
Bearing Capacity of Nominally Unsatisfactory Bearing Materials
Soil Load Bearing Tests
Footings

Table 2–3. Checklist for structural review in the 1979 edition of the Tenant Construction Manual (continued).

Provision
Foundation Piers
Foundation Walls
Pile Foundations
Administrative Requirements
Minimum Pile Penetrations
Minimum Spacing of Piles
Capping and Bracing of Piles
General Requirements for Installation of Piles
Allowable Axial Loads on Piles
Allowable Lateral Load
Pile Driving Operations
Equipment
Procedures
Pile Types
Timber Piles
Precast Concrete Piles
Cast-in-place Concrete Piles
Compacted Concrete Piles
Steel “H” Sections
Concrete Filled Pipe Piles
Caisson Piles
Composite Piles
Underpinning
Stability
Inspection
Controlled Fills
Boring Operations
Piling; Installation and Testing
Subgrade for Footings, Foundation Piers, and Walls
Support of Adjacent Properties or Building
Reports Required
Verification – Stabilized Overburden
Bearing Capacity of Nominally Unsatisfactory Bearing Material
Alternate or Similitude Method for Pile Load Verification
Substantiation of Higher Allowable Pile Loads

Controlled Inspection of Materials, Operations, and Equipment

The revised introduction to the section on controlled inspection of materials, operations, and equipment in the 1979 manual provided a better explanation of the relevance of this section. The purpose of this section was to list some of the materials, operations, and equipment that normally required the services of a licensed professional engineer in order to assure compliance with the inspection procedures contained in 106.0 and 107.0 of the 1968 NYC Building Code.

The inspection requirements for concrete and steel in the 1979 manual are essentially the same as those in the 1971 manual, with some minor editorial changes (see Table 2–2). For concrete, an inspection requirement for proper use of admixtures was added. For steel, the requirement for checking welders' licenses or qualifications was dropped, as this item was covered in the new rules and regulations relating to structural items given in Section 5 of the manual.

In lieu of the general inspection requirements related to (1) materials, assemblies, forms and methods of construction, and (2) inspections during progress of work, and (3) final inspection, requirements were given for structural materials and assemblies subject to and not subject to controlled inspection, which are defined in C26-106.3 of the 1968 NYC Building Code. The checklist for items subject to controlled inspections is given in Table 2–4. Mill, manufacturers', and suppliers' inspection and test reports were accepted as evidence of compliance with the provisions of the code for all structural materials and assemblies not subject to controlled inspection. Spray-on fireproofing was added to the list of items requiring controlled inspection in this edition of the manual, since such inspection was added for the first time in C26-502.2(f) of the 1968 NYC Building Code in 1976 (Local Law 55). This new paragraph required that the installation of all sprayed-on fire protection of structural members, except those encased in concrete, be subject to the controlled inspection requirements of C26-106.3. According to C26-106.3, all materials designated for controlled inspection were to be inspected and/or tested to verify compliance with code requirements. All required inspections and tests were to be made and witnessed by or under the direct supervision of an architect or engineer who the owner retained and who was acceptable to the architect or engineer who prepared the plans. The architect or engineer was to file with the NYC Building Department signed copies of all inspection and test reports, together with a signed statement that the material and its use or incorporation into the building complied with code requirements.

Table 2–4. Checklist for items subject to controlled inspection in the 1979 edition of the Tenant Construction Manual.

Borings or Test Pits
Piles
Soil
Controlled Fill
Underpinning
Welding
Aluminum
Laminated Wood

Table 2–4. Checklist for items subject to controlled inspection in the 1979 edition of the Tenant Construction Manual (continued).

High Strength Bolts
Fire Stops
Heating System
Ventilation System
Refrigeration System
High Pressure System
Prestressed Concrete
Precast Concrete
Chimney Smoke Vent
Cable Fittings
Spray-on Fireproofing

2.1.3 March 1984 Edition, Revised March 1990[4]

General Requirements

The general requirements were moved from Section 2 to Section 3 of the 1990 edition of the manual and contained essentially the same requirements as those in previous editions. Additional requirements were included concerning the role of consultants working on the project who are not the architect or engineer of record. The requirement that the tenant comply with the provisions of all federal, state, municipal, local, and departmental laws, ordinances, rules, regulations, and orders was moved to a more prominent location in this section. This requirement was in accordance with the policy of the PANYNJ at that time.

Structural Requirements

The structural requirements section was moved from Section 5 to Section 6 in the 1990 edition. As in previous editions of the manual, the NYC Building Code was to be used for work performed in New York City. However, unlike the previous editions, no specific editions of the code were listed.

In regard to the rules and regulations of the New York City Department of Buildings, the section title in the 1990 edition of the manual reads as follows: “Rules and Regulations of the Department of Buildings, such as:” This implies that the list of rules and regulations listed in the 1990 edition is not necessarily exhaustive. As noted in the previous section, nine rules and regulations first appeared in the 1979 edition of the manual. In the 1990 edition, only five rules are listed. The following rules and regulations, which appeared in the 1979 edition, are not explicitly listed in the 1990 edition: (1) application of spray-on fireproofing, (2) arc and gas welding, (3) transparent glass doors and fixed adjacent glass sidelights, and (4) manufacture, testing, and use of concrete masonry units.

[4] See Appendix C for the general and structural requirements in the March 1984, Revised March 1990 edition of the Tenant Construction Review Manual (PANYNJ 1990). Also included is Amendment #1 to the manual, dated October 23, 1990.

A new subsection on Standards was added to the 1990 edition. The organizations whose standards are cited are: (1) American Association of State Highway and Transportation Officials and (2) American Railway Engineering Association.

The section containing Port Authority design criteria was significantly expanded. Most notably, all structures were required to be designed for earthquake zone 2 forces in accordance with the Building Officials Conference of America (BOCA) code. Local laws that contained seismic provisions more stringent than those in the BOCA code were to take precedence. Also, reference was made to American Society for Testing Materials (ASTM) E 580, Standard Practice for Application of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Requiring Moderate Seismic Restraint for lightweight ceilings to resist seismic forces.

The checklist for structural review that appeared in earlier editions of the manual (see Table 2–1 and Table 2–3) was replaced; the 1990 edition of this list is summarized in Table 2–5.

Controlled Inspection of Materials, Operations, and Equipment

The inspection requirements, in Section 14 of the 1990 edition of the manual, were significantly reorganized and modified compared with those in the earlier editions of the manual. Like earlier editions of the manual, the NYC Building Code and its referenced standards were specifically referenced for the following requirements: (1) acceptance (approval) of materials, assemblies, forms, methods of construction, and (2) inspection of materials, assemblies, and construction.

Requirements for approval/acceptance of materials were abstracted directly from NYC Building Code Sections C26-106.1, 106.2, 107.1, and 107.2. No materials, assemblies, forms, method of construction, equipment, machinery, or devices were acceptable unless approved by the Code Test Method of the Materials and Equipment Acceptance (MEA) Division of the Office of the Commissioner of the Buildings Department of New York City or approved by the New York City Board of Standards and Appeals (BSA).

Controlled inspections requirements were abstracted from NYC Building Code Sections C26-106.3 and 107.3. All materials, equipment, and construction designated by the Code for controlled inspection were required to be inspected and/or tested to verify compliance with the Code. Controlled inspection was required to be made and witnessed by or under the direct supervision of a registered architect or professional engineer retained by the tenant and acceptable to the architect or engineer responsible for the plans. The inspecting design professional was to be independent of the design professional responsible for the work. The list of items subject to controlled inspection was essentially the same as the list in the 1979 edition (see Table 2–4), with the following exceptions: (1) steel (welding, high-strength bolts, and cable fittings) and formwork were added, (2) structural integrity during construction operations was added, and (3) Code section numbers and references to other resource documents were added for all items. Table 2–6 contains the list as it appeared in the 1990 edition of the manual.

Table 2–5. Details of structural review in the 1990 edition of the Tenant Construction Manual.

Provision
Design Calculations
Design criteria and applicable codes
Reference standards
Materials
Type of construction and foundation
Design loads, including wind and other existing forces
Machinery and equipment loads in excess of 1000 lbs., including an evaluation of any potential vibration
Allowable soil bearing capacity
Design analysis and drawings of all connections other than AISC standard framed or seated beam connections
Analysis and sketches of expansion joints
Design of bracing systems and rigid joints
Wind drift and deflections
Ponding
Computer printouts and users' manuals
Investigation of superimposed loads from adjacent construction on structure and foundation
Investigation of existing structural system and foundation under additional loads due to alterations
Where it has been established that post-construction settlements of foundations are to be monitored, the monitoring program, the limits of such settlement that the structure can tolerate, and the necessary adjustments shall be submitted for review
Drawings
Design code and reference standards
Materials
Design live loads, wind, and other forces
Machinery and equipment loads in excess of 1000 lbs., including footprints or support layout(s) plus technical details of vibration isolators
Allowable soil bearing capacity
Pile type, capacity, and minimum tip elevation
Column schedule showing accumulated design load at each level for dead and live loads
Stress diagram(s) for trusses
Datum and ground water elevations
Typical moment connection details
Details of non-standard connections
Lists of materials subject to controlled inspection
Construction sequence
Specifications
Shall clearly define the scope of work and materials required for the contract
Shall include limitations, restrictions, or conditions due to existing environs and/or requirements for the methods of construction or staging

Table 2–6. Checklist for items subject to controlled inspection in the 1990 edition of the Tenant Construction Manual.

Item	Code Section or Resource Document
Borings or Test Pits	C26-1112.2
Piles	C26-1112.3
Soil	–
Subgrade for foundation	C26-1112.5
Controlled Fill	–
Underpinning	C26-1112.6
Concrete	Tables 10-1 and 10-2
Prestressed concrete	–
Precast concrete	–
Formwork	C26-1904.3(b)
Steel – welding, high strength bolts, and cable fittings	Table 10-2
Aluminum – welding	Table 10-2
Laminated wood	Table 10-2
Firestops	C26-504.7(g)
Spray-on fireproofing	C26-502.2(f)
Heating systems	C26-1401.1(a) and 1401.2(b)
Ventilation System	C26-1301.2 and 1301.3
Refrigeration System	C26-1301.4
High Pressure System	–
Chimney Smoke Vent	C26-1501.1(e) and 1504.1(b)
Exterior walls	C26-150.1
Structural integrity during construction operations	Department of Buildings, Rules

2.1.4 March 1997 Edition[5]

General Requirements

The general requirements are essentially the same as those in previous editions of the manual.

Structural Requirements

The most notable change was made to the Port Authority design criteria section. The NYC Building Code was mandated to be used for earthquake design, subject to the modifications contained in Attachment S3. The modifications contained in this section pertain to Table 23-P, Horizontal Force Factor C_p of referenced standard RS 9-6, Earthquake Loads. The manual added horizontal force factors for overhead

[5] See Appendix D for the general and structural requirements in the March 1997 edition of the Tenant Construction Review Manual (PANYNJ 1997).

signs, anchorage for suspended ceilings weighing more than 4 psf without the weight of light fixtures, elevator and counterweight guardrails and supports, sprinkler piping, gas and high hazard piping, other piping, and heating, ventilation, and air conditioning (HVAC) ducts, along with new notes pertaining to sprinkler piping, other piping, and HVAC ducts. These requirements, which were originally outlined in a Port Authority Memorandum[6] and which were included with other such requirements in the document *Port Authority Standards Exceeding Code – Quality Assurance* dated April 26, 1999 (PANYNJ 1999), were added to the manual to ensure that potential overhead hazards would not fall on building occupants during a seismic event.

The details of structural review in the 1997 edition were the same as those in the 1990 edition (see Table 2–5), except that the list of materials subject to controlled inspections was deleted.

Controlled Inspection of Materials, Operations, and Equipment

Some additions and modifications were made to the inspection requirements in the 1990 edition of the manual. The checklist for items subject to controlled inspection was also updated to include the updated NYC Building Code section numbers (see Table 2–7).

2.2 STANDARDS FOR STRUCTURAL INTEGRITY INSPECTION OF THE WORLD TRADE CENTER TOWERS A & B

2.2.1 Overview

In March of 1986, the Infrastructure Engineering Design Division of the Engineering Department of PANYNJ issued the *Standards for Structural Integrity Inspection of the World Trade Center Towers A & B* (PANYNJ 1986).[7] These standards were to assist the PANYNJ in the evaluation of the structural integrity of WTC 1 and WTC 2 and were designed to anticipate structural degradation. If such degradation were to occur, the standards also contained provisions for repair.

Three methods were used to evaluate the structural integrity of the towers: (1) statistical inspections, (2) reports, and (3) continued measurements. In the first method, qualified outside consultants under PANYNJ management were to perform periodic visual inspection of selected structural components in "higher-potential trouble areas." It was anticipated that PANYNJ in-house personnel would be able to perform such inspections in the future. The periodic inspections were to be supplemented by occasional visual inspections when the structure was exposed during tenant remodeling or general maintenance work.

In the second method, the evaluation would be based on problems identified in various reports. These reports may include maintenance reports of non-structural repairs, water leakage, and tenant complaints about unusual building movements, vibration, or noise.

[6] PANYNJ Memorandum dated August 8, 1995 from Oscar Suros, Manager of the Engineering Department Quality Assurance Division to Eugene J. Fasullo, Director and Chief Engineer (see Appendix G of this report).

[7] See Appendix E for the complete document.

In the third method, the evaluation would be based on measurements of building movements or deformation using appropriate tests and instruments. Measurements were to be performed on individual components in the towers as well as on the entire towers themselves.

The periodic inspection program outlined in PANYNJ (1986) is adapted from "Standards for In-depth Structural Integrity Inspection of Buildings," which was issued by the Engineering Department of PANYNJ in October of 1984 and which was relevant to any building owned and operated by the PANYNJ. The other sections in PANYNJ (1986) pertain exclusively to WTC 1 and WTC 2.

Table 2–7. Checklist for items subject to controlled inspection in the 1997 edition of the Tenant Construction Manual.

Item	Code Section or Resource Document
Borings or Test Pits	27-720
Piles	27-721
Subgrade for foundation	27-723
Controlled Fill	27-679(a)
Underpinning	27-724
Concrete	Tables 10-1 and 10-2
Formwork	27-1035(b)
Steel – welding, high strength bolts, and cable fittings	Table 10-2
Aluminum – welding	Table 10-2
Laminated wood	Table 10-2
Firestopping	27-345(h)
Masonry	Table 10-2
Exterior Wall Insulation and Finish Systems	27-335.1(c)13
Spray-on fireproofing	27-324(f)
Heating and combustion equipment	27-793(a), 27-794(b)
Ventilation System	27-779, 27-780
Refrigeration System	27-781
High Pressure System	Department of Buildings, Rules Section 20-02(b)(2)(i)
Welding of gas distribution piping	RS-16, P115.8(h)
Chimney Smoke Vent	27-856(e), 27-879(b)
Curtain/Panel Wall	Rules of the City of New York, Title 1, Department of Buildings, Chapter 32
Structural integrity during construction operations	Rules of the City of New York, Title 1, Department of Buildings, Chapter 16

2.2.2 Inspection Program

Visual Inspections

The PANYNJ recognized that the visual inspection of the entire structure, or even a major portion of it, in WTC 1 or WTC 2 was not practical, as stated in PANYNJ (1986). Thus, a statistical inspection program was implemented. This approach involved sampling those components and systems that were important to structural integrity at locations with "a relatively higher potential for occurrence of defects or problems."

The inspection team was required to carry with them the following items: (1) a set of reduced drawings of the building(s), (2) field notebooks, (3) a camera, and (4) a tape recorder. Equipment, clothing, methods, and procedures were to conform strictly to PANYNJ safety regulations and to any applicable federal, state, or local regulations.

Visual inspection was to be supplemented by the use of simple hand tools, measurements, and recording techniques, as required. Loose, cracked, or rust-stained spray-on fireproofing and concrete or masonry encasement covering structural steel members and connections was to be removed prior to examining the steel. After inspection, any removed fire proofing was required to be properly replaced. Also, where it was necessary to drill a hole through a structural steel element to provide access for a borescope or any other device for inspection, the access hole was to be sealed with weld metal, body putty, or caulking, as appropriate.

Periodic inspection in WTC 1 and WTC 2 was to be performed by PANYNJ or its consultants on the following components at various time intervals, as noted below:

1. TV antenna mast on the top of WTC 1.

   This program, the details of which are given in Appendix A of PANYNJ (1986), consisted of four parts: (a) inspection of the structural steel elements in the antenna, (b) inspection of the high tensile bolts and studs, (c) inspection of the weatherproof enclosure, and (4) inspection of the radomes. Inspection of these components was to be performed on a "continuing basis," as weather and operational restrictions permitted. A complete inspection of the mast structure within the weatherproof enclosure was to be performed at least once a year; the other components were to be inspected at least once every 3 years.

   The elements of the inspection program for the antenna mast, the high tensile bolts and studs, the weatherproof enclosure, and the radomes are given in Chapters II, III, IV, and V, respectively, of Appendix A (see Appendix E of this report).

2. Exterior roof and wall elements.

   Every year, the exterior roof and wall elements were to be inspected for signs of water intrusion. Roof leakage was to be ascertained from an examination of the spaces immediately below the roof areas. Wall leakage was to be determined from signs of water staining of interior finishes.

3. Room occupancies.

   An inspection of room occupancies and uses throughout both towers was to be performed on an annual basis to verify that design live load was not exceeded. A schedule of allowable live loads was to be maintained and updated as structural modifications were made. According to PANYNJ (1986), no such schedule existed at that time.

4. Accessible column envelopes, including fireproofing.

   Every second year, accessible columns were to be inspected for bowing or deviation from plumb. Also, fireproofing was to be examined for signs of rust or cracking. Inspection for lateral displacement or rotation of columns in elevator shafts where the columns were braced on only one axis by connecting beams or concrete slabs was required. The location of these columns is given in Appendix C of PANYNJ (1986).

   At Sublevel 5, the slabs on ground surrounding each column were to be examined for signs of rust or deformation.

5. Fireproofing and masonry partitions on diagonal bracing and transfer trusses.

   Fireproofing and masonry partitions enclosing the diagonal bracing on exterior column lines in both towers below the Service Level Floor and the transfer trusses below floor 1 in WTC 2 under exterior and core columns were to be inspected every second year for cracking, stains, and other possible signs of structural distress.

6. Hat truss members.

   Every second year, the hat truss members between floor 107 and the roof in the core area were to be inspected. Locations of these members are given in Appendix C of PANYNJ (1986).

7. Exterior box columns and spandrel plates.

   Exterior box columns and spandrel plates under column trees below floor 7 were to be inspected every fourth year. Exterior aluminum covers and spray-on fireproofing were to be removed to gain access to the exterior surfaces of the box columns and spandrel plates. Both the columns and plates were to be visually inspected for bowing or distortion, cracking, and corrosion. Visual inspection was also required for accessible welds. Ultrasonic testing of full or partial penetration welds and adjacent base metal was to be performed where base metal thickness exceeded 1.5 in.

   The interior of the box columns was to be examined by a borescope for the presence of water and the existence of rust on the interior plate surface. This was to be accomplished by drilling an access hole in the column or the spandrel plate at the locations noted in PANYNJ (1986).

   The “tree” junction where the three superstructure columns merged was also to be inspected. The top surface of the horizontal diaphragm plate that capped the tapered box column just

below the point where the three separate columns merged was to be examined, as was the exterior column plate between this location and the column splice at elevation +372 ft 4 in.

8. Steel floor framing over mechanical spaces.

   Every fourth year, the steel floor framing over mechanical spaces and other areas without suspended ceilings was to be inspected. No other details are given in the document.

9. Concrete slabs, partitions, and finishes.

   Concrete slabs, partitions, and finishes were to be inspected every fourth year for signs of distress, which could indicate excessive structural deformation.

Occasional inspections were also to be made of the structural steel framing, connections, and the concrete slabs when general repairs or remodeling was done that involved removing ceilings, partitions, finishes, or other coverings. In particular, the top of the concrete slab was to be examined for cracking, spalling, and exposed or corroded top reinforcement. Where reinforcing bars were corroded and where concrete had spalled, repairs were to be made as tenant relocation permitted.

General maintenance reports and complaints from tenants were to be used to search for possible problems related to underlying structural defects. Water damage caused by leaks at the roof level or at the exterior walls, broken plumbing, and cracks in partitions or the concrete floor slab were to be reviewed to determine whether such events were caused by structural deformations. Records were to be kept of tenant complaints of building sway, floor vibration, sagging ceilings, unusual noise, and other items. Visual inspection of the appropriate area of the building was to be performed where a reasonable assessment of the data in the reports or logs was tied to a specific structural element or system. Reports and log data were to be correlated with testing and measurements described in Section B of Chapter IV in PANYNJ (1986), which is discussed in the next section of this report.

Periodic Measurements

Periodic measurements of various types of deformation and vibration were to be made for the purposes of monitoring changes in certain important characteristics of the buildings. Adverse changes in such measurements were assumed to reflect possible structural deterioration.

Measurements of the following items were to be performed on a periodic basis:

1. Natural frequency of the towers.

   Accelerometers were to be installed on Mechanical floor 75 in WTC 2, one at each exterior wall near its midpoint (oriented to respond to horizontal displacements parallel to the wall) and two near the geometric center of the floor (to respond to displacements along the N-S and E-W axes of the building). Figure 1 in Appendix C of PANYNJ (1986) shows the location of the accelerometers (see Appendix E of this report).

The accelerometers in WTC 2, along with those already installed in WTC 1, were to be used to measure natural frequencies of the towers on a monthly basis. Wind speed and direction were also to be recorded at that time.

No documents reviewed indicate that accelerometers were installed in WTC 2.

2. Natural frequency of the TV mast on WTC 1.

   Accelerometers and amplifiers were to be installed within the heated enclosure of the TV mast on the top of WTC 1 at a level of about two-thirds of the height of the mast above its base. One accelerometer was to be oriented to measure N-S displacements, and one was to be oriented to measure E-W displacements. Displacement measurements, as well as wind speed and direction, were to be recorded once a month.

   No documents reviewed indicate that accelerometers were installed on the TV mast.

3. Natural frequency of the floor construction.

   The natural frequency of the floor construction was to be measured when floor space had been emptied due to tenant change or remodeling. Figure 2 in Appendix C of PANYNJ (1986) shows the three zones outside of the core area on a typical floor (see Appendix E of this report): (1) corner zone (two-way floor trusses), (2) short-span zone (short-span floor trusses), and (3) long-span zone (long-span floor trusses).

   In each tower, Mechanical floors 7, 41, and 75, and Tenant floors 9, 43, and 77, directly above the Mechanical Floors, were not included in the floor frequency measurement program, because they were framed with wide-flange steel beams and not trusses. However, these floors were to be inspected visually. It was also noted that Telephone Equipment Floors 10 through 13 in WTC 2, which were framed with floor trusses similar to typical tenant floors but were more heavily loaded than such floors, would have different dynamic characteristics in the three zones than would the corresponding zones in the tenant floors.

   The natural frequency and damping values of the floor structure within a zone was to be measured by performing a “heel drop” test. In such tests, vibrations induced in the floor structure by a vertical impact are recorded using an accelerometer attached to the floor. Measurements were taken for an impact load of 100 lbs dropped from approximately 6 in. above the floor slab on to a 1 in. thick neoprene pad.

4. Viscoelastic dampers.

   It was noted in PANYNJ (1986) that the testing program for the viscoelastic dampers should continue. This program consisted of continuously measuring and recording the movements of WTC 1 that were 3 in. or more. Wind speed and direction were also to be measured. It was anticipated that such measurements would continue until the end of 1985 or longer, depending on available funds.

Twelve viscoelastic damping units (four units from each of three floors) were to be removed from WTC 1 annually and were to be tested by the Minnesota Mining and Manufacturing Company, who were the manufacturers of the damping units. Temperature effects and shear strength were to be tested. See Chapter 3 of this report and the report titled Design and Construction of Structural Systems of WTC 1, 2, and 7 (NIST Special Publication 1000-6A) for more information on these tests.

A log of tenant complaints on noise and building sway was to be maintained on a continuous basis.

5. Plumbness and level.

   Building plumbness and floor level checks were to be performed semiannually for each tower, preferably in the early morning hours in August when wind velocity was low and outside air temperatures were moderate.

   Building plumbness was to be determined by measuring the offsets from a vertical laser beam, which was to be projected up from the bottom of freight elevator shaft 50, to the shaft walls. Offset measurements were to be taken at 20-story intervals.

   Floor levelness was to be determined by measuring the relative elevation of sixteen benchmarks on the floor slab at floor 70 of each tower.

2.2.3 In-House Inspection Personnel

A list of duties, responsibilities, and minimum qualifications of the inspection supervisor, inspection crew leader, and inspection crew members from the PANYNJ is given in Chapter V of PANYNJ (1986).

The Supervisor of the Structural Integrity Inspection of the Buildings, who reported to the Engineer of Design, Infrastructure, was responsible for planning and directing the inspection, as well as preparing the inspection report. The Supervisor was required to have the following minimum qualifications:

- Professional Engineering License in New York or New Jersey specializing in structural engineering
- Five years of experience in responsible charge in structural design of buildings and 5 years experience in responsible charge in inspection of building construction, inspection of existing buildings, or maintenance of building structures.

The Supervisor did not have to conduct the inspection nor be present at the site at all times during the inspection. Rather, the Supervisor was to be familiar with the scope of the project and was expected to provide leadership and guidance. That person was also responsible for setting up and supervising any required training programs for inspection team members.

In addition to the general qualifications listed below for team members, crew leaders of the Inspection Team were required to have three years experience in responsible charge in inspection of building construction, inspection of existing buildings, or maintenance of building structures.

Field inspection crew members were expected to perform the required inspections without continuous supervision after initially receiving "moderate" guidance from the crew leader. The following qualifications were listed:

- Acute observation skills
- Common sense
- Strong motivation and persistence in carrying out any necessary follow-up procedures

As a minimum, an inspector should:

- Be able to climb steel and function comfortably at great heights and in difficult positions;
- Be a high school graduate or equivalent, with commensurate reading, verbal, and written communication skills;
- Be able to read and understand construction drawings and other documents;
- Be able to letter legibly and sketch technical details;
- Be able to operate a camera;
- Have a working knowledge of the use of measuring devices, such as rulers, tapes, gauges, protractors, and calipers; and
- Exhibit a proper concern for safety while inspecting.

PANYNJ (1986) also states that it was desirable, but not mandatory, that inspectors have some prior experience in related work, such as high steel construction, structural maintenance or inspection, or surveying.

2.2.4 Outside Consultants and Suppliers of Special Services

This section contains the requirements for outside consulting firms hired by the PANYNJ to perform periodic visual inspections or to accomplish tasks requiring special skills. The consulting firm was to assign a Supervisor who was a Professional Engineer licensed in New York or New Jersey and who possessed at least 5 years of experience in the design and field supervision of projects of comparable size and complexity. Field inspectors from the consulting firm were to have as a minimum the qualifications that were required for in-house inspectors, as outlined in Sec. 2.2.3 of this report.

The consulting firm was required to submit to the PANYNJ a list and description of comparable projects that were previously undertaken, and a list of the personnel, along with their qualifications and experience, who would be assigned to the inspection project.

2.2.5 Record Keeping and Follow-up Procedure

Defects and Signs of Distress

Chapter VII of PANYNJ (1986) lists the defects and signs of distress that were to be noted and recorded during inspection of the structural steel and the reinforced concrete. A summary is provided in Table 2–8.

Table 2–8. Defects and signs of distress to be recorded during inspection of WTC 1 and WTC 2.

Material	Defect/Sign of Distress	Description
Structural Steel	Rust	Rust was to be classified as follows: • Light – light, loose formation pitting the paint surface • Moderate – a looser formation with scales or flakes that have formed • Severe – heavy, stratified rust or scale with pitting of the metal surface. Net metal thickness and size of penetration, if any, was to be measured where pitting had occurred.
	Cracks	Cracks were to be classified as follows: • Fine • Medium • Open The length, size, and location of any crack were to be recorded. Any crack was deemed to be potentially serious, and was required to be reported immediately.
	Buckles and kinks	The type, location, and extent, and amount of deformation were to be recorded.
	Connection and joint	Fine cracks in the paint at joints were deemed an indication of large strains due to stress concentrations. Records were to be made of the following: • Sheared, missing, deformed, or loose bolts • Gusset plate deformations • Cracks in welds or in adjacent base metal
	Alignment, excessive deflection, or bowing	Records were to be made of any floor truss, beam, or column that was misaligned, deflected, or bowing.
	Paint	Paint was to be examined for cracking, chipping, rust pitting, and chalking.
Reinforced Concrete[a]	Scaling	Scaling was to be classified as light, medium, heavy, or severe. Records were to be made of the depth, extent, and location of the scaling.
	Cracking	Cracks were to be classified as follows: • Partial or through the member • Direction relative to framing or column lines • Horizontal, vertical, or diagonal • D-, map, or random Records were to be made of the location, width, depth, and length of the cracking.

	Spalling	Spalls were to be classified as small, large, hollow area, joint spall, pop-out, or mudball. Records were to be made of the depth, size or extent, and location of the spalling.

a. Definitions of the defects and classifications as to degree of severity are referenced for reinforced concrete in the PANYNJ document *Standards for In-depth Structural Integrity Inspection of Buildings*, October 1984.

Source: PANYNJ 1986.

Inspection Records

Each component that was inspected was to be identified as follows:

- General location – building number and floor or floors
- Description label – column, beam, floor truss, viscoelastic damper, slab, etc.
- Piece mark and column designations at each end as applicable
- Type and location of affected part

The inspection record should include the description of the defect or distress. Measurements, sketches, and photographs were to be included in the record in those cases where a written description was not adequate. A tape recorder may also be used in addition to the written record.

If the Supervisor or the inspection team uncovered defects or indications of distress that appeared to require more than routine attention, a separate report of such findings was to be submitted to the Engineer of Design was to be immediately notified in person.

Three categories of urgency were established for repairs. Repairs falling into the "immediate" category included possible closure of the area and/or structure affected until interim remedial action (such as shoring or removal of a potentially unsafe element or structure) could be implemented. Such action was to be undertaken immediately after discovery, and a description of the action taken and recommendations for permanent repair were to be included in the inspection report.

The "priority" category was for those conditions where no immediate action was required, or for which immediate action had been completed, but for which further investigation, design, and implementation of interim or long-term repairs should be undertaken on a priority basis (i.e., taking precedence over all other scheduled work).

Repairs falling into the "routine" or "non-priority" category could be undertaken as part of a scheduled major work program or other scheduled project, or when routine facility maintenance was to be performed, depending on the type of repair that was required.

Measurements and Test Records

The measurements and test records section of PANYNJ (1986) outlines the various measurements and test data that were to be recorded during the inspection process for the items listed in Sec. 2.2.2 of this

report. Also given are the criteria that determine whether a possible problem may exist, based on the recorded measurements.

2.2.6 Excluded Work

In the last chapter of PANYNJ (1986) it was noted that the standards for structural inspection were applicable to only structural steel and reinforced concrete members in WTC 1 and WTC 2. Glass and glazing, facade panels, ceilings, partitions, elevators, stairs, and mechanical equipment were listed as components outside the scope of the document.

2.3 ARCHITECTURAL AND STRUCTURAL DESIGN GUIDELINES, SPECIFICATIONS AND STANDARD DETAILS

The document entitled Architectural and Structural Design Guidelines, Specifications and Standard Details was issued on February 27, 1998 by PANYNJ and contained architectural and structural design requirements for tenant alterations that were to be made specifically at WTC 1 and WTC 2 (PANYNJ 1998).[8] The following discussion focuses on the structural requirements contained in this document.

2.3.1 Structural Design Guidelines

General

Prior to any design work, the tenant's consultants were required to perform a field inspection of all areas that would be affected by the alterations so that the latest information was available for all structural elements, including, but not limited to truss reinforcement, stair openings in slabs, and core-hole locations.

The tenant's consultants were required to submit calculations and construction drawings to PANYNJ for review and approval. All construction documents were required to be signed and sealed by a professional engineer or registered architect licensed to practice in the state of New York.

Calculations, Loads, and Design Parameters

For tenant alteration project, proposed floor loads were to be compared with the allowable design loads contained in Drawing STR-01 (see Appendix E). If the proposed floor loads would overstress the existing structural members, the floor system was allowed to be reinforced to carry the additional loads.

Calculations to compare the proposed loading with the allowable loads were required to conform to the latest edition of the NYC Building Code. Both allowable stress design and load-and-resistance-factor design were acceptable design methods.

The document recognized that portions of the corner floor areas would be able to carry greater loads than those shown in Drawing STR-01, due to the existing two-way truss system. Higher loads were allowed in

[8] This document is contained in Appendix F of this report.

non-critical corner areas if it could be shown by analysis that such loads could be safely carried by the floor system.

The document required to show and locate on the construction drawings the weight of any equipment or cluster of equipment exceeding 500 lb and all files and shelves. In the latter case, a legend was to be shown on the drawings to indicate each type of file or shelving unit and the size and number of tiers for files and the height for shelves. Examples that show such weights on the construction documents can be found in Chapter 4 of this report.

Minimum loads to be used in the calculations were also specified. These loads are summarized in Table 2–9.

Table 2–9. Minimum loads specified for tenant alterations in PANYNJ Architectural and Structural Design Guidelines, Specifications, and Standard Details.

Item or Use		Minimum Load
File cabinets		33 psf per tier, including the weight of the cabinet
Open shelves for paper storage		46 pcf of the net volume plus the weight of the shelves
Mechanized file storage		Use manufacturer's indicated fully loaded weight, or the net weight of the storage unit plus 46 pcf for contents
Libraries	Aisle loading for aisle width less than or equal to 30 in.	30 psf
	Aisle loading for aisle width greater than 30 in.	60 psf
	Reading areas	60 psf
	Open shelves	46 pcf of the net volume plus the weight of the shelves
File rooms aisle loading	Aisle width less than or equal to 30 in.	30 psf
	Aisle width greater than 30 in.	50 psf

Core Holes and Other Slab Penetrations

All proposed penetrations or drilling of cores in tower slabs were required to meet the criteria for location, spacing, and repair as specified in Drawings STR-02 through STR-08 (see Appendix F), and the section titled Structural Design Specifications, which is discussed below. As shown in the figures, there were some areas that were denoted as "prohibited" where no penetrations or cores were allowed, and there were some areas denoted as "restricted" where it was advisable not to locate penetrations or cores.

Hung Ceilings

For ceilings in the two-way truss areas of the towers, the size of the carrying channels and caddy clips were required to be larger than those required by the NYC Building Code, due to the long spans between

the trusses. The details in Drawings STR-09 through STR-14 (see Appendix F) were required to be provided on the construction drawings.

HVAC Equipment

The weight, dimensions, and location of all HVAC equipment were required on the drawings, including whether such units were floor mounted or hung from the framing above. Details for hanging ducts are in drawings HVAC-21 through HVAC-28. Calculations were required for all floor-mounted units showing that the existing framing would not be overstressed due to the weight of the equipment.

Walls

For walls over an opening, such as a door or other non-supportive materials, a lintel was required, or the wall was allowed to be suspended by studs from the framing above. In such cases, all connections were to be adequately designed for the loads.

Existing Steel

Holes were not allowed to be made in existing steel (beams, floor trusses, and columns) for hanging purposes, and welds were not allowed to be made to the trusses. Clamps approved by either the MEA Division of the Office of the Commissioner of the Buildings Department of New York City or by the New York City BSA were allowed.

2.3.2 Structural Specifications

Coring Criteria at Tower Power/Telephone Cells and Under Induction Units

The specifications given in the section on coring criteria were meant to supplement those given in the guidelines section, and were applicable to only those holes cored into the power/telephone cells and under induction units and only in the following typical tenant floors: (1) in WTC 1: floors 10 to 40, 45 to 74, and 78 to 105, and (2) in WTC 2: floors 14 to 40, 45 to 74, and 78 to 106.

The maximum core size allowed was 4 in. in diameter. The minimum average center-to-center spacing along a power/telephone cell for any 4 consecutive cored holes (including abandoned and filled holes) was 1 ft 4 in. Spacing criteria along power/telephone cells adjacent to holes offset from cells was provided in Drawing STR-05 (see Appendix F).

This section recommended avoiding cutting No. 4, No. 5, and No. 6 reinforcing bars in restricted zones. If such bars were to be cut, the bar repair details in Drawings STR-06 through STR-08 were to be followed (see Appendix F). As noted previously, coring was not allowed in prohibited zones, except within the induction units at the power/telephone cells only, which was considered a restricted area.

Rust, grease, and other contaminants were to be removed from structural steel and reinforcing bars prior to welding. All welders were to be qualified in accordance with the NYC Building Code and with other applicable laws and requirements.

This section required that all work conform to the latest edition of the NYC Building Code, including any revisions. Provisions in the latest editions of the following codes took precedence over those in the NYC Building Code whenever they were more stringent:

- American Institute of Steel Construction, Specification for the Design, Fabrication and Erection of Structural Steel for Buildings. Supplement 1 is specifically excluded.
- American Concrete Institute, Standard Building Code Requirements for Reinforced Concrete, ACI 318.
- American Welding Society (AWS), Structural Welding Code – Structural Steel (AWS D1.1) and Reinforcing Steel (AWS D1.4).

Any steel plates that were added to reinforce existing framing or for other reasons were required to conform to ASTM A36, and any reinforcing bars that were added were required to conform to ASTM A 615 Grade 60.

Welding materials for structural steel and reinforcing steel were required to be E7018 conforming to AWS A5.1 *Specifications for Covered Carbon Steel Arc Welding Electrodes*. Specifications for non-shrink grout were also specified.

Lightweight Ceiling Support System for Floors with Double Trusses

Specific proprietary concrete anchors were specified for any connections made to concrete. Other requirements were given for the type and sizes for clip angles, hangers, channels, and clamps. The contractor was to keep removal of fireproofing to a minimum and was to replaced removed fireproofing as “directed” by the Port Authority.

2.4 REFERENCES

PANYNJ (The Port Authority of New York and New Jersey). 1979. *Tenant Construction Review Manual*. (WTCI-134-P).

PANYNJ (The Port Authority of New York and New Jersey). 1986. *Standards for Structural Integrity Inspection of the World Trade Center Towers A & B.* Infrastructure Engineering Design Division, Engineering Department, The Port Authority of New York and New Jersey. (part of WTCI-66-P).

PANYNJ (The Port Authority of New York and New Jersey). 1990. *Tenant Construction Review Manual*. Engineering Quality Assurance Division, Engineering Department, The Port Authority of New York and New Jersey. (WTCI-132-P).

PANYNJ (The Port Authority of New York and New Jersey). 1997. *Tenant Construction Review Manual*. Engineering Quality Assurance Division, Engineering Department, The Port Authority of New York and New Jersey. (WTCI-131-P).

PANYNJ (The Port Authority of New York and New Jersey). 1998. *Architectural and Structural Design Guidelines, Specifications, and Standard Details – Architectural, Structural*. February. (WTCI-125-P).

PANYNJ (The Port Authority of New York and New Jersey). 1999. *Port Authority Standards Exceeding Code – Quality Assurance*. April. (WTCI-163-P).

PONYA (The Port of New York Authority). 1971. *Tenant Construction Review*. (WTCI-135-P).

Chapter 3
STRUCTURAL INSPECTION PROGRAMS DURING THE OCCUPANCY OF WTC 1, 2, AND 7

3.1 FACILITY CONDITION SURVEY REPORTS

The following facility condition survey reports, which include summaries on the condition of the structural systems in World Trade Center (WTC) 1, 2, and 7, were issued from 1990 to 2000 and are presented in chronological order.

3.1.1 Port Authority Facility Condition Survey Program – WTC 2

This section contains the findings of the condition survey of WTC 2 (Tower B), which was performed by the Engineering Quality Assurance Division (EQAD) of PANYNJ in 1990 (PANYNJ 1990).

Scope

The scope of the survey was based on recommendations made in *Standards for Structural Integrity Inspection of World Trade Center Towers A & B* (PANYNJ 1986). This document contains the minimum requirements of the periodic and occasional inspection programs that were to be implemented for WTC 1 and WTC 2. See Sec. 2.2 of this report for details on this document.

According to the facility condition survey report, the scope of work was designed to minimize impact on tenant and facility operations. Upon determination of minimum sampling sizes and inspection methods, EQAD performed a condition survey of structural and architectural elements. The following is a list of the structural elements that were inspected:

- Exterior wall system (including columns, spandrel plates, and connections)
- Core columns (including column splices and lateral bracing below the 7th floor; this part of the condition survey was primarily performed by the consulting firm Corddry, Carpenter, Dietz and Zack)
- Space frame (i.e., hat truss, including framing members and connections)
- Floor systems (including floor slabs and decks, trusses, rolled beams, bridging, and connections)
- Damping system (including damping units and connections)

Inspection Procedures and Methodology

To assess the condition of the structural system in the tower, EQAD performed both visual inspection and nondestructive testing methods. The thickness of steel members was checked using an ultrasonic thickness gauge. Fillet welds were tested for cracks and discontinuities using magnetic particle or dye penetration test methods, and groove welds were tested using the ultrasonic method.

Office Area Floors

The EQAD selected 30 office floors throughout the tower for inspection: 17, 18, 21, 27, 28, 29, 33, 34, 36, 37, 44, 45, 50, 55, 56, 62, 63, 64, 65, 74, 77, 82, 83, 90, 91, 92, 98, 100, 101, and 107. The following steps were taken when inspecting the structural elements at these levels:

1. Walk-through inspection with tenant representatives was performed to assess floor layout, determine operational areas that were important to the tenant, and select inspection locations.

2. A ceiling tile removal location plan was prepared for concealed spline ceilings.

3. Ceiling tiles were removed (performed by World Trade Department's structural contractor).

4. Floor framing and steel decking, inside faces of steel spandrel plates, spandrel splices, ceiling components, utility supports, and window seals were visually inspected. Structural steel members covered with fireproofing were examined for signs of deformation or corrosion.

5. Approximately seven floor framing locations were selected for fireproofing removal and a removal location plan was prepared. In order to inspect column splices, two exterior columns were selected for plaster removal, both above and below the splice.

6. Fireproofing was removed at designated locations (performed by World Trade Department's structural contractor).

7. An up-close inspection of exposed floor framing and column splices was performed for signs of cracking, deformation, or corrosion. Scrapers, wire brushes, and mirrors were used to accomplish this task.

8. Nondestructive testing was performed on column splice welds and welded floor framing connections (performed by the Materials and Research Division of PANYNJ, as directed by the Quality Assurance Division of PANYNJ).

9. Fireproofing and ceiling tiles were replaced, and plaster openings were repaired (performed by World Trade Department's structural contractor).

Table 3–1 contains the percentage of structural elements inspected per office floor and for the entire tower.

Table 3–1. Percentage of structural elements inspected per office floor and for the entire tower per the 1990 Facility Condition Survey Report for WTC 2.

Element	Type of Inspection	Percentage per Floor	Percentage Total Tower
Floor framing trusses	Visual	10	3
	Fireproofing removal	4	1
	Nondestructive testing	2	0.5
Exterior column spandrel plate splices	Visual	8	3
	Fireproofing removal	3	1
Exterior column splices	Visual and nondestructive testing	8	2

Mechanical Equipment Room (MER) and Space Frame

All four two-story MERs were visually inspected from the lower floor, which included inspection of floor framing and slab, interior columns, utility hangers and pads, and exterior setbacks. Concrete fireproofing for covering the steel floor framing was examined for delaminations and underlying corrosion.

Inspection of the space frame (hat truss) coincided with the 108th floor MER inspection. Fireproofing was removed from structural steel members and connections at several locations.

Core Columns

Core columns were inspected from the elevator shafts. This included visual inspection of (1) floor framing, columns, connections, and splices in 25 elevator shafts with fireproofing in place, (2) 10 eccentrically-braced column connections with fireproofing removed, and (3) 15 column splices with fireproofing removed.

Also, the core column lateral bracing at the first six floors was examined at two connection locations by removing the gypsum board firewall from the floor side. Nondestructive testing was also performed at some of the column splices.

Roof

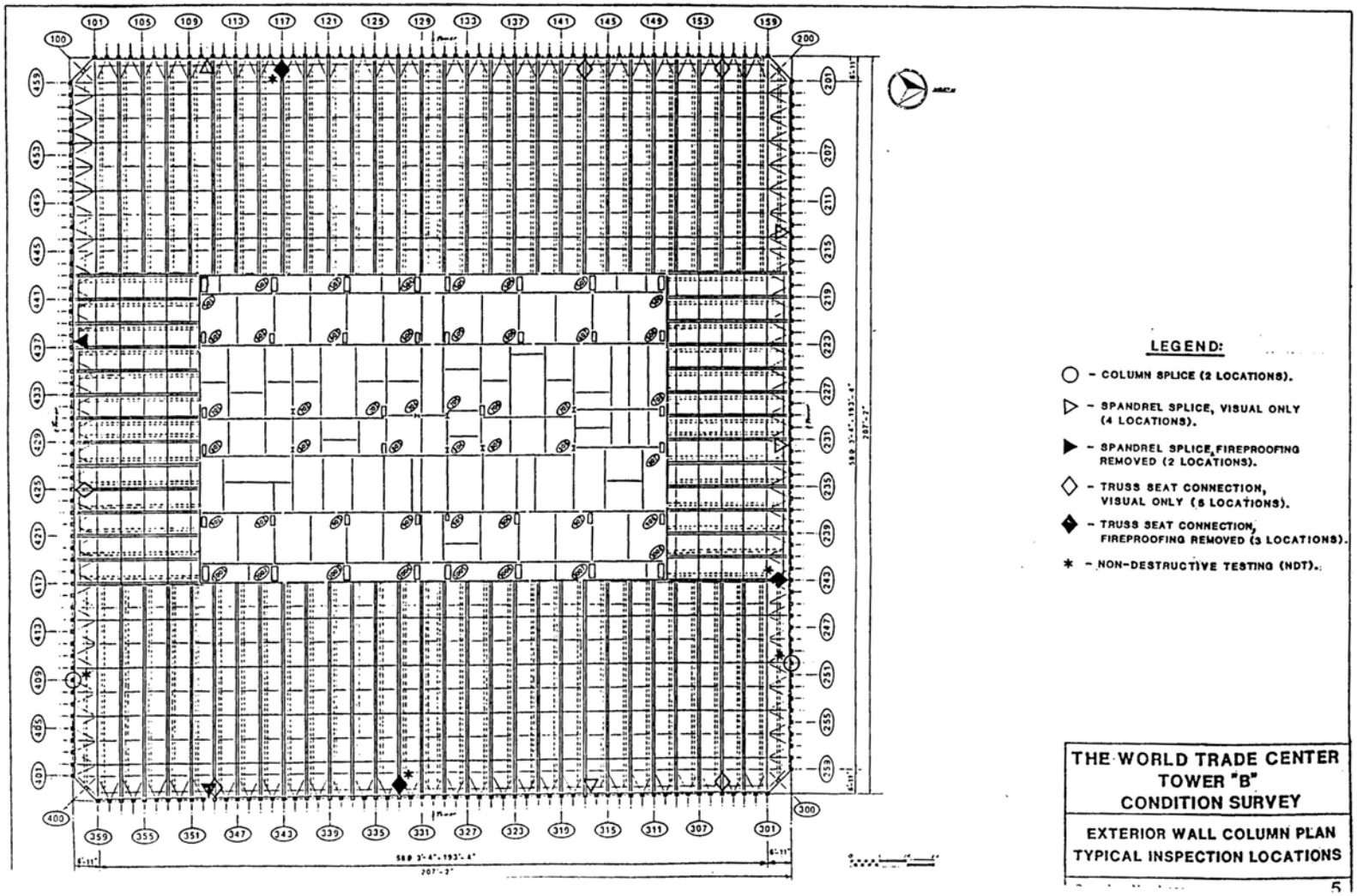
The roof and appurtenant structures along with the Observation Deck were visually inspected. The roof framing and underside of the concrete roof slab were visually inspected from the 110th floor, and the top surface of the concrete roof slab and the roof parapet were visually inspected at random locations.

Findings of Inspection

The following sections summarize the findings and recommendations from the 1990 survey report.

Exterior Walls (Columns and Spandrels)

Inspection of the exterior walls was made from inside the building. Inspection locations are indicated in Fig. 3–1, which is Drawing 5 from the report (PANYNJ 1990).



Source: PANYNJ 1990. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–1. Typical inspection locations of exterior wall per 1990 Condition Survey Report of WTC 2.

Floors 9 through 106—The exterior columns and spandrels were inspected on 30 floors at three areas of the wall panel: (1) column field splice connections, (2) spandrel field splice connections, and (3) inside spandrel plate face at the column/floor truss seat connections. Details of the splices at these locations are provided in Drawing 4 in the report, which is reproduced here in Fig. 3–2.

According to the report, exterior column splices were found to be in good condition.[1] A total of 59 splices were inspected throughout 30 floors. At 49 of these locations, nondestructive testing was performed on the plate splice welds (see Sections a–a and b–b in Fig. 3–2 for location of welds), and ultrasonic testing was performed to verify plate thickness. Bolt tightness was also checked, and no loose bolts were found. However, on floors 74 and 77 (above and below an MER floor), the column splices had only three bolts, although the design detail called for four. According to the report, since the column splices at MER floors are groove welded, the missing bolts have no structural significance.

The inside faces of the steel box column plates were found to have scattered areas of light corrosion and peeling paint, as did splice bolts, welds, cap and base plates, and column stiffeners. Ultrasonic thickness testing on these outer column plates above and below the splice location indicated no section loss.

Fillet shop welds connecting the cap and base plates to the interior of the box columns were visually inspected at all open splice locations, and most of the welds were tested using the magnetic particle method. No cracking or significant discontinuities were detected at any location. According to the report, overlaps and undercuts were observed at several locations, but they were not significant enough to affect the performance of the connection.

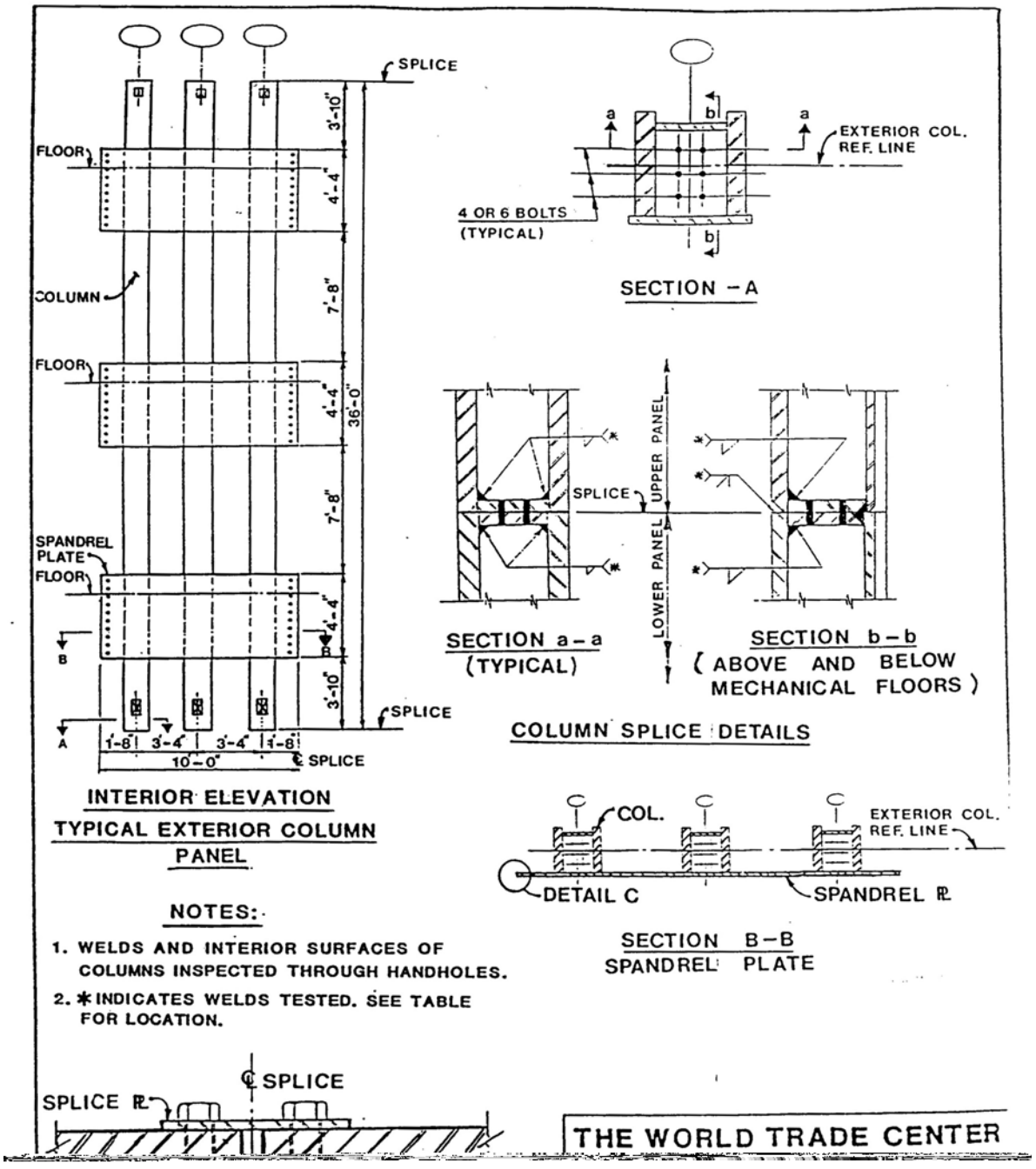
Groove weld splices were tested on the 74th floor using the dye penetrant method and on the 77th floor using the magnetic particle method. No discontinuities or cracks were detected.

Spandrel plates, splice plates, and spandrel bolted connections were also found to be in good condition. Scattered rust stains were observed on the spandrel fireproofing, typically at the splice plates. All splice plate bolts were observed to be tight. Fillet welds at the truss seat connections to the spandrels were also found to be in good condition.

Floors 107 through 110—Inspection was limited to the joints at the 108th floor. No structurally significant deterioration was found.

Recommendations—No priority recommendations for repair were made in the report. It was recommended, however, that a long-term maintenance program be developed and implemented to clean and paint the inside surfaces of the exterior box columns to prevent further corrosion of the structural steel.

[1] In this report, a structural member that receives a "good" condition rating requires no repairs. The structural member is defined to be in "original condition" (see page 11 of PANYNJ (1990) for this and other definitions).



Source: PANYNJ 1990. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–2. Splice details at typical inspection locations of exterior wall per the 1990 Condition Survey Report of WTC 2.

Core Columns

Inspection of the core columns was performed in two phases. In one phase, staff from the consulting firm of Corddry, Carpenter, Dietz and Zack inspected core columns from the elevator shafts. In the other phase, PANYNJ Quality Assurance Division staff inspected selected core corner columns from office area floors. They also inspected lateral core bracing at two locations from an elevator lobby on the 4th floor.

Core columns inspected from elevator shafts—The consultant randomly selected a total of 25 elevator shafts for inspection. Table B1 in the survey report contains a list of the elevator shafts that were visually inspected. Lateral bracing members, columns, and floor framing between the 2nd and 7th floors were inspected from eight other express elevator shafts.

Elevator core framing was inspected primarily with fireproofing materials in place. Only in elevator shaft number 52 between the 44th and 55th floors was the fireproofing removed at the column splices. According to the report, no defects were found in the existing fireproofing material. In most of the shafts, several small regions and a few large areas of fireproofing were found to be missing from core framing members, which, according to the report, was probably due to the high-speed elevators moving up and down the shafts. In particular, an 8 in. wide by 1 ft 6 in. long area of fireproofing was found to be missing on the top flange of the beam between shaft numbers 30 and 31 on floor 22. Also, 100 percent of the fireproofing was found to be missing from the south face of column 908 between floors 27 and 29 in shaft number 1. All exposed steel members were found to be in good condition with only isolated locations of light surface corrosion on the steel. Some minor shrinkage cracks were reported in the troweled-on fireproofing materials on the columns.

Gypsum wallboards surrounding the elevator shafts were also found to be in good condition, although isolated holes were detected at various locations as outlined in Table B2 of the survey report. At shaft number 4, a piece of wallboard was found to be loose in the southeast corner of the shaft; facility personnel repaired this piece.

Close-up inspection of column splices and eccentric-braced column connections with fireproofing removed at the locations designated in Tables B3 and B4 showed that all bolts, welds, and structural steel were in good condition. No defects in the welds were found after EQAD personnel performed ultrasonic tests on the butt welds at the column splices and magnetic particle tests on the fillet welds at the eccentrically-braced column connections.

Column splices and eccentrically-braced column connections in the express elevator shafts were not tested due to restricted access.

Quality Assurance personnel inspected the lateral bracing of the core columns at two locations (one between columns 606 and 607 and one between columns 907 and 908) on the 4th floor. Light surface corrosion was found on the bracing, splice plates, and bolts. The welds were tested using the magnetic particle method and were found to be in good condition, and no cracks were observed.

Core columns inspected from office area floors—Quality Assurance personnel inspected core corner columns at eight splice locations (see Table B6 in the survey report for locations). Seven of the splices were welded, and the welds were tested using the ultrasonic and magnetic particle methods. The eighth

location was a bolted splice connection. No defects were found in any of the welded splices. Steel columns exhibited light surface corrosion, as did the bolted splice on the bolts and splice plates.

Recommendations—No priority recommendations for repair were made in the report. It was recommended that the fireproofing that was missing from the elevator shaft framing members be replaced, including those regions where the fireproofing was removed for up-close inspection during the condition survey. This report also recommended that the holes in the gypsum wallboards surrounding the elevators, which are listed in Table B2 of the survey report, be repaired.

Floor Framing

Inspection locations for the floor framing at typical floors are shown in Drawing 9 of the report, which is reproduced here as Fig. 3–3. Findings for specific zones are reported below.

Main Lobby (floors 1 through 6)—Beams and connections that were inspected within the core in this zone were found to be in good condition. At various locations, fireproofing was missing, exposing light surface corrosion on the beams and connections.

Floors 9 through 41—Floor framing inspected in this zone was found to be in good condition. Light corrosion was observed on all core beams and beam connections, and on main truss connections on floors 28 and 37.

According to the report, the most significant deficiencies in this zone were found at the damping units (see Table C-1 in the survey report). Damping units on floors 18 and 37 were observed to be missing one fastener at each unit. Two fasteners were found to be missing in one damping unit on floor 29, as well as on floor 38. Also, at floor 38, a damping unit was observed to be missing four fasteners. According to the structural drawings (WSHJ 1967a), four fasteners were required to connect the damping unit to the member attached to the bottom chord of the floor truss, and two fasteners were required to connect the damping unit to the exterior column.

Source: PANYNJ 1990. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–3. Typical inspection locations of floor framing per the 1990 Condition Survey Report of WTC 2.

Floors 43 through 75—The floor framing in this zone was also found to be in good condition. Light corrosion was observed on the same members as in the previous zone.

Minor deficiencies were found at floor 64 and floor 75. A deformed bottom chord was found on the main truss along column 343 on the 64th floor. According to the report, "No signs of distress were observed." The entire floor framing was visually inspected on the 75th floor, since the fireproofing was being replaced on this level. Most of the exposed structural components and connections were found to be in good condition. Untightened bolts were found at truss seat connections at several locations, which, according to the report, did not significantly affect the structural integrity of the framing.

Hairline cracks were observed in the 2 in. thick concrete topping slab near the south exterior wall on the 44th floor. According to the report, these cracks were due to shrinkage and did not affect the structural integrity of the floor slab.

Floors 77 through 107—The floor framing in this zone was found to be in good condition, with light surface corrosion observed on all core framing beams and connections.

Minor deficiencies were found in floor slabs, where separation of the concrete slab from the metal deck forms was found at floors 93 and 108. According to the report, this condition did not affect the structural integrity of the slab, since decking served as formwork for the concrete and had no structural function.

Mechanical Equipment Rooms (Floors 7–8, 41–42, 75–76, 108–109)—The floor framing and slab inspected on the MER floors were found to be in good condition. On all MER floors, most of the structural framing was inaccessible due to heating, ventilation, and air conditioning (HVAC) ducts, fans, electrical equipment, or plumbing. No nondestructive testing was performed on these levels.

Hairline cracks were found in concrete beam encasement at various locations on all four MER floors. Exposed steel exhibited light surface corrosion, and no deterioration was found at the underside of floor slabs.

Selected elements of the space frame at various locations on the 107th through 110th floors were inspected and were found to be in good condition. Exposed truss elements and connections both exhibited light surface corrosion. Bolted and welded connections were also found to be in good condition.

Recommendations—No priority recommendations for repair were made in the report. As mentioned above, all the deficiencies found were considered to have no significant effect on structural integrity. It was recommended that utility supports found to be bowed or vibrating be replaced as part of the facility's regular maintenance program.

Roof

Roof framing, which consisted of rolled steel wide flange beams supporting a structural concrete slab, was found to be in good condition. Hairline cracks in the fireproofing and in the underside of the concrete slab were found at various locations.

Recommendations—No priority recommendations for repair were made in the report. Recommendations that were made were not structural in nature.

3.1.2 Port Authority Facility Condition Survey Program – WTC 1

This section contains the findings of the condition survey of WTC 1 (Tower A), which was performed in 1991 by the Office of Irwin G. Cantor, Consulting Engineers, for the EQAD of PANYNJ (PANYNJ 1991).

Scope

The scope of the survey was determined based on experience gained from the condition survey of WTC 2 in 1990, which was discussed in Sec. 3.1.1 of this report.

The scope of work was designed to minimize impact on tenant and facility operations, and was limited to vacant floors and tenant areas and partially occupied floors. The following is a list of the structural elements that were inspected:

1. Floor framing (long, short, and transverse trusses, rolled beams, concrete encased beams, bridging, and connections)
2. Damping system (damping units from bottom of trusses to exterior walls and connections)
3. Exterior wall system (columns, column splices, spandrel plates, splices, and bolted connections of spandrel beams)
4. Core columns (columns within elevator shafts, including visible floor beams)
5. Space frame (framing members and connections)
6. Mechanical equipment room (framing, machinery bases and utility supports, and exterior offsets)
7. Roof (slab, window washer rails, top façade, antenna bases, and window wash concrete walls)

Inspection Procedures and Methodology

To assess the condition of the structural system in the tower, both visual inspection and nondestructive testing methods were employed. The thickness of steel members was checked using an ultrasonic thickness gauge. Welds were tested using magnetic particle and/or dye penetration test methods.

Office Floor Areas

Fourteen office floors (11, 13, 22, 30, 35, 52, 54, 61, 65, 78, 84, 86, 90, and 93) throughout WTC 1 were selected for inspection. Inspection of the structural elements at these levels followed the following sequence:

1. Six long-span trusses and two short-span trusses were selected from the plans for even, random distribution of inspection locations throughout the floor area.

2. Floor framing, damping unit, utility supports, steel decking, inside faces of steel spandrel plates, spandrel splices, and core concrete or rolled steel members were visually inspected. Structural steel members were examined for signs of deformation or corrosion with fireproofing still in place.

3. The following locations for fireproof removal were selected and submitted: (a) six truss locations, (b) one core floor beam, (c) two spandrel plate splices, and (d) two exterior columns (plaster removal).

4. The 11 locations listed above were inspected up close, using lights, scrapers, wire brushes, and mirrors for signs of cracking, deformation, or corrosion. Photographs were taken of typical conditions and "Remarks" were documented.

5. Nondestructive testing was performed on column splice welds and welded floor framing connections. Testing was performed by either the Port Authority's Materials and Research Division or by Lucius Pitkin, Inc.

On 2 of the 14 floors inspected, column splices on seven core columns were inspected after removal of the gypsum board firewalls. Top sides of exposed concrete floor slabs were also inspected where carpeting or floor tiles had previously been removed.

Table 3–2 contains the number of structural elements inspected per office floor.

Table 3–2. Number of structural elements inspected per office floor per the 1991 Facility Condition Survey Report for WTC 1.

Element	Type of Inspection	Quantity
Floor framing trusses	Visual	22
	Fireproofing removal	6
	Nondestructive testing	4.3 (avg.)
Exterior column spandrel plate splices	Visual	6
	Fireproofing removal	2
Exterior column splices	Visual and Non-destructive testing	2

MER and Space Frame

All four two-story MERs were visually inspected from the lower floor and accessible upper floor levels. Floor framing, slabs, interior columns, and utility hangers and pads were inspected. Concrete fireproofing for covering the steel floor framing was examined for delaminations and underlying corrosion.

At the 107th and 108th floors, fireproofing was removed at nine locations. Of these, seven were welded connections that were tested by the magnetic particle method.

Core Columns

Core columns were inspected from the elevator shafts in addition to the corner core column splices that were inspected from the two office area floors. The elevator shaft inspections included visual inspection

of floor framing, columns, connections, and splices in 13 elevator shafts with fireproofing in place. Core column connections to floor beams in the core were also examined.

Roof

The roof concrete slab top surface and parapet were visually inspected, along with the roof framing and underside of the concrete roof slab.

Findings of Inspection

The following sections summarize the findings and recommendations from the WTC 1 survey report.

Exterior Walls (Columns and Spandrels)

Floors 9 through 106—Exterior column splices were found to be in good condition.[2] A total of 28 column splices were inspected throughout the 14 office floors. At 26 of these locations, nondestructive testing was performed on all of the splice welds and the box column plates; each test showed that the welds were in good condition. Ultrasonic testing was performed to verify thickness of the spandrel plates. These tests showed no loss of thickness. Tightness of the bolts in the spandrel beam splices was also checked, and no loose or missing bolts were found.

The inside faces of the steel box column plates exhibited scattered areas of light to moderate corrosion[3] and peeling paint. Light corrosion was also found at splice bolts, welds, cap and base plates, and diaphragms. Ultrasonic thickness testing on these outer column plates above and below the splice location indicated no section loss.

Fillet shop welds connecting the cap and base plates to the interior of the box columns were visually inspected at all open splice locations. No cracking or significant discontinuities were detected at any location.

Spandrel plates, splice plates, and bolted connections were also found to be in good condition. Scattered corrosion stains were observed on the spandrel fireproofing, typically at the splice plates and along the lower edges of the floor slabs. All splice plate bolts were observed to be tight. Fillet welds at the truss seat connections to the spandrels were also found to be in good condition.

A summary of the findings is contained in Table A-2 in the survey report, which is reproduced here as Table 3–3.

Floors 107 through 110—Inspection of the exterior walls was limited to the joints at the 108th floor. No structurally significant deterioration was found. Joint sealer in the column cladding was missing at nearly all of the 59 column seals.

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[2] In this survey report, a structural member that receives a "good" condition rating requires no repairs. The structural member is in "original condition" (see page 14 of PANYNJ (1991) for this and other definitions).

[3] In this survey report, "corrosion" and "rust" are used interchangeably. See page 15 of PANYNJ (1991) for a definition of corrosion.

Table 3–3. Findings from inspection of exterior wall column splices in WTC 1.

Floor	Col. No.	Condition of Column			Splice Plate Welds				Remarks
					NDT – Magnetic Particle		NDT – Dye Penetrant		
		Upper	Lower	Bolts	Upper	Lower	Upper	Lower	
10-11	403	M	L	T			A	A	Ultrasonic thickness shows no significant loss
	212	M	L	T			A	A	
12-13	215	L	L	T			A	A	
	324	L	L	T			A	A	
21-22	115	N	N	T			A	A	No NDT
	454	L	L	T			A	A	
29-30	233	L	L	T			A	A	Ultrasonic thickness shows no significant loss
	318	L	L	T			A	A	
34-35	121	L	L	T					
	112	M	L	T					
51-52	227	L	L	T			A	A	
	308	L	L	T			A	A	
53-54	203	L	L	T	A			A	
	329	L	L	T		A	A		
60-61	327	L	L	T	A			A	
	251	L	L	T	A			A	
64-65	324	L	L	T	A			A	
	236	L	L	T	A			A	
77-78	332	L	L	T	A			A	Ultrasonic attempted; reading erratic
	123	L	L	T	A			A	
83-84	106	L	L	T	A	A			
	454	L	L	T	A			A	
85-86	133	L	L	T	A			A	Upper column rotated 3/16 in. during construction
	209	L	L	T	A			A	
89-90	315	L	L	T	A			A	
	136	L	L	T	A			A	
92-93	124	L	L	T	A			A	Ultrasonic attempted; reading erratic
	336	L	L	T	A			A	

Key: A, acceptable (no loss of metal); L, light corrosion; M, moderate corrosion; N, no deterioration/defects; T, tight.

Recommendations—No priority recommendations for repair were made in the report. It was noted, however, that missing fireproofing should be replaced on the spandrel plates and splices, and that the joints in the aluminum cladding should be resealed where the seals were removed.

Core Columns

Inspection of the core columns was performed in three phases:

- Core columns were inspected from the elevator shafts.
- Seven core column splices were inspected from unoccupied office areas.
- Core floor beam to column connections were inspected at 25 of 56 locations on 14 floors.

Core columns inspected from elevator shafts—Inspection of the core columns in an elevator shaft was performed from the top of the elevator cab.

Thirteen elevator shafts (four express elevator shafts and nine local elevator shafts) were randomly selected for inspection with the concurrence of Port Authority personnel. The shafts that were selected for inspection can be found in Table B-1 of the report, which is reproduced here as Table 3–4.

Table 3–4. Visual inspection of elevator core framing in WTC 1.

Elevator Shaft Number	Floors Inspected	Adjacent Column Number	Remarks
2	1 – 44	907, 1007	No fireproofing removed
11	1 – 44	901, 1001	
12	1 – 78	501, 601	
15	1 – 78	503, 603	
26	9 – 16	708, 807	
35	17 – 24	706, 805	
43	33 – 40	702, 802	
52	46 – 54	708, 807	
62	55 – 61	706, 805	
67	62 – 67	702, 802	
77	80 – 87	708, 807	
80	79 – 87	806, 907	
90	93 – 101	703, 803	

In the express elevator shafts, beams framing in the north-south direction were typically encased in concrete. Steel in the other direction consisted of built-up welded box girders and columns with sprayed-on fireproofing. According to the report, no defects were found in the fireproofing that would suggest a problem with the steel columns, bracing, and floor framing. However, several small areas and a few large areas of fireproofing were missing from the steel girders and columns. It was suggested in the report that the small areas of exposure were caused by (1) the mounting of brackets and other hardware to support conduit and guide cables and (2) the movement of hoist cables that were rubbing the shaft girder.

According to the report, the probable cause of missing fireproofing on box columns was thought to be the forces induced by the high speed of the elevators moving up and down the shafts. All exposed steel was found to be in good condition with light to medium surface rust. Gypsum closure wallboards were found to be in good condition, except for isolated holes in two elevator shafts at the 58th and 69th floors (see Table B-2 in the survey report, which is reproduced here as Table 3–5). The report states that these openings represent a fire safety hazard that should be corrected.

Table 3–5. Locations of holes in gypsum wallboard around elevators in WTC 1.

Elevator Shaft Number	Floor Number
62	58
12	69
12	58

Local elevator shafts typically had wide-flange columns and girders with sprayed-on fireproofing. Fireproofing was found to be missing on some of the steel members where there was contact with hoist cables and where the steel served as staging support for maintenance workers servicing electrical conduits. The exposed steel was found to be in good condition with light surface rust. Steel beams supporting the elevator door saddles were encased in concrete, except for a few beams that were found to be partially encased (for example, in one case, concrete was missing from the bottom flange of one of the steel beams). The report states that the fireproofing should be replaced in these cases. The gypsum closure walls were also found to be in good condition except for a few isolated holes and/or projections into the shaft (see Table 3–5).

Core corner columns inspected from office area floors—Core corner columns were inspected at all four corners of the 92nd to 93rd floors and at three corners at the 77th to 78th floors. All seven locations were inspected by removing the five or more layers of gypsum wallboard around the splice locations, which were 3 ft 0 in. above the finished floor level.

On the 92nd to 93rd floors, all four splices were bolted connections. No defects were found at any of the bolted splices. Welded splices were found at all three locations on the 77th to 78th floors, and were tested using the dye penetrant method. Results from the tests showed that there were no surface cracks in the welds. Steel plates, bolts, and welds that were visible were found to have only light surface corrosion.

Core column to floor beam connections inspected from office floors—Twenty-five floor beam to column connections were visually inspected, and seven connections were inspected up-close throughout the tower (see Table B-3 in the report for locations, which is reproduced here as Table 3–6). No deformations were found in any of the connections that could be inspected. No inspection occurred where firewalls obstructed vision or where heavy beams supported minor beams. Either no or light corrosion was found on the exposed steel.

Table 3–6. Core column connection inspection in WTC 1.

Floor Number	Number of Beam to Column Connections Inspected		Corrosion	Deformation
	Visually	Up close with fireproofing removed		
10-11	3	1	L	N
12-13	4	4	N	N
21-22	0	0	–	–
29-30	4	0	N	N
34-35	3	0	L	N
51-52	0	0	–	–
53-54	1	0	L	N
60-61	2	0	L	N
64-65	0	0	–	–
77-78	0	0	–	–
83-84	0	0	–	–
85-86	2	0	L	N
89-90	4	1	L	N
92-93	2	1	L	N
Totals	25	7		

Key: L, light; N, none.

***Recommendations*—**No priority recommendations for repair were made in the report. It was recommended that the fireproofing that was missing from the elevator shaft framing members be replaced, including those regions where the fireproofing was removed for up-close inspection during the condition survey. It was also recommended that the holes in the gypsum wallboards surrounding the elevators, which are listed in Table B-2 of the survey report be repaired.

Floor Framing

Inspection locations for the floor framing were divided into three elevator zones: (1) Zone 1 (floors 9 through 41), (2) Zone 2 (floors 43 through 75), and (3) Zone 3 (floors 77 through 107).

***Office floors, trusses*—**Typical floor framing was inspected from below at five locations in Zone 1, four locations in Zone 2, and five locations in Zone 3. Fireproofing was removed at various locations on each floor that was inspected to provide up-close examination of the framing components and connections. Welds were tested at most of these locations using either the magnetic particle method or dye penetrant.

Two typical conditions were observed during inspection. First, small areas of fireproofing were missing at scattered locations throughout the floor framing. Second, the underside of the bottom plates of the seated connections of the trusses exhibited light rust. According to the report, this was the result of the welding process that had occurred above the plate, which heated the paint, causing it to fall off. No structural deficiency was noted due to this condition.

At all locations that were examined, the damping units were not covered with fireproofing. Small amounts of light rust were observed throughout. Also, the damping unit under the 30th floor was missing a non-structural bolt.

In some cases, the connection of the truss to the exterior spandrel plate did not have the typical two-bolt connection. Instead, the seat had one bolt and a weld. It is suggested in the report that the bolt holes may not have lined up during erection, so welding was used instead. These field welds were tested by either the magnetic particle or dye penetrant method, and were "found to be functioning properly."

On the 10th and 61st floors, diagonal members of bridging trusses were removed in order to allow 2 ft wide by 1 ft deep HVAC ducts to pass through parallel to the floor trusses. According to the report, the bottom chords of the bridging trusses were attached to the adjacent trusses "so that there was no decrease of structural integrity." No details are provided in the report on how these connections were made.

Office floors, metal deck—The metal deck was inspected from below at 22 locations per floor. No significant rust was observed because, according to the report, the metal deck was galvanized. However, in an area of approximately 500 ft^2 on the underside of the 84th floor, a scattering of light rust was observed through the fireproofing.

Office floors, concrete slab—In the core areas, the underside of the cast-in-place concrete slab was observed to be in good condition. A 4 in. by 4 in. area was spalled under the 11th floor, and a 6 in. by 6 in. by 2 in. deep spall was noted under the 54th floor. Also, a construction joint was found to be open south of columns 505 and 504 under the 13th floor.

Concrete slabs were also inspected from above at locations where floor tiles or carpeting were previously removed. In general, the slabs in the office floors were found to be in good condition, except for the slab at the southeast corner of the 60th floor. In this area, cracks were found, which formed at a 45 degree angle with the corner. Over a period of 4 months, the cracks did not open any further than originally measured. It was also observed that concrete slabs in the office areas were damaged by construction and removal of office partitions. Spalls resulting from nails being removed from the slab were noted on floors without tile or carpeting.

Table C-1 and C-2 in the survey report, which are reproduced here as Table 3–7 and Table 3–8, respectively, provide a summary of the locations and observations of the inspection for the trusses, connections, welds, secondary members and connections, damping units, and metal deck.

Recommendations—No priority recommendations for repair were made in the report for any of the floor framing members. Routine recommendations were made as follows: (1) patch elastomeric sealer at the construction joint south of columns 504 and 505 under the 13th floor, (2) even though the modifications made to the bridging trusses at the 10th and 61st floors did not meet the original design, no further modifications were needed, (3) patch spalls that were created in concrete slabs when partition rails were removed, and (4) patch cracks on the 60th floor with elastomeric sealer.

Table 3–7. Floor framing and slab inspection results for WTC 1.

Floor Level	Outer Framing – Main Trusses, Beams	Connections	Weld Test		Secondary Members and Connections	Damping Units	Metal Deck Underside
			Column Line	Test Condition			
ZONE 1							
11	G	G	155, 303, 443	G	G	L	G
13	G	G	305, 353, 421	G	G	L	G
22	G	G	123, 131, 331, 335	G	G	L	G
30	G	G, L	141, 423	G	G	L	G
35	G	G, L	121, 133	G	G	L	G
ZONE 2							
52	G, L	G, L		G, L	G		
54	G, L	G, L	151, 351, 353, 421	G	G		
61	G, L	G, L	243, 331, 305	G	G	L	G
65	G, L	L	157, 319, 423	G	G	L	G
ZONE 3							
78	G, L	L	131, 243	G	G, L	L	G
84	G, L	G, L	103, 107, 113, 121	G	G	L	G
86	G, L	G, L	131, 151, 217	G	G	L	G
90	G, L	G, L	135, 243, 319	G	G	L	G
93	G, L	G, L	117, 307, 443	G	G	L	G

Key: G, good condition; L, light corrosion.

MER and Space Frame

A 100 percent visual inspection was performed on all four mechanical equipment rooms (floors 7–8, 41–42, 75–76, and 108–109). According to the report, most floor framing was inaccessible due to the presence of HVAC ducts, fans, electrical piping, and plumbing equipment.

Mechanical Equipment Rooms—According to the report, the floor slabs at these levels were determined to be in good condition. Scattered cracks ranging in width from 1/16 in. to 1/8 in. were found on the slab surfaces. The report suggests that previously repaired cracks were found to be deteriorated due to load and vibration. Cracks were also found in equipment pedestal supports and column encasement.

Table 3–8. Core framing inspection results for WTC 1.

Floor Level	Beams	Beam Connection	Underside of Slab
ZONE 1			
11	G, L	G, L	G
13	G, L	G, L	G
22	G	G, L	G
30	G, L	G, L	G
35	L	L	G, L
ZONE 2			
52	L	L	G, L
54	L	G, L	G
61	G, L	G, L	G
65	L	L	G
ZONE 3			
78	G, L	G	G
84	G, L	G	G
86	L	G, L	G
90	L	G, L	G
93	L	L	G

Key: G, good condition; L, light corrosion.

Scattered patches of spray-on fireproofing were found to be missing from the metal decks, which were used in the perimeter areas (i.e., areas outside the core area). These areas had light rust visible on the underside of the metal deck. Concrete encasement on the steel beams in the core area was found to be in good condition with hairline cracks at scattered locations. In a few places, the encasement had spalled off of the steel beams, which exposed the welded wire fabric in the encasement and portions of the steel beams. The exposed steel was found to have a light coating of rust.

Visual inspection of the beam to column connections found them to be in good condition, according to the report. Exposed steel members exhibited only light surface corrosion where fireproofing was removed on floors 108 through 109.

A concrete encased beam at the 110th floor was subjected to steam from a leaking steam valve. Moderate rusting was confirmed on the member, and, according to the report, no discernible section loss was found.

Hangers supporting ducts, piping, etc., were also visually inspected. Hangers subject to excessive vibration, loose hanger rods, and the fatigue of pipe supports were found at various locations. According to the report, beams that supported the duct hangers had fireproofing missing where the hangers were mounted.

Detailed findings on the MER levels are shown in the four floor plans on pages 41 through 44 of the 1991 Facility Condition Survey Report for WTC 1.

Space Frame—Selected elements of the space frame (hat truss) were inspected at various locations on the 107th to 110th floors. A total of 75 diagonal bracing members were visually inspected without removing fireproofing. A total of 199 members were inspected in the space frame. Light rust was found on diagonal braces, beams, and connections where fireproofing was missing.

Recommendations—A priority recommendation was made in the report to replace the leaking valve under the 110th floor that rusted the floor beam. Routine recommendations were made as follows: (1) Repair the surface cracks in the MER concrete floor slabs with a surface sealer, (2) Repair the cracks in the concrete at the base of the columns, (3) Repair the cracks in the concrete pads supporting mechanical equipment, (4) Patch and repair the spalled concrete encasement of all appropriate structural members, and (5) Repair hangers that were found to be vibrating, bowed, sagged, and/or deformed.

Roof

A visual inspection of the top surface of the concrete roof deck and concrete wall at the inner perimeter of window washing rails was performed, and no significant structural deficiencies were found. Cracking and spalling was found at localized areas of the roof. Some of the spalled areas that had been previously patched with grout were found to be in poor condition due to exposure to weather.

Horizontal cracks and efflorescence, spalled concrete, and exposed reinforcing bars with minor corrosion were found at the exterior walls of the access stairway located at the roof. The report suggests that the spalling of the concrete was due to inadequate concrete cover over the reinforcing bars.

The helicopter pad at the southeast corner of the roof was visually inspected and was found to be in good condition. No deficiencies were found in the bases of the antennas, all of which were visually inspected.

Recommendations—No priority recommendations were made for the roof. Routine recommendations were made as follows: (1) Remove and replace the existing patches in the roof slab using a bonding agent and non-shrink grout as a replacement and (2) Patch spalled areas of exterior concrete curb of the access stairway located at the roof. Other routine recommendations in the report were not structural in nature.

3.1.3 Port Authority Facility Condition Survey Program – WTC 7

The Port Authority Facility Condition Survey Program – WTC 7 report contains the findings of the condition survey of WTC 7, which was performed by Ammann & Whitney in 1997 for the EQAD of PANYNJ (PANYNJ 1997).

Scope

The scope of work was designed to minimize impact on tenant and facility operations, and was limited to (1) unoccupied floors, which were the mechanical/electrical and general service floors (floors 3 through 6), and (2) floors that had vacant space (floors 7, 10, 18, 23, and 25). The following is a list of the structural elements that were inspected:

1. Foundation

2. Framing (column splices, wind bracing systems, and interior beam connections)

3. Floor slabs

4. Con Edison Substation

Inspection Procedures and Methodology

The inspection was primarily a visual inspection, with "hands-on" inspection[4] of approximately 5 percent of the "critical connections." A field inspection team visually inspected the structural elements noted in the previous section. Inspections were performed from the floor level and from ladders. A manlift was required to inspect the lobby and trading floor ceilings.

Column Splices

Table III-1 in the report, which is reproduced here as Table 3–9, contains the inspection point locations for the column splices in interior and exterior columns.

Table 3–9. Column splice inspection points in WTC 7.

Floor	Number of Inspection Points	Column Numbers	Location of Connection
INTERIOR COLUMNS			
5	3	58C (H), E3, & 79	See Drawing S-3
23	6	58(H), 59, 63(H), & 79–81	See Drawing S-8
EXTERIOR COLUMNS			
5	10	46–55	North side
	9	19–27	South side
	5	26, 7(H), 39–41	East side
	5	2, 3, & 12–14	West side
	2 Hangers	25A & 26	South side
23	1	25	West side

Key: (H), hands-on inspection performed at these locations.

Wind Bracing System

Tables III-2 and III-3 in the report, which are reproduced here as Tables 3–10 and 3–11, respectively, contain the inspection point locations for columns and girders that were part of the lateral-force-resisting system.

Interior Beam Connections

Table III-4 in the report, which is reproduced here as Table 3–12, contains the inspection point locations for the interior beam connections.

[4] What constituted hands-on inspection is not described in the report (PANYNJ 1997).

Table 3–10. Wind inspection points, columns, in WTC 7.

Floor	Number of Inspection Points	Column Numbers	Location of Connection
CORE			
1	4	64–73	North side
2	4	64–73	North side
LOWER EXTERIOR			
5	10	43, 46–54	North side
	4	25, 26, 27(H), 28(H)	South side
	3	28(H), 29, 30	East side
	4	12 – 14A	West side
6	2	28–29	East side
	3	6–8	West side
UPPER EXTERIOR			
23	1	29	East side
	1	12	West side

Key: (H), hands-on inspection performed at these locations.

Table 3–11. Wind inspection points, girders, in WTC 7.

Floor	Number of Inspection Points	Column Numbers	Location of Connection
5	3	16–19A	South side
6	8	46–54	North side
	1	55–56(H)	North side
	8	19–27	South side
	1	27–28(H)	South side
	5	28–30, & 38–41	East side
	4	2–3 & 12–14A	West side
8	2	23–25	South side
	2	28–30	East side
19	5	21–26	South side
	1	26–27(H)	South side
24	4	44–46 & 53–55	North side
	3	25–28(H)	South side
	1	35–36(H)	East side
	2	5–6 & 9–10	West side
44	1	42–43(H)	North side
	3	32–33, & 37–39	East side
	1	41–42	East side
	1	5–6	West side
Main Roof	1	57–1(H)	North side
	1	4–5	West side

Key: (H), hands-on inspection performed at these locations.

Table 3–12. Interior beam connection inspection points in WTC 7.

Floor	Number of Inspection Points
5	5
6	4
8	6
11	6
19	5
24	10
26	7
44	2
Main roof	5

Findings of Inspection

According to the report, the structural framing was found to be in good condition.[5] No problems or deterioration were found on the column splices, wind bracing, or the interior beam connections.

Rust buildup was found between the flanges of members that rested on top of one another at the main roof level where the steel framing was exposed. Although this was not considered to be a structural problem, it was recommended that the steel should be cleaned and painted to prevent further deterioration.

Throughout the building, fireproofing was found to be missing from the steel framing at locations where utility supports were installed. This condition was found on all of the floors that were inspected, but it was most prominent on the 5th floor framing above the main lobby and the 2nd floor framing above the loading dock area. The report recommended in the report that the fireproofing be replaced.

Loose concrete was found on the north face of column number 51 on the 46th floor of the cooling tower area.[6] Due to the potential hazard immediate action was recommended. Silverstein Properties personnel immediately removed the loose concrete.

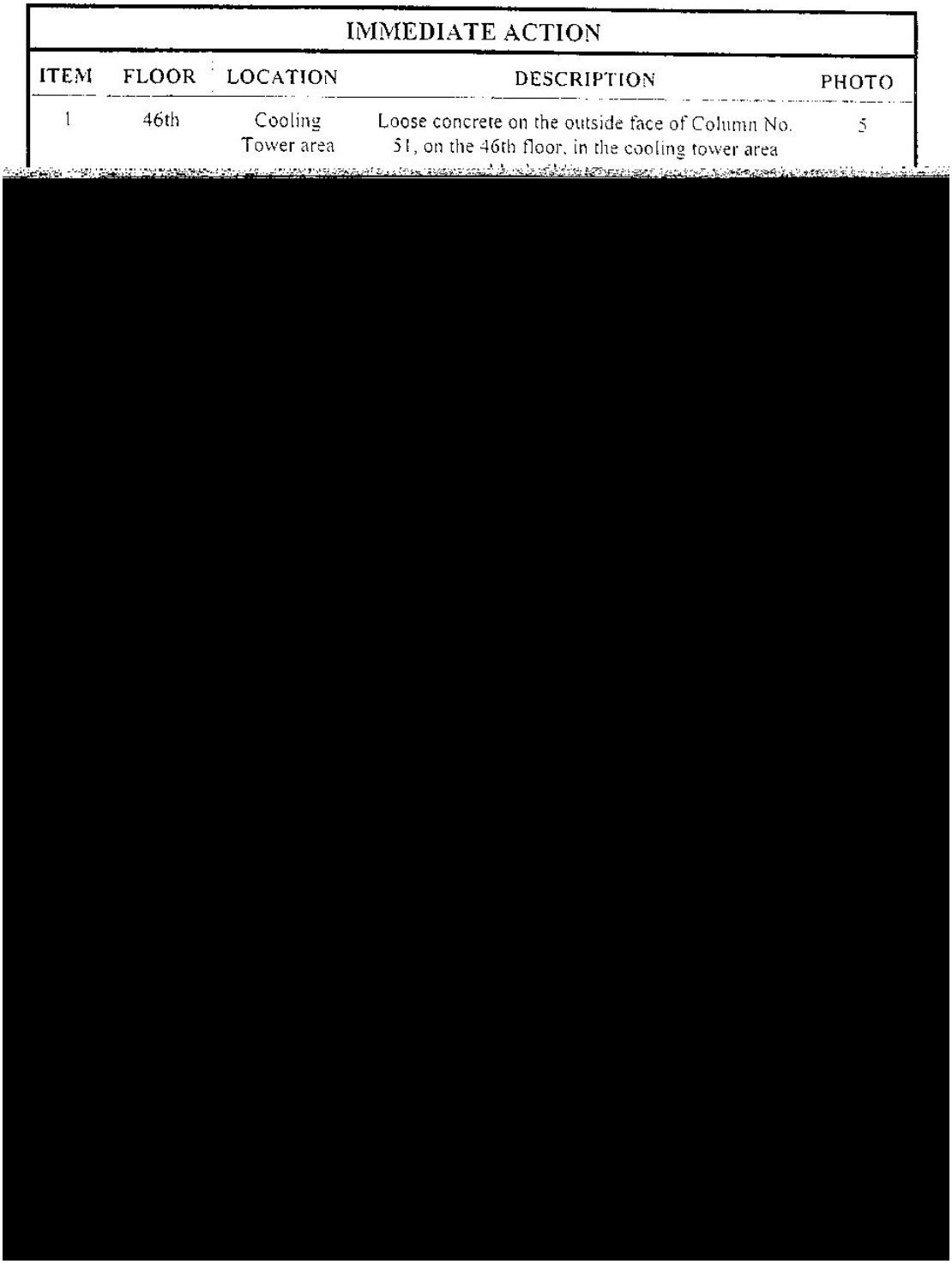
Floor slabs were found to be in good condition. Some of the exposed floor slabs exhibited shrinkage cracks on the top sides, and some had the composite metal deck damaged during construction. Neither of these conditions was considered to pose a structural problem. The report also recommended that delaminated concrete be removed at the concrete patch in the 6th floor slab.

A complete list of the recommendations made in the report for immediate action, safety items, and routine repairs is reproduced in Fig. 3–4.

[5] In this report (PANYNJ 1997), "good condition" means that the element is sound and performing its functions although it shows signs of use and may require some minor repairs, mostly routine.

[6] No information is given in PANYNJ (1997) on the size or exact location of this loose concrete.

The report also noted that the Con Edison station was in very good condition and that no action was required at that time.



IMMEDIATE ACTION

ITEM	FLOOR	LOCATION	DESCRIPTION	PHOTO
1	46th	Cooling Tower area	Loose concrete on the outside face of Column No. 51, on the 46th floor, in the cooling tower area	5

Source: PANYNJ 1997. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–4. Recommendations made in the 1997 Facility Condition Survey Report for WTC 7.

ROUTINE REPAIRS

ITEM	FLOOR	LOCATION	DESCRIPTION	PHOTO
1	47th main roof	North side of building in Cooling Tower area	Remove the wire ropes from the steel framing on the roof. Provide adequate support for the temporary scaffolding using the existing tie-back system	6
2	46th & 47th	North side of building in Cooling Tower area	Clean and paint the exposed steel framing and cooling tower catwalks on the 46th & 47th floors.	6
3	46th	Cooling Tower area	Seal all cracks in the exterior brick walls of the 46th floor cooling tower area.	16
4	47th	Inside face of	Secure and seal electrical fixtures on the roof	

[redacted]

Source: PANYNJ 1997. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–4. Recommendations made in the 1997 Facility Condition Survey Report for WTC 7 (continued).

3.1.4 Due Diligence Physical Condition Survey – WTC 1 and WTC 2

The Due Dilligence Physical Condition Survey – WTC 1 and WTC 2 report contains the findings of the condition survey of WTC 1 and WTC 2, which was performed by Merritt & Harris, Inc. in 2000 for PANYNJ (Merritt & Harris 2000).

Scope

On-site evaluations were performed to assess the general physical condition of the property, as it existed at that time. In particular, WTC 1, WTC 2, WTC 4, WTC 5, the retail mall and plaza, central services, and the subgrade were inspected. The following discussion focuses on the findings for WTC 1 and WTC 2.

Inspection Procedures and Methodology

Observations were limited to those portions of the project that were visible during walk-through. In many areas, building finishes concealed structural components from view. The consultant neither took material samples nor performed tests on the building materials or systems.

Findings of Inspection

The following findings and recommendations were reported for both WTC 1 and WTC 2.

According to the report, the building structure appeared to be in good overall condition, based on observations of portions of the structure that were not concealed by building finishes. No apparent movement or settlement of foundations was observed, and interior slabs were reported to be in good condition.

The report notes that Leslie E. Robertson Associates (LERA) and other engineering firms had performed, on a regular basis, Structural Integrity Inspections (SII) of various structural systems and that those studies have indicated the following deficiencies: (1) rusting of steel columns in the elevator shafts, (2) missing fireproofing, and (3) floor coring damage. The due diligence condition survey report goes on to note that the most recent SII recommended repairs were underway at the time the report was written.

Damping units had been tested every 5 years, most recently in 1996. The report notes that approximately two-dozen damping units were kept in stock for replacement. The report also states that LERA strongly recommended that the analysis of wind acceleration measurements be continued.

The report notes that an ongoing program of re-fireproofing structural steel members was in place at the time of the inspection. Re-fireproofing the structural steel was supposed to provide a two-hour fire rating for those members. Such work was performed on an entire floor when the space was being built-out for new occupancy. At the time of inspection by Merritt & Harris, Inc., approximately 30 floors had been completed in the two towers.

3.2 STRUCTURAL INTEGRITY INSPECTION PROGRAM

3.2.1 Overview

In 1986, the PANYNJ implemented an inspection program to detect, record, and correct any signs of distress, deterioration, or deformation that could signal structural problems for WTC 1 and WTC 2 (PANYNJ 1986). This program for structural integrity, which was based on an inspection and testing plan prepared by LERA, contained detailed guidelines on inspection, record-keeping, and follow-up procedures. It included periodic inspection intervals for the TV antenna mast, exterior roof and wall elements, room occupancies and uses, accessible columns, fireproofing envelopes, bracing truss members

between floor 107 and the roof (hat truss), steel floor framing, and concrete slabs. Details of the SII program are presented in Sec. 2.2 of this report, including the required follow-up procedures, which are outlined in Sec. 2.2.5.

Inspection findings under the SII program were to be categorized as "Immediate," "Priority," or "Routine." Findings requiring "immediate action" would include possible closure of the area and/or structure until interim remedial measures (such as shoring or removal of a potentially unsafe element or structural member or members) could be implemented. "Priority" findings addressed those conditions for which no immediate action was required or for which immediate action has been completed, but for which further investigation, design, or implementation of interim or long-term repairs should be undertaken on a priority basis, i.e., taking precedence over all other scheduled work. For "routine" or non-priority cases, further investigation and/or remedial work could be undertaken as part of a scheduled major work program or routine facility maintenance. Where inspection procedures involved the removal of fireproofing, such fireproofing was to be properly replaced on completion of inspection.

In January of 1990, LERA submitted a proposal to the PANYNJ for monitoring the structural integrity of the World Trade Center Complex.[7] The proposal contained the scope of testing and inspection services for WTC 1, WTC 2, WTC 4, WTC 5, WTC 6, the Vista Hotel, and the subgrade and was based on a modified and expanded version of the 1986 action plan that was previously submitted to PANYNJ.

The scope of services presented in the proposal included three separate approaches to identifying potential component and/or system degradation:

1. Statistical Inspections – Periodic statistical testing and inspection of structural components in areas that had a higher potential for trouble.

2. Review of Reports – Examination of maintenance reports (e.g., nonstructural repairs, water leakage, and tenant complaints about building movements and/or vibration) for indications of possible structural degradation.

3. Continued Measurements – Evaluation of the performance of structural systems through continued measurement of movement and deformations using appropriate tests and instruments.

The program called for inspection or monitoring of the following items, among other things, in WTC 1 and WTC 2:

1. TV mast (WTC 1 only)

2. Roof water tightness and curtain wall

3. Space usage

[7] Letter dated January 12, 1990 from Saw-Teen See of Leslie E. Robertson Associates to Suren Batra of the Port Authority of New York and New Jersey (WTCI-123-P; see Appendix G of this report).

4. Accessible columns, including exterior box columns at locations of spandrel intersections and "tree" junctions below floor 7 and above floor 1 (Plaza Level)

5. Bracing at exterior column line below elevation 294 ft 0 in., and in WTC 2 only, the transfer trusses below floor 1 under exterior columns

6. Hat truss between floor 107 and the roof

7. Floor framing over mechanical spaces

8. Concrete slabs, partitions, and finishes

9. Steel framing, slabs, and the like where exposed for general repairs or tenant remodeling

10. Measurement of natural frequency of tower and TV mast

11. Floor natural frequency

12. Damping units

13. Plaster ceilings in main lobby

14. Marble wall panel supports

15. Review of maintenance reports

16. Fire stairs

Inspection and monitoring of these items were proposed to occur at regular intervals. Estimated manpower and cost estimates based on proposed inspection intervals were also given, and are shown here in Fig. 3–5. A detailed inspection program outlining the steps required for visual inspections and periodic measurements was also contained in the proposal.

3.2.2 Summary of Structural Integrity Inspection Program Reports

LERA and other engineering firms conducted periodic inspections of the towers under the WTC Structural Integrity Inspection Program, which was based on the proposal originally submitted to PANYNJ by LERA in 1990. The following sections of this report summarize the findings from the SII Program reports related to the structural aspects of the towers.

The PANYNJ has reported that the construction records on repairs following the SII reports were destroyed when the towers collapsed on September 11, 2001. In addition, the PANYNJ has reported that any missing fireproofing that was identified in the SII reports to be repaired was done so on a routine basis.

Space Usage Surveys

The purpose of the space usage surveys was to identify possible structural overloading of the slabs and floor framing due to changes in occupancies and uses and/or due to additions of heavy equipment or furniture. The inspections were conducted by a walk-through by LERA personnel on predetermined floors within WTC 1 and WTC 2. Such usage surveys were initially proposed to be conducted annually on an ongoing basis (see Fig. 3–5). Surveys actually were conducted annually over a five-year period starting in 1995 (two surveys were conducted in 1996). A summary of the findings from the space usage reports is contained in Table 3–13.

Accessible Columns

Surveys of the accessible columns (columns in the core area that were not enclosed by an architectural finish, which can be visually inspected) in the elevator shafts of WTC 1 and WTC 2 were performed to:

- Ascertain the condition of the accessible columns with respect to rusting, cracking, bowing, and deviation from plumb
- Identify specific locations of structural distress or damage
- Identify locations of damage to the fireproofing
- Identify lateral displacement or rotation of the column about a vertical axis where the column was directly braced on only one axis by connecting beams or concrete slabs
- Identify deformations of the slabs-on-ground surrounding each column at the sublevel.

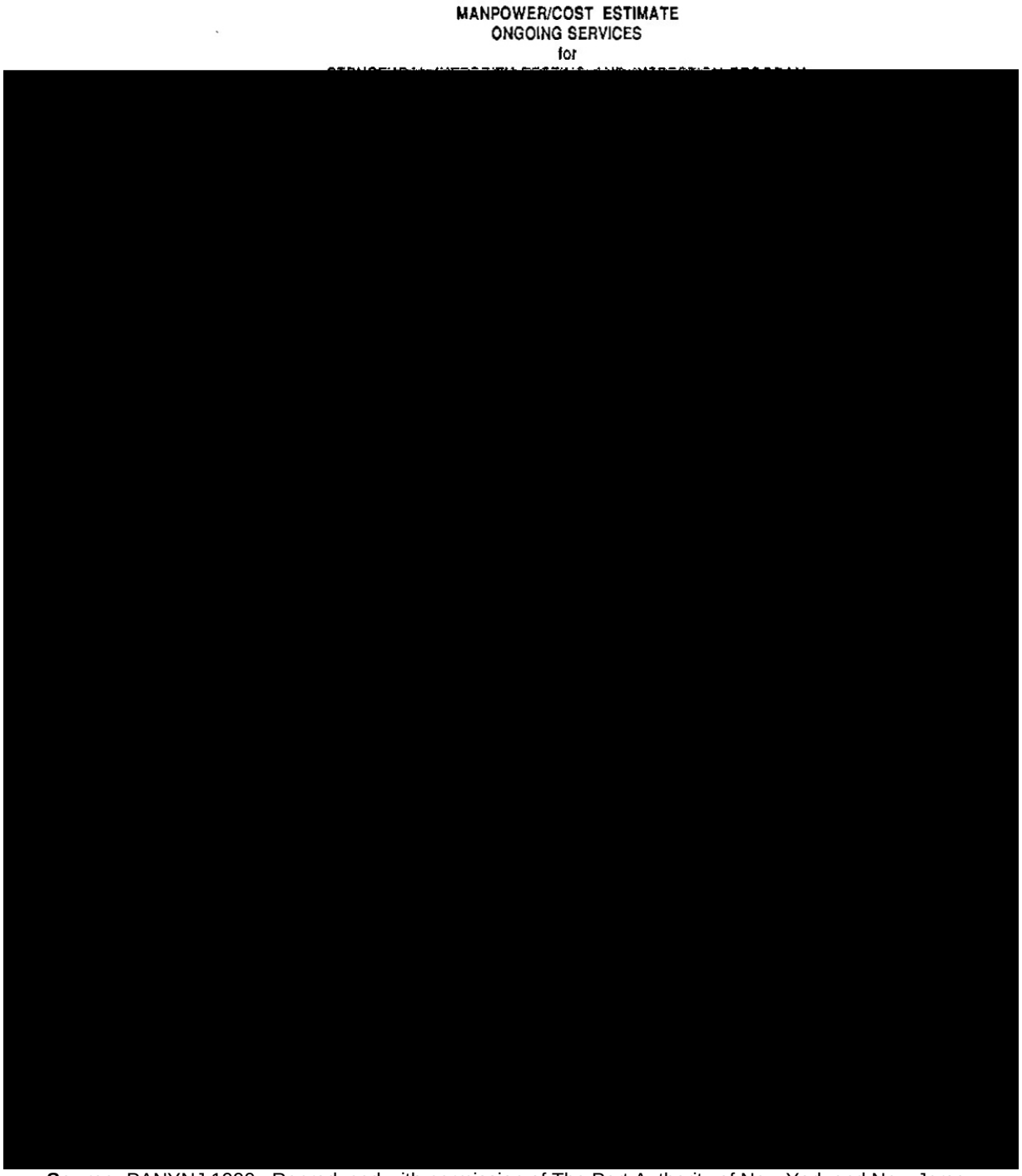
Accessible column surveys were proposed to be performed every two years on an ongoing basis (see Fig. 3–5). As seen in Table 3–14, which contains a summary of the findings from the accessible columns reports, the proposed inspection schedule was not followed exactly. See Appendix G of this report for the exact locations where the columns were inspected over the height of both towers in all of the SII reports.

MANPOWER/COST ESTIMATE
ONE-TIME STARTUP COSTS
for
STRUCTURAL INTEGRITY MONITORING PROGRAM
for
THE WORLD TRADE CENTER

Building/Inspection	MANPOWER ESTIMATE Hours/Inspection By Skill				COST ESTIMATE		
	Partner	Engineer	Technician	Consultant	Labor/Cost Inspection	Estimated Expenses	Total One-Time Cost
One World Trade Center							
1. TV Mast	0	0	0	0	0	0	0
One and Two World Trade Center							
2. Curtainwall & Roof	16	60	40	0	5,960	596	6,556
3. Space Usage Survey	30	120	50	0	10,550	1,055	11,605
4. Accessible Columns	0	0	0	0	0	0	0
5. Bracing below E1, 294	0	0	0	0	0	0	0
6. Hat Truss	0	0	0	0	0	0	0
7. Plaza level box columns	10	20	0	0	1,850	185	2,035
8. MER floor framing	0	0	0	0	0	0	0
9. Slabs, partitions & finishes	10	40	0	0	2,850	285	3,135
10. Floor framing	10	40	0	0	2,850	285	3,135
11. Natural frequency measurements	40	160	20	80	19,000	1,900	20,900
12. Natural frequency of floors	50	300	0	80	26,050	2,605	28,655
13. Damper testing	0	0	0	0	0	0	0
14. Lobby ceilings	0	0	0	0	0	0	0
15. Marble wall panel supports	0	0	0	0	0	0	0
16. Review of maintenance reports	8	20	0	0	1,680	168	1,848
17. Fire Stairs	10	40	10	0	3,250	325	3,575
Sub-Total 1 & 2 WTC	**184**	**800**	**120**	**160**	**$74,040**	**$7,404**	**$81,444**
Four, Five & Six World Trade Center Vista Hotel & Sub-Grade							
18. Curtain walls & roofs	16	50	30	0	5,060	506	5,566
19. Space usage survey	16	60	30	0	5,560	556	6,116
20. Cantilever trusses	10	20	0	0	1,850	185	2,035
21. MER floor framing	0	0	0	0	0	0	0
22. Slabs, partitions & finishes	10	40	0	0	2,850	285	3,135
23. Floor framing	10	40	0	0	2,850	285	3,135
24. Plaster ceilings	20	40	0	0	3,700	370	4,070
25. Marble wall panel supports	0	0	0	0	0	0	0
26. Plaza slabs	16	40	40	0	4,960	496	5,456
27. Accessible columns	16	30	30	0	4,060	406	4,466
[redacted]							

Source: PANYNJ 1990. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–5. Estimated manpower and cost estimates for structural integrity inspections for WTC 1 and WTC 2.



Source: PANYNJ 1990. Reproduced with permission of The Port Authority of New York and New Jersey.

Figure 3–5. Estimated manpower and cost estimates for structural integrity inspections for WTC 1 and WTC 2 (continued).

Table 3–13. Summary of findings from space usage reports.

Date of Report	Floors Inspected	Recommendations[a]			LERA/WTCI Reference Numbers
		Immediate	Priority	Routine	
12/31/95	85–110	None	PANYNJ to distribute load of granite slabs on floor 106 of WTC 1 over larger area.	Re-inspect floors with heavy file storage cabinets.	R2753/67-L
05/20/96	85–110	None	None	PANYNJ to inform tenant of allowable safe loads (safe was found on floor 91 of WTC 1 that could not be confirmed on approved drawings).	4105/66-L
09/20/96	66–84	None	None	PANYNJ to review adequacy of floor framing system on floor 79 of WTC 2 where file storage and lateral file cabinets where found that were not on the approved drawings. PANYNJ to inform tenant to remove file storage blocking aisles on floor 80 of WTC 1.	4010/66-L
07/31/97	44–65	None	None	PANYNJ to inform tenants on floors 47 and 53 of WTC 1 of allowable safe loads (safes were found that could not be confirmed on approved drawings). PANYNJ to inform tenant to remove file storage blocking aisles on floor 61 of WTC 1.	69-L
06/15/98	25–43	None	None	None	4049/66-L
05/31/99	1–24	None	None	PANYNJ to repair spalling concrete floor slab on floor 10 of WTC 2.	4040/66-L

a. Immediate – Action includes possible closure of the area and/or structure affected until remedial actions are implemented. Priority – This action takes precedence over all other scheduled work. This work should not wait for routine repair procedures since waiting may make the damaged area less accessible or allow the damage to quickly worsen to an "immediate" category. Routine – Further investigation and/or remedial work can be undertaken as a part of a scheduled work program or routine facility maintenance. This action also refers to all non-priority items.

Table 3–14. Summary of findings from accessible columns reports.

Date of Report	Recommendations[a]			LERA/WTCI Reference Numbers
	Immediate	Priority	Routine	
01/29/93	None	None	PANYNJ to repair all spalled and missing fireproofing on the columns.	4078/66-L
04/14/95	None	None	PANYNJ to properly clean and repair fireproofing on all exposed steel (columns and connecting beams) at many or all of the floor levels that were inspected. PANYNJ to clean and repair all corroded steel in elevator pits due to water damage.	4079/66-L
05/17/96	None	PANYNJ to test damaged (cause unknown) beam webs in elevator shaft 34B in WTC 2 below floors 9 and 10. PANYNJ to add new web stiffeners to these beams as a minimum.	PANYNJ to repair deteriorated fireproofing on columns and connecting beams throughout all of the shafts inspected in accordance with Appendix E of the SII report. PANYNJ to repair drywall in elevator shaft 95A, floor 100 in WTC 1. PANYNJ to repair fireproofing at base of columns in elevator pits in all of the shafts that were inspected. PANYNJ to reduce cable sway using a cable damping system in all of the shafts that were inspected. PANYNJ to investigate fire rating of damaged shaft wall in elevator pit 61B in WTC 2 at floor 42.	4004/66-L
05/23/97	None	PANYNJ to repair deteriorated fireproofing on column 905 between floors 35–41 in WTC 2 in accordance with Appendix E of the SII report.	PANYNJ to repair deteriorated fireproofing on all of the columns, connecting beams, and elevator pits throughout all of the shafts that were inspected in accordance with Appendix E of the SII report.	4004a/66-L

Table 3–14. Summary of findings from accessible columns reports (continued).

Date of Report	Recommendations[a]			LERA/WTCI Reference Numbers
	Immediate	Priority	Routine	
05/30/98	None	PANYNJ to repair deteriorated fireproofing on columns on floors 2–17 and 29-40 in WTC 1 in accordance with Appendix D of the SII report. PANYNJ to replace fireproofing that is missing over the entire height of floor 48 in elevator shaft 68A in WTC 1. PANYNJ to replace missing fireproofing on column 902 in elevator shaft 9B at floors 10, 18, and 34; on column 803 in elevator shaft 47B at floors 4 and 31; and, on column 805 in elevator shaft 94B at floor 77 in WTC 2.	PANYNJ to repair deteriorated fireproofing on columns and connecting beams throughout all of the shafts that were inspected in accordance with Appendix E of the SII report. PANYNJ to reduce cable sway using a cable damping system in all of the shafts that were inspected. PANYNJ to repair fireproofing at base of columns in elevator pits that were inspected per Appendix D in the SII report.	4050/66-L

a. Immediate – Action includes possible closure of the area and/or structure affected until remedial actions are implemented. Priority – This action takes precedence over all other scheduled work. This work should not wait for routine repair procedures since waiting may make the damaged area less accessible or allow the damage to quickly worsen to an "immediate" category. Routine – Further investigation and/or remedial work can be undertaken as a part of a scheduled work program or routine facility maintenance. This action also refers to all non-priority items.

Plaza Level Box Columns

The purpose of the inspection of the Plaza Level box columns was to assess their overall structural integrity, including the condition of the fireproofing. As can be seen from Fig. 3–5, the proposed inspection interval was four years. One such inspection was performed in April of 1998. The east face of WTC 1 and the north face of WTC 2 were visually inspected between the Concourse Level ceiling and the underside of the Plaza Level slab. The columns between the Concourse floor level and ceiling level were inaccessible due to their enclosures.

A summary of the findings from the Plaza Level box columns report is given in Table 3–15. The report notes that fireproofing was missing from approximately 2–3 percent of the Plaza Level box columns and seated beam connections in WTC 1 and about 1–2 percent in WTC 2.

Table 3–15. Summary of findings from Plaza Level box column report.

Date of Report	Recommendations[a]			LERA/WTCI Reference Numbers
	Immediate	Priority	Routine	
05/08/98	None	None	PANYNJ to clean all exposed steel on Plaza Level columns 236, 242, and 248 in WTC 1 and repair damaged fireproofing on columns and seated beam connections in both towers.	4002/66-L

a. Immediate – Action includes possible closure of the area and/or structure affected until remedial actions are implemented.
Priority – This action takes precedence over all other scheduled work. This work should not wait for routine repair procedures since waiting may make the damaged area less accessible or allow the damage to quickly worsen to an "immediate" category.
Routine – Further investigation and/or remedial work can be undertaken as a part of a scheduled work program or routine facility maintenance. This action also refers to all non-priority items.

Bracing below Elevation 294 ft 0 in.

Below Elevation 294 ft 0 in. (Sublevel 1) in both WTC 1 and WTC 2, diagonal bracing was used in place of deep spandrels between the exterior columns to resist lateral loads from the tower above. The purpose of the inspection of the bracing system in the perimeter walls of the towers was to:

- Assess the overall performance and structural integrity of the bracing (and, in 1991 only, the transfer trusses below elevation 310 ft 0 in. in WTC 2);
- Identify specific locations of structural distress or damage;
- Identify locations of damage to the structural fireproofing systems; and
- Provide recommendations for remedial work for both structural and fireproofing damage.

As can be seen from Fig. 3–5, the proposed inspection interval was two years, which is less than the actual inspection interval shown in Table 3–16. The 1995 SII report notes that the only prior inspection of the bracing was done on October 31, 1991. Also, the 1995 SII report recommended that future inspections should be performed every two years, with particular attention given to corrosion and fireproofing. In both the 1991 and 1995 SII reports, it is noted that the observed thickness of the fireproofing on the bracing members was between 0.25 in. and 1 in.

It is evident from Table 3–16 that the PANYNJ did not complete action on a number of "routine" category recommendations from the 1991 report. Remedial work for these recommendations was to be carried out as part of a scheduled maintenance program. Such recommendations include draining of flooded areas due to water leaks was not fully accomplished, and repairs to the connections between the braces and the columns were not made. Fireproofing was not applied to the transfer truss between columns 242 and 248 at the B1 Level in WTC 2. Also, fireproofing was not repaired on some of the bracing members at Level B6 and at other levels. It appears that all of the damaged concrete masonry unit (CMU) walls acting as fireproofing, which were identified in the 1991 SII report, were repaired; many additional CMU walls were noted for repair in the 1995 SII report.

Table 3–16. Summary of findings from bracing reports.

Date of Report	Recommendations[a]			LERA/WTCI Reference Numbers
	Immediate	Priority	Routine	
10/31/91	None	None	PANYNJ to drain flooded areas due to water leaks in Level B6 of WTC 1 and WTC 2. PANYNJ also to repair any corroded steel and welds at the connections of the bracing members to the columns due to flooding and to reapply fireproofing after painting all steel with a zinc-rich paint. PANYNJ to clean, repair, and reinstall fireproofing on structural members at Level B6 in the Mechanical Equipment Rooms of both towers. PANYNJ to repair CMU walls that serve as fireproofing at various locations in WTC 1 and WTC 2 as noted in the report. PANYNJ to repair all spray fireproofing on the braces in WTC 1 and WTC 2 and the transfer truss in WTC 2 between columns 242 and 248 at the B1 Level.	4096/66-L
03/01/95	None	None	PANYNJ to drain flooded areas due to water leaks in Level B6 of WTC 1 and WTC 2. PANYNJ also to repair any corroded steel and welds at the connections of the bracing members to the columns due to flooding and to reapply fireproofing after painting all steel with a zinc-rich paint. PANYNJ to clean, repair, and reinstall fireproofing on structural members at Level B6 in the Mechanical Equipment Rooms of both towers. PANYNJ to repair CMU walls that serve as fireproofing at various locations in WTC 1 and WTC 2 as noted in the report. PANYNJ to repair all spray fireproofing on the braces in WTC 1 and WTC 2 and the transfer truss in WTC 2 between columns 242 and 248 at the B1 Level.	4066/66-L

a. Immediate – Action includes possible closure of the area and/or structure affected until remedial actions are implemented. Priority – This action takes precedence over all other scheduled work. This work should not wait for routine repair procedures since waiting may make the damaged area less accessible or allow the damage to quickly worsen to an "immediate" category. Routine – Further investigation and/or remedial work can be undertaken as a part of a scheduled work program or routine facility maintenance. This action also refers to all non-priority items.

The 1995 SII report notes that large areas of fireproofing on the structural steel members were removed or damaged due to the February 1993 bombing of WTC 1. During reconstruction of this area, fireproofing

was reapplied to the structural steel members. LERA was asked by the PANYNJ to inspect this fireproofing as part of the 1995 structural integrity inspection of the bracing members, and LERA "…found no place where these refireproofing efforts were incomplete."

Hat Trusses

The purpose of the inspection of the hat trusses between floor 107 and the roof was to:

- Assess the overall performance and structural integrity of the hat trusses;
- Identify specific locations of structural distress or damage;
- Identify locations of damage to the structural fireproofing systems; and
- Provide recommendations for remedial work for both structural and fireproofing damage.

During the inspections, access to some of the bracing members was either not possible or not practical. A summary of the findings from the hat truss reports is contained in Table 3–17. Note that the actual inspection interval is greater than the proposed interval of two years (see Fig. 3–5). Fireproofing that was intentionally removed during the Facility Condition Survey inspections performed by the PANYNJ in 1990 and 1991 for WTC1 and WTC 2, respectively, was found not to be repaired.

Table 3–17. Summary of findings from hat truss reports.

Date of Report	Recommendations[a]			LERA/WTCI Reference Numbers
	Immediate	Priority	Routine	
10/21/92	None	None	PANYNJ to repair exposed area of steel with either spray-on or troweled-on fireproofing. PANYNJ to repair existing cracks in the topping slabs on floor 108 of both towers. PANYNJ to apply fireproofing and reconstruct column enclosures on columns 903 and 904 on floor 110 in WTC 2. PANYNJ to replace damaged portions of gypsum wallboard that serves as fireproofing around columns 707 and 708 on floor 108 of WTC 1.	R2579/67-L
02/21/95	None	None	PANYNJ to repair exposed area of steel with either spray-on or troweled-on fireproofing. PANYNJ to repair existing cracks in the topping slabs on floor 108 of both towers. PANYNJ to replace or repair damaged portions of gypsum wallboard that serves as fireproofing around columns identified in report.	4014/66-L

a. Immediate – Action includes possible closure of the area and/or structure affected until remedial actions are implemented.
Priority – This action takes precedence over all other scheduled work. This work should not wait for routine repair procedures since waiting may make the damaged area less accessible or allow the damage to quickly worsen to an "immediate" category.
Routine – Further investigation and/or remedial work can be undertaken as a part of a scheduled work program or routine facility maintenance. This action also refers to all non-priority items.

Floor Framing over Mechanical Areas

The purpose of the inspection program for the floor framing supporting the MER was to:

- Assess the overall performance and structural integrity of the steel and concrete framing;
- Identify locations of defects and signs of distress in slabs, partitions, column enclosures, and concrete supports for mechanical equipment;
- Identify locations of damaged fireproofing;
- Compare the findings with those of previous inspection; and
- Provide recommendations and procedures for remedial work for both structural and fireproofing damages and/or inadequacies.

Table 3–18 contains a summary of the reports for the floor framing over mechanical areas and shows that the proposed inspection interval of 4 years (see Fig. 3–5) was followed or exceeded.

The reports indicate that damaged CMU walls in Level B6 of WTC 1 and WTC 2 still existed in 1996. Such damages were found initially during the structural integrity inspection of the diagonal bracing in 1991 and again in 1995 (see Table 3–16). Similarly, damaged fireproofing on the perimeter diagonal bracing members at this level in WTC 1 and WTC 2, which was initially found in 1991 and 1995, still existed in 1999. The 1999 SII floor framing over mechanical areas report lists the following items for which repairs were not completed from previous inspections: (1) cracks in slabs on all MER floors in both towers; (2) spalled concrete on Level B6 in WTC 1; (3) fireproofing hanging from the underside of the metal deck on floor 107 in WTC 2; (4) Damaged fireproofing to the beam on floor 107 in WTC 1; (5) A 3 ft by 3 ft hole in the gypsum wallboard on floor 41 in WTC 1; and (6) damaged CMU walls at Level B6 in both towers.

Floor Framing over Tenant Areas

The purpose of the inspection program for the floor framing supporting the tenant areas was to:

- Assess the overall performance and integrity of the steel and concrete framing;
- Identify locations and signs of distress in slabs, partitions, column enclosures, and steel framing;
- Identify locations of inadequate fireproofing; and
- Provide recommendations and procedures for remedial work for both structural and fireproofing damage and/or inadequacies.

Table 3–19 contains a summary of the reports for the floor framing over tenant areas. The proposed inspection interval of 2 years (see Fig. 3–5) was followed, with one deviation.

Table 3–18. Summary of findings from reports on floor framing over mechanical areas.

Date of Report	Recommendations[a]			LERA/WTCI Reference Numbers
	Immediate	Priority	Routine	
11/03/92	None	None	PANYNJ to replace missing fireproofing.	R2582/67-L
04/12/96	None	PANYNJ to re-apply fireproofing to deck on floor 108 in WTC 2. PANYNJ to patch fireproofing on beam supporting floor 107 in WTC 1 in accordance with procedure in Appendix D of the SII report.	PANYNJ to repair cracks throughout all MER floors. PANYNJ to repair spalled concrete at 3 locations at level B6 in WTC 1 using methods given in Appendix C of the SII report. PANYNJ to repair damaged fireproofing to framing supporting floor 74 in WTC 1 in accordance with procedure in Appendix D of the SII report. PANYNJ to replace damaged drywall on floor 42 in WTC 1. PANYNJ to patch fireproofing on perimeter bracing at locations indicated in the report on level B6 in WTC 1 and WTC 2 in accordance with procedure in Appendix D of the SII report. PANYNJ to replace damaged CMU walls in level B6 in WTC 1 and WTC 2 in accordance with procedure in Appendix D of the SII report. PANYNJ to patch damaged fireproofing on hat trusses at floor 108 in WTC 2 in accordance with procedure in Appendix D of the SII report.	R2776/67-L

Table 3–18. Summary of findings from reports on floor framing over mechanical areas (continued).

Date of Report	Recommendations[a]			LERA/WTCI Reference Numbers
	Immediate	Priority	Routine	
05/99	None	PANYNJ to stop leak in overhead pipe on floor 75 in WTC 1. Condition of inadequate fireproofing reported in 1996 study could not be verified since a drop ceiling was subsequently installed in the area in question.	PANYNJ to repair spalled concrete at Level B6 in both towers in accordance with procedure in Appendix C of the SII report. PANYNJ to patch cracking (new and from previous repair) in slabs on all MERs in both towers in accordance with procedure in Appendix C of the SII report. PANYNJ to remove debris on perimeter areaways on all MERs in both towers. PANYNJ to patch spalled concrete in perimeter areaways on floor 108 in WTC 1 towers in accordance with procedure in Appendix C of the SII report. PANYNJ to repair spalled concrete at parapet wall on floor 108 in WTC 1 towers in accordance with procedure in Appendix C of the SII report. PANYNJ to repair cracked column pedestal on floor 41 in WTC 1 towers in accordance with procedure in Appendix C of the SII report. PANYNJ to verify if newly constructed cantilevered deck on all MERs in both towers was engineered. PANYNJ to verify if existing floor framing was evaluated for additional loads due to new construction of enclosed mechanical rooms on all MERs in both towers. PANYNJ to patch fireproofing to perimeter bracing at Level B6 in WTC 2 towers in accordance with procedure in Appendix D of the SII report. PANYNJ to replace damaged CMU walls in level B6 in WTC 1 and WTC 2 in accordance with procedure in Appendix D of the SII report. PANYNJ to patch damaged fireproofing on hat trusses at floor 108 in WTC 1 in accordance with procedure in Appendix D of the SII report.	4041/66-L

a. Immediate – Action includes possible closure of the area and/or structure affected until remedial actions are implemented.
Priority – This action takes precedence over all other scheduled work. This work should not wait for routine repair procedures since waiting may make the damaged area less accessible or allow the damage to quickly worsen to an "immediate" category.
Routine – Further investigation and/or remedial work can be undertaken as a part of a scheduled work program or routine facility maintenance. This action also refers to all non-priority items.

Natural Frequency Measurements

The purpose of the inspection program was to determine the natural frequencies of oscillation of WTC 1 due to wind excitation. Only WTC 1 was instrumented with accelerometers which were located at six locations on floor 108. The accelerometers measured the accelerations in both principal directions of the building with respect to time due to wind. Data were recorded on tape whenever the acceleration of floor 108 exceeded approximately 0.003g. A spectral analysis of the recorded accelerations was made; peaks on this spectrum corresponded to the natural frequencies of various modes of vibration of the towers. The computed natural frequencies were to be compared with corresponding values that had been determined in the past. A significant change in the tower's dynamic behavior was considered to be a possible indication of diminishing structural integrity. According to the reports, characteristics that may be observed or inferred by review of the recorded acceleration data were:

- Integrity of the lateral-load-resisting system;
- Condition of the viscoelastic damping system;
- Condition of other sources of inherent structural damping; and
- Other changes that affect fundamental characteristics of the lateral-load-resisting system.

Three reports were prepared by LERA. Dates and references for the reports are contained in Table 3–20.

The 1993 and 1995 reports compare the then available measured first mode natural frequencies of WTC 1 to those determined by the structural engineer in 1966, which were 0.084 Hz in the north-south direction and 0.096 in the east-west direction (WSHJ 1966). A summary of the measured first mode natural frequencies from the 1995 report, which contained the most current data, is given in Table 3–21.

Table 3–19. Summary of findings from reports on floor framing over tenant areas.

Date of Report	Recommendations[a]			LERA/WTCI Reference Numbers
	Immediate	Priority	Routine	
11/03/92	None	None	PANYNJ to replace fireproofing on steel members and repair or replace damaged CMU walls on floors noted in report. PANYNJ to perform survey of core holes, especially in prohibited areas.	R2582/67-L
04/01/95	None	None	PANYNJ to replace fireproofing on steel members and repair or replace damaged CMU walls on floors noted in report. PANYNJ to perform survey of core holes, especially in prohibited areas. PANYNJ to patch spalled concrete at locations noted in report.	R2582/67-L
12/10/97	None	None	PANYNJ to replace fireproofing on steel members and repair or replace damaged CMU walls on floors noted in report. PANYNJ to perform survey of core holes, especially in prohibited areas. PANYNJ to patch spalled concrete with exposed reinforcement at locations noted in report. PANYNJ to fill cores/holes in slab at locations noted in report.	4012/66-L
11/29/99	None	PANYNJ to restore fireproofing on truss at floor 89 of WTC 2. PANYNJ to repair spalled concrete on floor 89 of WTC 2 in accordance with repair procedures given in Appendix D of the SII report. PANYNJ to repair spalled concrete on floors 33 and 91 of WTC 1 in accordance with repair procedures given in Appendix D of the SII report. PANYNJ to fill in cores with damaged reinforcement on floor 91 of WTC 1.	None	4023/66-L

a. Immediate – Action includes possible closure of the area and/or structure affected until remedial actions are implemented.
Priority – This action takes precedence over all other scheduled work. This work should not wait for routine repair procedures since waiting may make the damaged area less accessible or allow the damage to quickly worsen to an "immediate" category.
Routine – Further investigation and/or remedial work can be undertaken as a part of a scheduled work program or routine facility maintenance. This action also refers to all non-priority items.

Table 3–20. Reports on natural frequency measurements.

Date of Report	LERA/WTCI Reference Numbers
02/01/93	4073/66-L
04/12/95	4056/66-L
07/11/00	4094/66-L

Table 3–21. Measured first mode natural frequencies for WTC 1.

Event Date	Wind Speed (mph) and Direction	Measured Frequency (Hz)	
		N–S	E–W
10/11/78	11.5, E/SE	0.098	0.105
01/24/79	33.0, E/SE	0.089	0.093
03/21/80	41.0, E/SE	0.085	0.092
12/11/92	49.0	0.087	0.092
02/02/93	20.0, NW	0.085	0.095
03/13/93	32.0, NW	0.085	0.094
03/10/94	14.0, W	0.094	0.094
12/25/94	37.0, W	0.081	0.091

Both the 1993 and 1995 reports conclude that the measured and computed first mode frequencies compare well, especially for the greater wind speeds. The 1995 report also concluded that the February 1993 bombing had no permanent measurable effect on the dynamic response of WTC 1. Both reports recommended that WTC 2 be instrumented similarly to WTC 1.

The 2000 SII report pointed out that PANYNJ had not been able to analyze the data acquired from the instrumentation of WTC 1 since 1998 because the PANYNJ laboratory that contained playback and analytical equipment necessary to assess the recorded data was dismantled in the fall of 1998. The report recommended that the capability to assess and analyze the accelerometer data be re-established promptly. The report further recommended that WTC 1 be additionally instrumented at a mid-level floor, and that WTC 2 be instrumented at its top floor and at a mid-level floor. The final recommendation from the 2000 report was that the responsibility for data collection and processing be transferred to a university or a similar academic research institution. Note that the proposed inspection interval of one year (see Fig. 3–5) was not followed.

Natural Frequencies of Floors

The purpose of this inspection program was to determine the natural frequencies of the floor systems in WTC 1 and WTC 2 and to compare them with corresponding values that were determined in the past. A significant change in the vibration characteristics of the floor system was considered to be a possible indication of diminishing structural integrity. The proposed inspection schedule (see Fig. 3–5) included measurement of the natural frequencies of floors every year on an ongoing basis, the proposed inspection schedule was not followed.

For purposes of determining the natural frequencies of the floor construction, a typical tower floor was divided into three zones, which corresponded to the type of floor truss that was utilized in that zone: short-span zone, long-span zone, and two-way zone.

Vibration characteristics of the floor systems were studied both analytically and experimentally. In 1971, Teledyne Geotronics of Long Beach, CA made field measurements of vertical vibration on floors 13, 27, and 32 of WTC 1 using seismometers. These field measurements were obtained under the direction of Skilling, Helle, Christiansen, Robertson (SHCR). SHCR also made analytical estimates of the natural frequencies of the floor systems at that time (SHCR 1971). They determined that the natural frequencies of the long-span and short-span trusses, considering viscoelastic damping, were 4.6 Hz and 7.9 Hz, respectively. A summary of the natural frequency test results for WTC 1 is contained in Table 3–22.

Table 3–22. Summary of natural frequency test results for floors of WTC 1, March 1971.

Floor Zone	Frequency Range (Hz)
Long-span	4.6 to 5.1
Two-way	4.6 to 5.7 7.0 to 7.9
Short-span	7.9

In March of 1995, Cerami and Associates, of New York, NY, made field measurements on floors 17, 22, 26, 38, and 88 of WTC 1 and floors 23, 24, an 58 of WTC 2 using the following equipment: piezo-electric accelerometer, vibration meter, peak band pass filter, and strip chart recorder (Cerami 1996). The floors were subjected to a standard heel-drop test or by jumping in place. All field work was performed under the direction of LERA. A summary of the test results for WTC 1 and WTC 2 is given in Table 3–23.

The SII report produced by LERA in April of 1995 summarized the analytical and experimental results to date (LERA 1995). Based on the available data, the report concluded that there had been no significant measurable change in the performance of the typical floor systems in WTC 1 and WTC 2.

Table 3–23. Summary of natural frequency test results for floors of WTC 1 and WTC 2, March 1995.

Floor Zone	Frequency Range (Hz)
WTC 1	
Long-span	4.5 to 5.3
Two-way	4.6 to 4.9 6.6 to 7.6
Short-span	7.8 to 8.8
WTC 2	
Long-span	4.8 to 5.6
Two-way	4.9 to 5.4 7.5 to 7.8
Short-span	7.9 to 8.0

Viscoelastic Damping Units

The report by LERA in May of 1996 provided a summary of the integrity of the viscoelastic damping units in WTC 1 and WTC 2 (LERA 1996). The integrity assessment represented a continuation of the on-going monitoring program for the damping units. A historical review related to the damping units is given in Appendix A of the SII report, which can be found in Appendix G of this report.

The report was based on information in the following studies:

- Laboratory testing of four in-service damper units taken from the towers (two per tower) performed by the Minnesota Mining and Manufacturing Company (Appendix A in LERA report)
- Analysis of measured dynamic response of WTC 1 to actual wind events conducted by the University of Western Ontario (Appendix B in LERA report)
- Investigation of Aging Effects – World Trade Center Dampers, Robert Fowler & Associates P.C., October 1, 1984 (Appendix C in LERA report).

Details of each study can be found in the applicable appendices cited above.

To assess the integrity of the damping units, the following characteristics were examined:

- Average loss tangent
- The mechanical behavior of the viscoelastic material used in the damping units was modeled by a linear viscoelastic law, where the stress-strain characteristics of the material are dependent on time and on the temperature of the material (WSHJ 1967b). When subjected to a uniform shear strain, which is a sinusoidal function of time, the stress-strain diagram of the viscoelastic material is elliptical. The area within the ellipse represents the work done per cycle of strain, which is dissipated as heat.
- The loss tangent, which is the ratio of the loss shear modulus of the viscoelastic material to the storage (elastic) shear modulus of the viscoelastic material, is directly proportional to the energy that can be dissipated per cycle of vibration in the damping unit. Thus, to achieve maximum damping for a given material, the loss tangent should be made as great as possible. Over time, it was possible for the loss tangent to decrease.
- Average stiffness
- The stiffness of a damping unit was defined as the force it would take to produce a deformation of 0.020 in. in the viscoelastic material. The loss tangent is also directly proportional to the stiffness. Over time, it was possible for the stiffness to decrease.
- Mean damping ratios of WTC 1
- Damping of building sway motion in WTC 1 was achieved primarily from two sources: (1) intrinsic damping by the building structure and (2) damping from the viscoelastic

The program included inspection or monitoring of the following items, among other things, in WTC 1 and WTC 2:

- TV mast (WTC 1 only)
- Roof water tightness and curtain wall
- Space usage
- Accessible columns, including exterior box columns at locations of spandrel intersections and "tree" junctions below floor 7 and above floor 1 (Plaza Level)
- Bracing at exterior column line below elevation 294 ft 0 in., and in WTC 2 only, the transfer trusses below floor 1 under exterior columns
- Hat truss between floor 107 and the roof
- Floor framing over mechanical spaces
- Concrete slabs, partitions, and finishes
- Steel framing, slabs, and the like where exposed for general repairs or tenant remodeling
- Measurement of natural frequency of tower and TV mast
- Floor natural frequency
- Damping units
- Plaster ceilings in main lobby
- Marble wall panel supports
- Review of maintenance reports
- Fire stairs

3.3.2 Findings from Inspection Programs

In general, the structural integrity inspections found that the structural systems of WTC 1, 2, and 7 were in good condition. The inspection consultants made numerous routine and some priority recommendations for repairs to the PANYNJ, as outlined in the above sections of this report. As noted above, it is evident that the PANYNJ did not complete action on some of these recommendations. Also, according to the PANYNJ, all of the construction records on repairs following the inspections were lost on September 11, 2001. Thus, it cannot be determined whether all of the recommended repairs were performed.

Table 3–25 gives a chronological summary of the locations where fireproofing was reported to be missing in WTC 1, 2, and 7, based on the findings from the applicable inspection programs.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7.

Date	Inspection Program	Building(s)	Location/Description
April 1990	Port Authority Facility Condition Survey Program – WTC 2	WTC 2	• Several small regions and a few large areas of fireproofing was found missing in elevator shafts 1–4, 8–13, 16, 18–21, 23, 24, 31, 35, 40, 42, 47, 52, and 58 (see Table B1 in the inspection report for floor levels that were inspected in these shafts). • 8 in. wide by 1 ft-6 in. long area of fireproofing was found missing on top flange of beam between shafts 30 and 31 on floor 22. • 100% of fireproofing was found missing on south face of Column 908 between floors 27 and 29 in Shaft 1. • On floors 1–6, fireproofing was found missing on the floor framing at various locations. • Hairline cracks were found in the concrete beam encasement (fireproofing) at scattered locations on all four mechanical equipment room levels.
October 1991	Port Authority Facility Condition Survey Program – WTC 1	WTC 1	• Missing fireproofing was found at various locations on the exterior wall columns and spandrel plates (exact locations were not given in the report). • Several small areas and a few large areas of fireproofing was found missing from steel beams and columns in elevator shafts 2, 11, 12, 15, 26, 35, 43, 52, 62, 67, 77, 80, and 90 (see Table B-1 in the inspection report for floor levels that were inspected in these shafts). • Fireproofing was found missing on a connection between a core column and a floor beam on floor 30 (exact location was not given in the report). • Small areas of fireproofing were found missing from the floor framing at scattered locations on floors 9 through 107 (exact locations were not given in the report). • Fireproofing was found missing on many damping units on floors 9 through 107 (exact locations were not given in the report). • On 43rd floor, fireproofing was found missing on an area of 25 ft by 60 ft on the underside of metal deck between column lines 351 to 359 and 411 to 428. Fireproofing was also found missing on the floor beams in this area. • On the 77th floor, fireproofing was found missing on an approximately 100 sq ft area of metal deck.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
October 1991	SII Report on Bracing Below Elevation 294 ft 0 in.	WTC 1 and WTC 2	• Between columns 148 and 151 of WTC 2 at the underside of Level B1, CMU wall acting as fireproofing was removed to allow pipes to pass through. • Between columns 154 and 157 of WTC 2 at Level B2, CMU wall acting as fireproofing was removed for a doorway opening. • Between columns 133 and 136 of WTC 2 at the underside of Level B1, CMU wall acting as fireproofing was removed for a doorway opening. • Between columns 154 and 157 of WTC 2 between LevelsB5 and B6, CMU wall acting as fireproofing was removed for a doorway opening. • Some degree of damage was found on all of the spray-on fireproofing on the diagonal bracing members between Levels B4 and B5 in both WTC 1 and WTC 2. • Fireproofing (CMU and spray-on) was found missing at the intersection of diagonal bracing members G120B, G121B, and column 139 on Level B6 in WTC 2. • CMU fireproofing was found missing at the intersection of diagonal bracing member G119B and column 130 on Level B6 in WTC 2. • Fireproofing (CMU and spray-on) was found missing at the intersection of diagonal bracing member G418B and column 421 on Level B5 in WTC 2. • At the base of column 357 on Level B6 in WTC 1, CMU fireproofing was found missing. • Damaged fireproofing due to flooding was found at the intersection of diagonal bracing member G320A and column 324 on Level B6 in WTC 1. • Fireproofing was found missing on the transfer truss members located between column 242 and 248 on Level B1 in WTC 2.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
October 1992	SII Report on Hat Trusses	WTC 1 and WTC 2	• Fireproofing that was removed during the Facility Condition Survey inspections performed in 1990 and 1991 was not repaired. • Fireproofing was found missing on two columns of the elevator machine room on floor 110 of WTC 2. • Considerable damage was found to gypsum wallboard acting as fireproofing between column lines 806 and 807 on floor 107 in WTC 2. • Gypsum wallboard acting as fireproofing was found missing around columns 903 and 904 on floor 110 in WTC 2. • Damaged gypsum wallboard acting as fireproofing was found around columns 707 and 708 on floor 108 in WTC 1. • Fireproofing was found missing or damaged on the steel members: (a) between columns 804 and 905 on floor 108 in WTC 1; (b) between columns 701 and 801 on floor 108 in WTC 1; (c) between columns 707 and 708 on floor 110 in WTC 2; (d) between columns 903 and 904 on floor 110 in WTC 2; (e) between columns 702 and 703 on floor 108 in WTC 1; (f) between columns 802 and 803 on floor 109 in WTC 1; (g) between columns 704 and 804A on floor 110 of WTC 1; (h) between columns 807 and 908 on floor 108 of WTC 1; (i) between columns 608 and 708 on floor108 of WTC 1; (j) between columns 1004 and 1005 on floor 108 of WTC 1; (k) between columns 603 and 606 on floor 107 of WTC 2; (l) between columns 331 and 1004 on floor 110 of WTC 2; (m) between columns 605 and 705 on floor 108 of WTC 1; (n) between columns 802 and 803 on floor 109 of WTC 1; and, (o) between columns 704 and 804A on floor 110 of WTC 1. • Extensive gypsum wallboard damage was found between columns 904 and 1004 on floor 110 in WTC 1. Other gypsum wallboard damage was found at scattered locations on floors 108-110 in WTC 1 and WTC 2.
November 1992	SII Report on Floor Framing Over Tenant/Mechanical Areas	WTC 1 and WTC 2	• Fireproofing was found missing on some steel members in WTC 2 (exact locations were not specified in the report).

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
November 1992	SII Report on Floor Framing Over Tenant/Mechanical Areas	WTC 1 and WTC 2	• CMU fireproofing was found missing on Levels B2 and B4 of WTC 2 next to the central corridor. • Fireproofing was found not be reapplied after asbestos removal on floors 9, 10, and 12 (see Appendix A of SII report for exact locations). • Fireproofing was found missing on some beams in the core area on floors 15 and 48 in WTC 2. Fireproofing was also found missing on the undersides of metal deck and top chords of floor trusses (exact locations were not specified in the report).
January 1993	SII Report on Accessible Columns	WTC 1 and WTC 2	• Spalling and missing fireproofing was found on the steel members in the express elevator shafts in both towers (members and locations were not specified in the report). • Large areas of fireproofing were found missing on the faces of columns 606 and 607 in WTC 1. • Fireproofing was found missing at the splice location of column 701 in WTC 1. • Isolated areas of spalled fireproofing were found on members in the local elevator shafts (members and locations were not specified in the report).
February 1995	SII Report on Hat Trusses	WTC 1 and WTC 2	• Fireproofing that was removed during the Facility Condition Survey inspections performed in 1990 and 1991 was not repaired. • Damaged gypsum wallboard was found at column 704 on floor 109 in WTC 1. • Damaged gypsum wallboard was found between columns 904 and 1004 on floor 110 of WTC 1. • Fireproofing was found missing at the following connections: (a) column 904 on floor 108 of WTC 2; (b) between columns 804 and 904 on floor 108 of WTC 2; and (c) Between columns 604 and 704 on floor 108 of WTC 2.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
February 1995 (continued)	SII Report on Hat Trusses	WTC 1 and WTC 2	• Fireproofing was found missing or damaged on the steel members: (a) between columns 503 and 504 on floor 109 in WTC 1; (b) between columns 702 and 703 on floor 109 in WTC 1; (c) between columns 705 and 706 on floor 110 in WTC 1; (d) between columns 707 and 709 on floor 108 in WTC 1; (e) between columns 702 and 703 on floor 108 in WTC 1; (f) between columns 801 and 802 on floor 108 in WTC 1; (g) between columns 802 and 803 on floor 109 in WTC 1; (h) between columns 803 and 805 on floor 110 in WTC 1; (i) between columns 701 and 801 on floor 108 of WTC 1; (j) between columns 329-1005, 332-1004, and 903-1003 on floor 110 in WTC 1; (k) between columns 804 and 904 on floor 108 in WTC 1; (l) between columns 504-604, and 704-804 on floor 109 in WTC 1; (m) between columns 704 and 804A on floor 110 in WTC 1; (n) between columns 604-704 and 604-705 on floor 109 in WTC 1; (o) between columns 805 and 905 on floor 109 in WTC 1; (p) between columns 608-708, 305-310, 234-238, and 149-508 on floor 108 in WTC 1; (q) between columns 504 and 506 on floor 109 in WTC 2; (r) between columns 603 and 606 on floor 107 in WTC 2; (s) between columns 706 and 707 on floors 108 and 110 in WTC 2; (t) between columns 802-803 and 805-806 on floor 108 in WTC 2; (u) between columns 1004 and 1005 on floor 110 in WTC 2; (v) between columns 1005 and 1006 on floor 108 in WTC 2; (w) between columns 331-1104, 804-904, and 904-1004 on floor 110 in WTC 2; and (x) between columns 903 and 904 on floor 110 of WTC 2.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
March 1995	SII Report on Bracing Below Elevation 294 ft 0 in.	WTC 1 and WTC 2	• Fireproofing (CMU and spray-on) was found missing or damaged on the steel members in WTC 1: (a) between columns 101-103, 121-124, 131-136, 133-139, 148-151, 224-227, 236-239, 245-248, 248-251, 257-259, and 401-403 on Levels B5-B6; (b) between columns 121-124, 127-130, 148-151, 142-145, 139-142, 136-139, 145-151, 151-154, and 251-254 on Levels B2-B3; (c) between columns 254-257, 303-306, 306-309, and 445-448 on Levels B4-B5; (d) between columns 251-254, 348-351, 401-406, 406-409, and 434-454 on Levels B1-B2; and, (e) between columns 454-457 on Levels B3-B4. • CMU fireproofing was found removed at column 409 between Levels B5 and B6 in WTC 1. • CMU fireproofing was removed between columns 433 and 436 between Levels B4 and B6 in WTC 1. • Fireproofing was found missing at column 421 between Levels B4 and B5 and at column 427 between Levels B5 and B6 in WTC 1. • Fireproofing (CMU and spray-on) was found missing or damaged on the steel members in WTC 2: (a) between columns 115-118, 139-142, 142-145, 145-148, and 212-218 on Levels B5-B6; (b) between columns 218-221, 330-333, and 342-345 on Levels B4-B5; (c) between columns 227-230 on Levels B3-B4; (d) between columns 133-136, 218-221, 227-230, 436-439, and 439-442, and at column 101 on Levels B1-B2; (e) between columns 242-248 between level B1 and floor 1; (f) between columns 139-148 and 327-330 on Levels B2-B3; (g) between columns 412-415, 415-421, and 421-424 on Levels B4-B6; and, (h) between columns 321-324, 439-442, 448-451, and 451-454 on Levels B4-B5. • CMU fireproofing was removed at column 252 between Level B1 and floor 1 in WTC 2. • CMU fireproofing was removed between columns 418 and 421 and between columns 433 and 436 between Levels B3 and B4 in WTC 2. • CMU fireproofing was removed between columns 454 and 457 between Levels B2 and B3 in WTC 2. • CMU fireproofing was removed between columns 412 and 415 and between column 115 and 118 between Levels B1 and B2 in WTC 2. • CMU fireproofing was removed between columns 154 and 157 between Levels B5 and B6 in WTC 2.
April 1995	SII Report on Framing Over Tenant Areas	WTC 1 and WTC 2	• Fireproofing was found not be reapplied after asbestos removal on floors 17 and 22. • Fireproofing was found missing on floor members at multiple locations in WTC 1 and WTC 2. • Large areas of fireproofing were found missing on the underside of the floor trusses on floor 38 in WTC 1.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
April 1995	SII Report on Accessible Columns	WTC 1 and WTC 2	• Large areas of fireproofing were found missing in service elevators 49A, 49 B, 50A, and 50 B in both towers. • Fireproofing was found missing or damaged on the following columns in WTC 1: (a) column 901 between floors 2-44; (b) column 907 at Level B2 and floors 9, 16-20, 28-31, 34, and 36-38; (c) column 906 at Level B2; (d) column 903 at floors 31, 33, 34, 38, and 39; (e) column 902 at Level B2 and floors 39, 41, and 43; (f) column 601 between floors 2-78; (g) column 605 between floors 3-5; (h) column 606 at floors 8, 11, 19, 25-30, and 43-45; (i) column 607 between floors 2-78; (j) column 608 between floors 2-78; (k) column 704 between Level B1 and floor 78; (l) column 603and 606 at Level B2; (m) column 704 at Levels B1-B3; and, (n) columns 802 and 905 at Level B3. • Fireproofing was found missing or damaged on the following columns in WTC 2: (a) column 908 on floors 27-31 and 33-36; (b) column 907 at floor 21; (c) column 902 at floors 7, 20, 22, 25, 34-36, 39, and 40; (d) column 901 at floors 15 and 31; (e) column 601 at floors 25 and 35-37; (f) column 602 at floors 7, 10, 12, 14,15, 27, 42, 48, 63, 66, and 75; (g) column 603 at floors 3 and 25; (h) columns 605 and 606 at Level B2; (i) column 607 at floors 29, 30, 47, 57, 59, 64, and 74; (j) column 608 at floors 41, 45, and 80; (k) column 703 at Level B6 and at floors 5, 17, and 48; (l) column 704 at Level B6 and at floors 48 and 74; and, (m) column 903 at Level B2.
April 1996	SII Report on Framing Over Mechanical Areas	WTC 1 and WTC 2	• Fireproofing was found tearing away from the underside of the metal deck on F08 in WTC 2. • Damaged fireproofing was found on a beam in the southwest corner of the core on floor 107 in WTC 1. • Fireproofing was found missing or damaged at many locations on the floor members supporting floor 75 in WTC 1. • A 3 ft by 3 ft hole was found in the gypsum wallboard in the core area on floor 41 in WTC 1. • Damaged CMU fireproofing for the perimeter diagonal bracing at Level B6 was found at 5 locations in WTC 1 and 3 locations in WTC 2. • Damaged CMU fireproofing was found on 2 columns in WTC 1 and WTC 2 columns in WTC 2 at Level B6. • Fireproofing was found missing at 3 locations in the hat truss on floor 108 in WTC 2.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
May 1996	SII Report on Accessible Columns	WTC 1 and WTC 2	• Fireproofing was found missing at the column bases that were inspected in the elevator pits in both towers. • Fireproofing was found missing or damaged on columns in the following elevator shafts of WTC 1: (a) Shaft 6A, floor 77, column 904; (b) Shaft 17A, floor 1, column 604; (c) Shaft 34A, floor 15, column 706; (d) Shaft 35A, floors 6-7, column 805; (e) Shafts 69A and 70A, throughout entire shaft, columns 802 and 702; (f) Shaft 88A, floor 91, column 802; and (g) Shaft 95A, floors 98-100, column 706. • Fireproofing was found missing or damaged on columns in the following elevator shafts of WTC 2: (a) Shaft 18B, floor 3, column 605; (b) Shaft 19B, floors 2, 5, 46, 55, and 73, column 606; (c) Shaft 20B, floors 22, 47, 49, 57, and 64, column 606; (d) Shaft 21B, floor 21, column 607; (e) Shafts 34B and 35 B, throughout entire shafts, columns 706 and 805; (f) Shaft 34B, floor 23, column 702; (g) Shaft 43B, floor 6, column 702; (h) Shaft 62B, floor 57, column 805; (i) Shaft 70B, floors 69 and 72, column 702; (j) Shaft 88B, throughout entire shaft, column 802; and, (k) Shaft 96B, floor 101, column 706.
May 1996 (continued)	SII Report on Accessible Columns	WTC 1 and WTC 2	• Fireproofing was found missing or damaged on connecting steel beams to columns in the following elevator shafts of WTC 1: (a) Shaft 34A, floors 22-23, column 706; (b) Shaft 35A, floors 11 and 17, column 805; (c) Shafts 42A and 43A, throughout entire shaft, columns 702 and 802; (d) Shafts 61A and 62A, throughout entire shaft, columns 706 and 805; (e) Shafts 69A and 70A, throughout entire shaft, columns 702 and 802; (f) Shafts 78A and 79A, floor 76, column 707; (g) Shaft 89A, Levels B1-B3, column 702; and, (h) Shafts 96A and 97A, throughout entire shafts, columns 707 and 806. • Fireproofing was found missing or damaged on connecting steel beams to columns in the following elevator shafts of WTC 2: (a) Shaft 7B, throughout entire shaft, column 903; (b) Shaft 18B, floors 3 and 13, column 605; (c) Shaft 19B, throughout entire shaft, column 606; (d) Shaft 20B, floors 12, 13, 55, 57, 62, 67, 70, 74, and 77, column 606; (e) Shaft 34B, floor 24, column 706; (f) Shaft 42B, floor 32, column 702; (g) Shaft 43B, throughout entire shaft, column 702; (h) Shafts 61B and 62B, throughout entire shafts, columns 706 and 805; (i) Shaft 88B, throughout entire shaft, column 802; (j) Shaft 89B, floors, 82, 91, 96 and up, (k) column 702; Shaft 89B, throughout entire shaft, column 802; and, (l) Shaft 96B, floor 77, column 706.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
April 1997	Port Authority Facility Condition Survey Program – WTC 7	WTC 7	• Fireproofing was found missing on steel framing at floors 1, 2, 5, 6, 8, 11, 19, 23, 24, 26, and 44. Largest areas of missing fireproofing were found on floor 5 above the Main Lobby and floor 2 above the Loading Dock area.
May 1997	SII Report on Accessible Columns	WTC 1 and WTC 2	• Fireproofing was found missing at the column bases that were inspected in the elevator pits in both towers. • Fireproofing was found missing or damaged on columns in the following elevator shafts of WTC 1: (a) Shaft 10A, floors 3, 9, 10, 22, and 27, column 902; (b) Shaft 11A, floors 8 and 30-33, column 901; (c) Shaft 24A, floor 4, column 807; (d) Shaft 40A, floors 3 and 33, column 702; (e) Shaft 51A, floor 45, column 807; (f) Shaft 52A, floors 45 and 53, column 708; (g) Shaft 57A, floors 44, 45, and 61, column 806; (h) Shaft 58A, floors 60 and 61, column 707; (i) Shaft 84A, floors 82 and 91, column 702; (j) Shaft 90A, floors 79, 91, and 95, column 703; and (k) Shaft 91A, floor 100, column 803. • Fireproofing was found missing or damaged on columns in the following elevator shafts of WTC 2: (a) Shaft 24B, floor 16, column 807; (b) Shaft 25B, floors 2, 11, and 14, column 708; (c) Shaft 30B, floor 23, column 806; (d) Shaft 31B, floors 2-4, 6, 15, 25, column 707; (e) Shaft 36B, floors 8 and 15, column 801; (f) Shaft 37B, floor 32, column 701; (g) Shaft 48B, floors 35-41, column 905; (h) Shaft 52B, floors 45 and 51, column 708; (i) Shaft 57B, floor 52, column 806; (j) Shaft 58B, floors 57 and 60, column 707; (k) Shaft 67B, floor 47, column 702; (l) Shaft 68B, floor 44, column 802; (m) Shaft 90B, floors 94, 96, 98, and 99, column 703; and, (n) Shaft 91B, floors 84, 96, and 98, column 803. • Fireproofing was found missing or damaged on connecting steel beams to columns in the following elevator shafts of WTC 1: (a) Shaft 10A, floors 16 and 22, column 902; (b) Shaft 24A, floors 2, 3, and 9, columns 708 and 807; (c) Shaft 41A, floors 19-24, column 802; and, (d) Shaft 84A, floor 81, column 702. • Fireproofing was found missing or damaged on connecting steel beams to columns in the following elevator shafts of WTC 2: (a) Shaft 24B, floors 2, 5, and 12, column 807; (b) Shaft 48B, throughout entire shaft, column 905; (c) Shaft 57B, floors 44 and 55, column 806; (d) Shaft 64B, floor 49, column 701; (e) Shaft 68B, floors 44, 47, and 56, column 802; (f) Shaft 88B, floors 82 and 84,column 802; and (g) Shaft 90B, floor 98, column 703.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
December 1997	SII Report on Floor Framing Over Tenant Areas	WTC 1 and WTC 2	• Fireproofing was found missing or damaged on the floor framing on the following floors in WTC 1: 15, 20, 28, 92, 95, 96, and 97. On floors 95-97, the fireproofing was found to be less than 0.25 in. thick. On the other floors, the fireproofing appeared to be fairly new, and was found to be approximately 1.5 to 2.0 in. thick. • Fireproofing was found missing or damaged on the floor framing on the following floors in WTC 2: 35, 37, 38, 57, 77, 78, 86, 87, 92, and 93. On floors 77, 86, 87, 92,and 93, the fireproofing was found to be less than 0.25 in. thick. On floors 35 and 57, the fireproofing appeared to be fairly new, and was found to be approximately 1.5 to 2.0 in. thick.
May 1998	SII Report on Plaza Level Box Columns	WTC 1 and WTC 2	• In WTC 1, approximately 2 to 3% of the fireproofing on the plaza level columns was found to be deteriorated and/or missing. • Fireproofing was found to be deteriorated and/or missing on the column and seated beam connections at columns 236, 242, and 248 in WTC 1. • In WTC 2, approximately 1 to 2% of the fireproofing on the plaza level columns was found to be deteriorated and/or missing.
May 1998	SII Report on Accessible Columns	WTC 1 and WTC 2	• Fireproofing was found missing at the column bases that were inspected in the elevator pits in both towers. • Fireproofing was found missing or damaged on columns in the following elevator shafts of WTC 1: (a) Shaft 5A, floor 7, column 906; (b) Shaft 29A, floor 11, column 806; (c) Shaft 30A, floors 8 and 24, column 806; (d) Shaft 46A, floors 32 and 40, column 703; (e) Shaft 47A, floors 19, 23, 26, and 32, column 803; (f) Shaft 48A, floors 2-17, 18, and 29-40, column 905; (g) Shaft 56A, floors 45 and 46, column 806; (h) Shaft 67A, floor 48, column 702; (i) Shaft 68A, floors, 48, 66, and 67, column 802; (j) Shaft 73A, floor 43, column 703; and (k) Shaft 78A, floors 77, 78, and 86, column 707.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
May 1998 (continued)	SII Report on Accessible Columns	WTC 1 and WTC 2	• Fireproofing was found missing or damaged on columns in the following elevator shafts of WTC 2: (a) Shaft 3B, floors 7 and 39, column 907; (b) Shaft 4B, floors 3, 5 and 23, column 906; (c) Shaft 8B, floor 14, column 903; (d) Shaft 9B, floors 10, 18, 23, and 34, column 902; (e) Shaft 16B, throughout entire shaft, column 603; (f) Shaft 17B, floors 28, 31, 38, 45, 52, 58, 59, 66, 69, and 73, column 604; (g) Shaft 28B, Level B1, column 707; (h) Shaft 40B, Level B1, column 702; (i) Shaft 41B, floor 2, column 802; (j) Shaft 46B, Level B1 and floors 2, 8, 13, 17, 20, and 35, column 705; (k) Shaft 47B, floors 4, 7, 17, 31, and 40, column 803; (l) Shaft 74B, floor 66, column 803; (m) Shaft 83B, floor 89, column 701; (n) Shaft 85B, floors 83, 89, and 93, column 802; and, (o) Shaft 94B, floors 77, 101, 104, and 106. • Fireproofing was found missing or damaged on connecting steel beams to columns in the following elevator shafts of WTC 1: (a) Shaft 28A, throughout entire shaft, column 707; (b) Shaft 29A, floors 9 and 12, column 806; (c) Shaft 30A, floors 10 and 25, column 806; (d) Shaft 31A, throughout entire shaft, column 707; (e) Shaft 46A, throughout entire shaft, column 703; (f) Shaft 47A, floors 16, 17, 32, and 34, column 803; (g) Shaft 55A, floors 44-49 and 56, column 707; (h) Shaft 56A, floor 48, column 806; (i) Shaft 67A, throughout entire shaft, column 802; (j) Shaft 68A, floor 61, column 802; (k) Shaft 78A, floor 82, column 707; and (l) Shaft 79A, throughout entire shaft, column 806. • Fireproofing was found missing or damaged on connecting steel beams to columns in the following elevator shafts of WTC 1: (a) Shaft 4B, floors 7, 15, 23, 31, 39, and 40, column 906; (b) Shaft 8B, floors 14, 20, and 45, column 903; (c) Shaft 9B, floor 34, column 902; (d) Shaft 16B, floors 2-48, column 603; (e) Shaft 17B, floors 28, 40, 48, and 69, column 604; (f) Shaft 40B, throughout entire shaft, column 702; (g) Shaft 46B, throughout entire shaft, column 703; (h) Shaft 47B, floors 6, 9, 13, 15, 27, 31, 33, and 34, column 803; (i) Shaft 82B, floors 86 and 87, column 801; (j) Shaft 83B, floor 86, column 701; (l) Shaft 84B, floor 94, column 702; (m) Shaft 85B, floors 78, 79, and 86-88, column 802; (n) Shaft 94B, floors 89 and 101, column 805; and (p) Shaft 95B, floors 81, 87, 94, and 101, column 706.

Table 3–25. Summary of locations where fireproofing was found missing during structural inspections of WTC 1, 2, and 7 (continued).

Date	Inspection Program	Building(s)	Location/Description
May 1999	SII Report on Floor Framing Over Mechanical Areas	WTC 1 and WTC 2	• Fireproofing was found missing on four perimeter braces in Level B6 of WTC 2. Most of other fireproofing on perimeter braces as reported in 1996 report was found to be repaired. • A 3 ft by 3 ft hole was found in the gypsum wallboard in the core area on floor 41 in WTC 1. • Damaged CMU fireproofing for the perimeter diagonal bracing at Level B6 was found at 5 locations in WTC 1 and 3 locations in WTC 2. • Damaged CMU fireproofing was found on 2 columns in WTC 1 and WTC 2 columns in WTC 2 at Level B6. • Fireproofing was found damaged on one of the hat truss members on floor 108 in WTC 1. Most missing fireproofing on hat truss members as reported in the 1996 was found to be repaired in WTC 2.
November 1999	SII Report on Floor Framing Over Tenant Areas	WTC 1 and WTC 2	• A 6 ft length of fireproofing was found to be missing on the bottom chord of one of the long-span floor trusses spanning from the core to the west wall on floor 89 in WTC 2 (see Appendix B of SII report for exact location of floor truss).

3.4 REFERENCES

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Chapter 4
SIGNIFICANT MODIFICATIONS AND REPAIRS TO THE STRUCTURAL FRAMING SYSTEMS OF WTC 1, 2, AND 7

4.1 OVERVIEW

This chapter contains a summary of the significant modifications and repairs that were made to the structural framing systems of World Trade Center (WTC) 1, 2, and 7 from initial occupancy to September 11, 2001, including a discussion of the repairs that were made after the February 1993 bombing of WTC 1.

4.2 MODIFICATIONS AND REPAIRS MADE TO WTC 1

4.2.1 Openings Made in Floor Slabs

Structural modifications involving openings made in the floor slabs are listed in Table 4–1, along with a brief description of the work that was performed with respect to the modifications.

In all of the cases cited in Table 4–1, except for the 1995 case, documents included general notes and drawings that listed the codes, design criteria, and materials that were used in the design, and the proposed sequence of construction. Structural calculations on the design of new structural members and on the check of the capacities of existing structural members were included for the modifications made in 1995 and 1997. The documents for the 1999 modifications include comments made by the Tenant Construction Review Unit of the Port Authority of New York and New Jersey (PANYNJ or Port Authority) in regard to the project submittal. The Tenant Alteration Application Request Form, submitted to the Port Authority on behalf of the tenant, is also included.

Smaller floor penetrations, also made in the floor slabs, are not included in Table 4–1. In 1995, a number of openings were made in the floor slabs on levels 106 and 107 (Windows on the World Restaurant) to allow installation of equipment (W95-1114, PANYNJ, Newark).[1] The maximum opening size was 5 ft 0 in. by 2 ft 6 in., and new beams were introduced to support the beams added around the openings. The structural engineer for this project was Leslie E. Robertson Associates (LERA). LERA was also the structural engineer for the chiller and condenser pipe penetrations on floors 94 through 100 that were made in 1998 for the tenant J&H Marsh & McLennan (W98-1197-02, PANYNJ, Newark). Openings ranged in size from 6 in. diameter core holes to 1 ft 6 in. by 6 in. slab openings.

4.2.2 Openings in Floor Slabs That Were Subsequently Closed

Openings in floor slabs that were subsequently closed are listed in Table 4–2. These openings were cut primarily for stairways.

[1] The Port Authority document number is given in brackets; document was obtained from PANYNJ office in Newark, NJ.

General notes and drawings were provided for the 1985 and 1987 modifications listed in the table. These included the codes, design criteria, and materials that were used in the design, and the proposed sequence of construction. Design of the new structural members and checks of the capacities of existing structural members are contained in the documents for the modifications made in 1998.

Table 4–1. Openings made in floor slabs in WTC 1.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1978	93–95	The Heyward-Robinson Co. Inc.	SHCR	Slab openings were cut in floors 94 and 95 between columns 901, 902, 1001, and 1002 in core to accommodate new stair linking floors 93 through 95. Portions of existing beams on floors 94 and 95 were removed, and new beams were added to frame new openings. Support framing for 3 hour fire door was also provided.	LERA Box 8
1979	99–101	Deloitte Haskins & Sells	SHCR	Slab openings were cut in floors 100 and 101 between columns 707, 708, 806, and 807 in core to accommodate new stair between these levels. Slab opening was also cut in floor 99 between columns 701, 702, 801, and 802 to accommodate new stair. Existing framing was removed and new structural members were added.	LERA Box 8
1985	89, 90	Swiss Bank International	Robertson Fowler & Associates	Slab opening was cut on floor 90 between columns 901, 902, 1001, and 1002 in core to accommodate new stair connecting floors 89 and 90. Existing framing was removed on floor 90 and new structural members were added on both floors.	LERA Box 8
1995	107	Windows on the World Restaurant	LERA	Slab openings were cut in floor 107 for grease arrestors (exact location of openings could not be determined from drawings).	W95-1114 PANYNJ (Newark)
1997	105–Roof	Unknown	LERA	Slab openings were cut for new elevator 99A near columns 704 and 804A in the core. Existing structural members were checked on floor 105 (support of pit beams), floor 110 (support of machine beams) and the penthouse roof (support of elevator) for the appropriate loads. It was determined that some of the beams on floor 105 and the roof were overstressed (not more than 4%) due to the increased loads. These members were not reinforced (calculations state that beams are O.K. since overstress < 5%).	WTCI-66-L
1999	93–100	J&H Marsh & McClennan	Gensler	Several openings were cut in the floor slabs for stairs linking the different floors occupied by the tenant (exact location of openings could not be determined from drawings). Mention is also made to new framing supporting the Skyfold Partition.	W98-1197-03 PANYNJ (Newark)

Table 4–2. Openings in floor slabs that were closed in WTC 1.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1972	95	Fiduciary Trust Co.	SHCR	New beams and floor deck were added to frame existing openings near column lines 124 and 239.	LERA Box 8
1985	95	Deloitte Haskins & Sells	Robertson Fowler & Associates	New beam and floor deck were added to frame existing opening between columns 901, 902, 1001, and 1002 in the core.	LERA Box 8
1987	91, 92	ADT	LERA	New beams and deck were added to frame existing stair opening in core near columns 603 and 702.	LERA Box 8
1998	96, 100	Unknown	LERA	New beams and deck were added to frame existing stair openings between columns 119 and 123 on floor 96 (outside of core) and near columns 707, 708, 806, and 807 on floor 100 (inside core)	W98-1192 PANYNJ (Newark)

4.2.3 Structural Members That Were Reinforced

Various floor members were reinforced to accommodate floor loads that were greater than the original design loads. A summary of reinforced members is contained in Table 4–3. In the introduction to documents submitted for the 1998 modifications, it is stated that the existing structural elements were checked using the PANYNJ Design Guidelines and Specifications. Calculations show that the Port Authority criteria were used for the existing loads on the floor system. The Tenant Alteration Application Review Request Form that was submitted to the Port Authority on behalf of the tenant was also included in the submittal package.

4.2.4 Repair Work Following the February 26, 1993 Explosion

Damage from the Explosion

The explosion of February 26, 1993 occurred on the second basement level (Level B2) near the center of the south wall of WTC 1 and adjacent to the Vista Hotel. Structural steel columns, diagonal braces, and spandrel beams in the immediate vicinity of the blast were damaged. Concrete floor slabs at Levels B1 and B2 in the parking garage and unreinforced masonry walls were also damaged over a large area. A discussion on the structural damage in WTC 1 caused by the blast is given below. A summary of the damage assessment in WTC 1 at Level B1 and Level B2 can be found in the floor plans in Figs. 4–1 and 4–2, respectively.

The explosion tore out the diagonal brace between Column 324 at Level B2 and Column 327 at Level B1 and severely bent the brace between Column 324 at Level B2 and Column 321 at Level B1 (see Figs. 4–1 and 4–2) (LERA 1993a). The braces on the south face of WTC 1 that were damaged by the blast are shown in Fig. 4–3.

Spandrel beams at Level B1 from Column 321 to 324 and from Column 324 to 327 were also damaged by the blast. Spandrels were bowed and cracked, and some had missing bolts (LERA 1993b).

Table 4–3. Structural members that were reinforced in WTC 1.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1979	97–100	Deloitte Haskins & Sells	SHCR	On floor 98, beams between columns 601 and 602 and between 701 and 702 were reinforced with bottom cover plates to support mechanical files that were hung from framing at this level. On floor 98, bridging trusses on the east side of the core between columns 218 and 221 were reinforced with new diagonals. No information is given on why the bridging trusses needed to be reinforced. On floor 99, 32 in. deep floor trusses along column lines 309, 311, 313, 315, 317, 319, 321, 323, 325, 327, and 329 were reinforced by welding additional rods and angles to the web members near the supports. Double angles were also welded to the bottom chords near midspan and to the top chords near the supports. No information was found on the reason why the trusses needed to be reinforced. On floor 99, core perimeter columns were reinforced with 3 new plates. No information was found on why the columns had to be reinforced. On floor 100, supports for a moveable wall were installed.	LERA Box 8
1996	86	WTC Planning	LERA	Floor trusses were reinforced in the northwest corner of the building to accommodate new loads due to various types of filing systems.	LERA Box 9
1998	85	Ohrenstein & Brown	Gilsanz Murray Steficek	Steel beams and cover plates on existing beams were added to support load from new filing system. Also, existing floor trusses were reinforced by welding plates to the bottom chords.	WC98-1186 PANYNJ (Newark)
2001	47, 48	First Union Capital Management	LERA	Floor trusses were reinforced to accommodate loads from new safes and filing cabinets.	W01-1115 PANYNJ (Newark)

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Figure 4–1. Damage assessment for WTC 1 at Level B1.

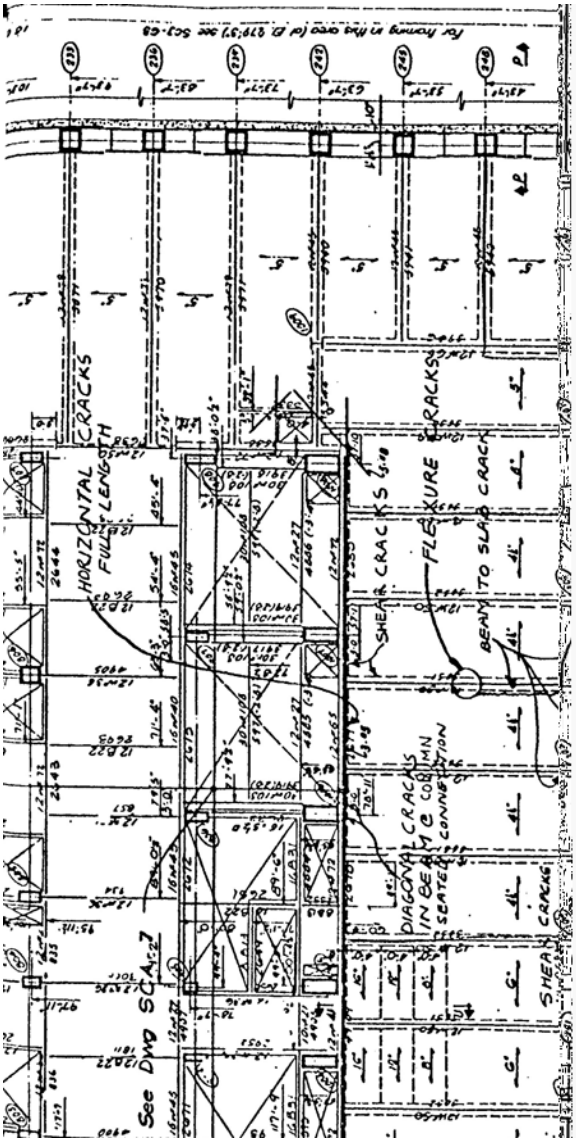

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Figure 4–2. Damage assessment for WTC 1 at Level B2.

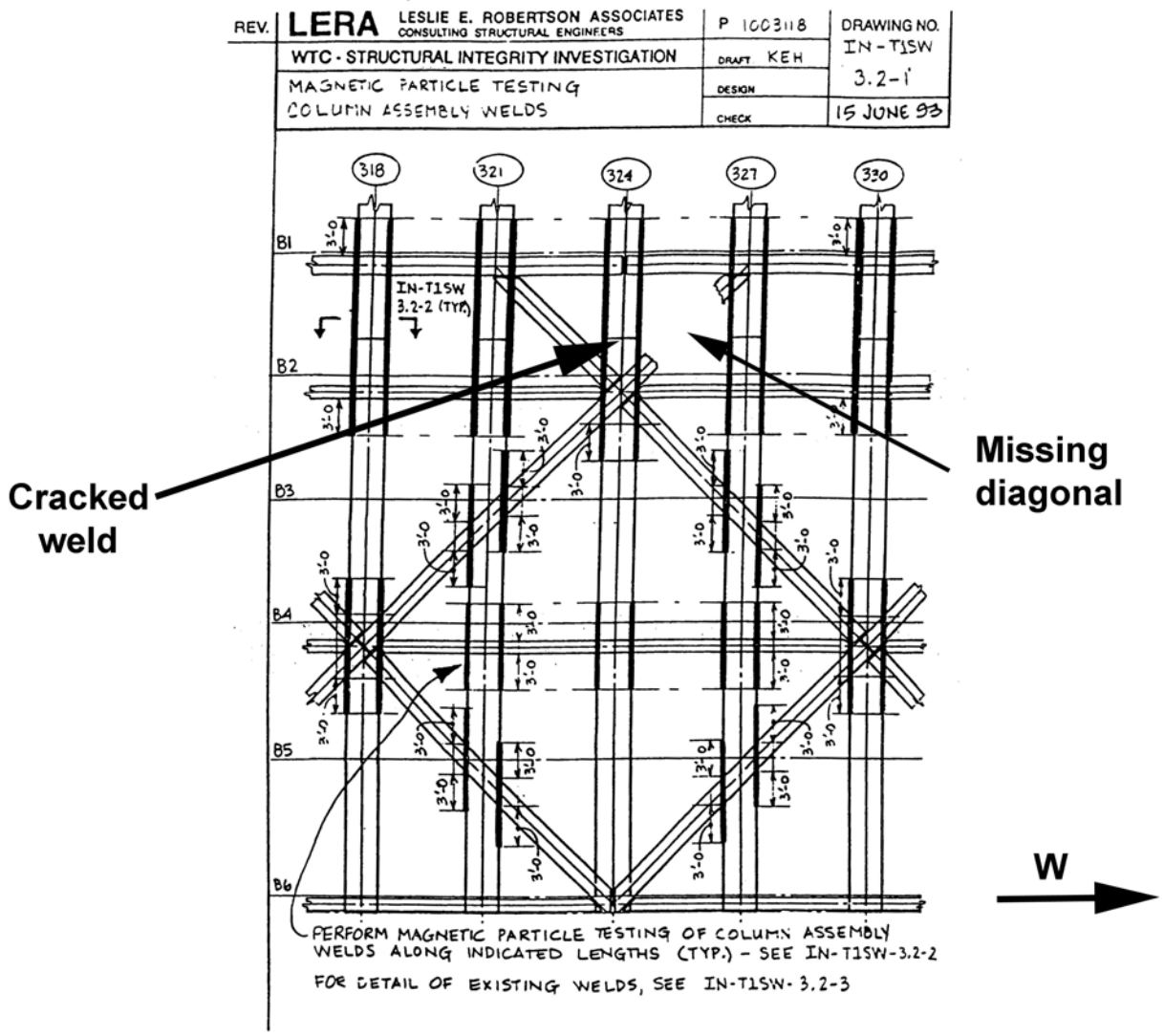

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Figure 4–3. Bracing on south face of WTC 1 damaged by blast.

LERA observed a crack along the edge of the field splice in Column 324, located 3 ft above Level B2, that extended across most of the four faces of the column. Lucius Pitkin, Inc., a testing company that was hired to perform detailed examinations of the structural steel members and welds, confirmed the crack in Column 324. Ultrasonic testing was used to determine that the crack extended across the full width of the weld on the south face of the column and at each end of the weld on the north face. Magnetic-particle testing procedures were used to determine that the crack extended across the weld on the east face of the column and the majority of the weld on the west face as well. A small inward bow above Level B2 was also observed on the south face of this column. LERA noted that the braces and cracked column should be repaired, but they were not critical to the structural integrity of the building (LERA 1993a).

The explosion damaged the floor beams framing into the tower side of Column 324 (see Figs. 4–1 and 4–2) (Woodson 1993). The floor beam that framed into Column 324 at Level B1 sustained a

horizontal displacement of about 2.5 in., and the beam at Level B2 had a displacement of about 1 in. The bolted end connections of these beams also failed. Damage to floor beam connections also occurred at Columns 321 and 324 at Levels B3 and B4.

The concrete spandrel beam at Level B3 between Columns 318 and 330 sustained damage as a result of the blast. Similar damage occurred to the spandrel beam at Level B4 between the same columns.

The masonry walls in WTC 1 were also damaged by the explosion (Woodson 1993). The 6 in. thick walls on the south side of WTC 1 were breached over distances of approximately 50 ft to the east and 120 ft to the west of the blast origin. The 20 ft long masonry wall that formed part of the mechanical plenum that was located 10 ft inside of WTC 1 (near columns 321, 324, and 327) was completely destroyed. The masonry walls of the elevator shafts located approximately 60 ft inside of WTC 1 were also damaged. Other masonry walls inside of WTC 1 were damaged at distances of up to 90 ft from the blast origin. None of the damaged walls were load bearing, and none were supported at the top. The walls were built to 1 in. below the structure above; the joint was subsequently caulked. Many of the damaged walls deflected as though they were free at the top.

Repair Work

The diagonal bracing members between Levels B1 and B2 that were damaged by the explosion were removed and replaced with new members, which consisted of plates that were welded together (see Fig. 4–4). Also, new plates were added on the flanges of the diagonal between Column 312 at Level B2 and Column 315 at Level B1 (see Fig. 4–4).

New plates were added to the damaged spandrel beam at Level B1 between Columns 324 and 327 (see Fig. 4–4 and Fig. 4–5) and between Columns 321 and 324. Also, the cracked weld on the south face of the spandrel beam at Level B1 near Column 324 was removed and replaced (see Fig. 4–6).

LERA prescribed an eight-step procedure for repair to the crack in Column 324 immediately adjacent to the field weld at the column splice above Level B2 (LERA 1993a). No documentation was found to confirm that this crack was repaired according to that procedure.

The Level B1 floor beams framing into Columns 321, 324, and 327 that were damaged during the explosion were repaired by welding new short segments of W12×53 to the existing beams (see Fig. 4–7). New welded connections between the new beam segments and existing columns were provided.

Connections between floor beams and columns on Levels B3 and B4 were also repaired. As shown in Fig. 4–8, the damaged connection at Level B3 was removed, and a new beam seat and clip angle were installed at the connection between the W12×72 beam framing into Column 324. New web connection angles were installed for the beam framing into the same column at Level B4. At Level B3, repairs were made to the damaged bolts and to the gouge in the weld in the connection between the existing W12×72 floor beam and Column 321 (see Fig. 4–9).

Along the south face of WTC 1, the damaged concrete spandrel beams were demolished and replaced. Figures 4–10 and 4–11 show the details of the repair between Columns 318 and 330 at Levels B3 and B4, respectively. Similar repairs were made to the concrete spandrel between Columns 333 and 345 at Level B3.

Columns 321, 324, and 327 were encased in 4 in. thick concrete masonry units (CMU) at the subgrade levels after the explosion, as depicted in Fig. 4–12. According to the drawings, existing spray-on fireproofing on spandrels and diagonals was to be

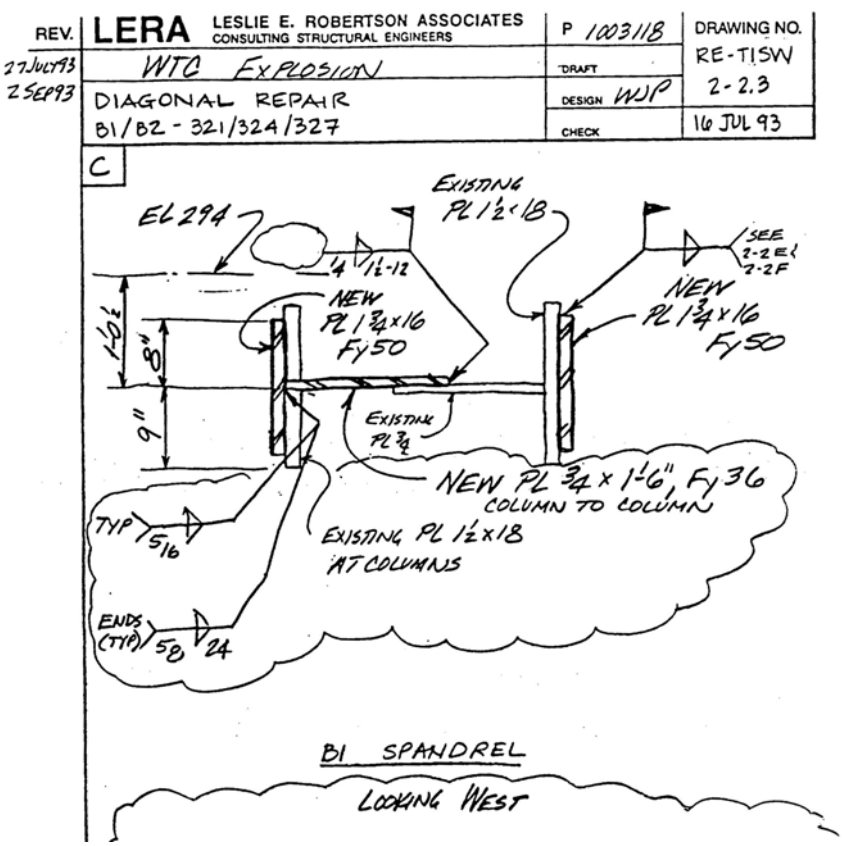

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Figure 4–5. Repair of damaged spandrel beam in level B1 of WTC 1.

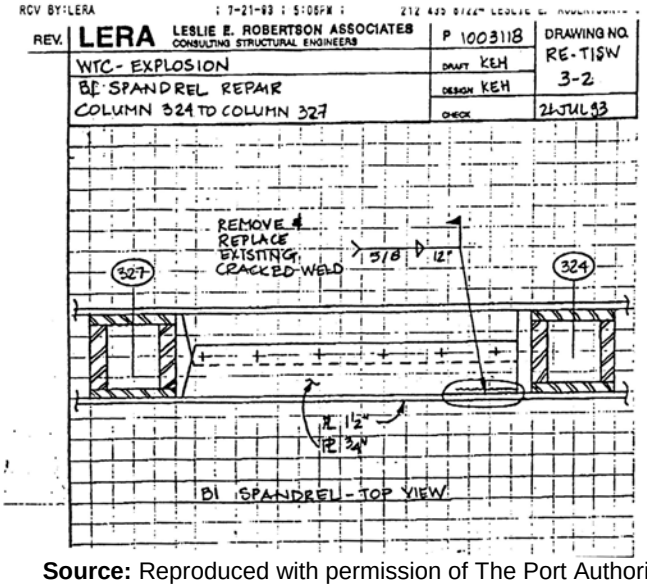

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Figure 4–6. Repair of cracked weld on spandrel beam in level B1 of WTC 1.

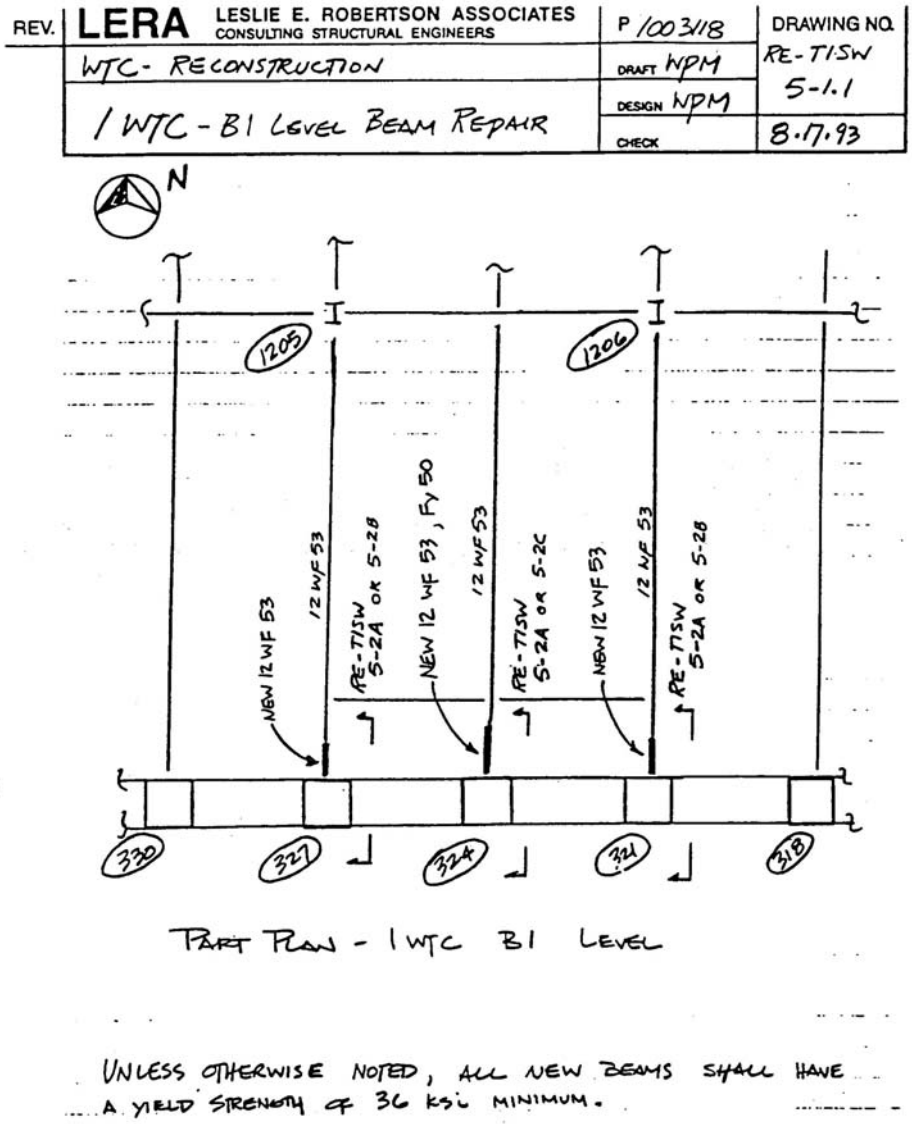

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Figure 4–7. Repair of damaged floor beams at Level B1 in WTC 1.

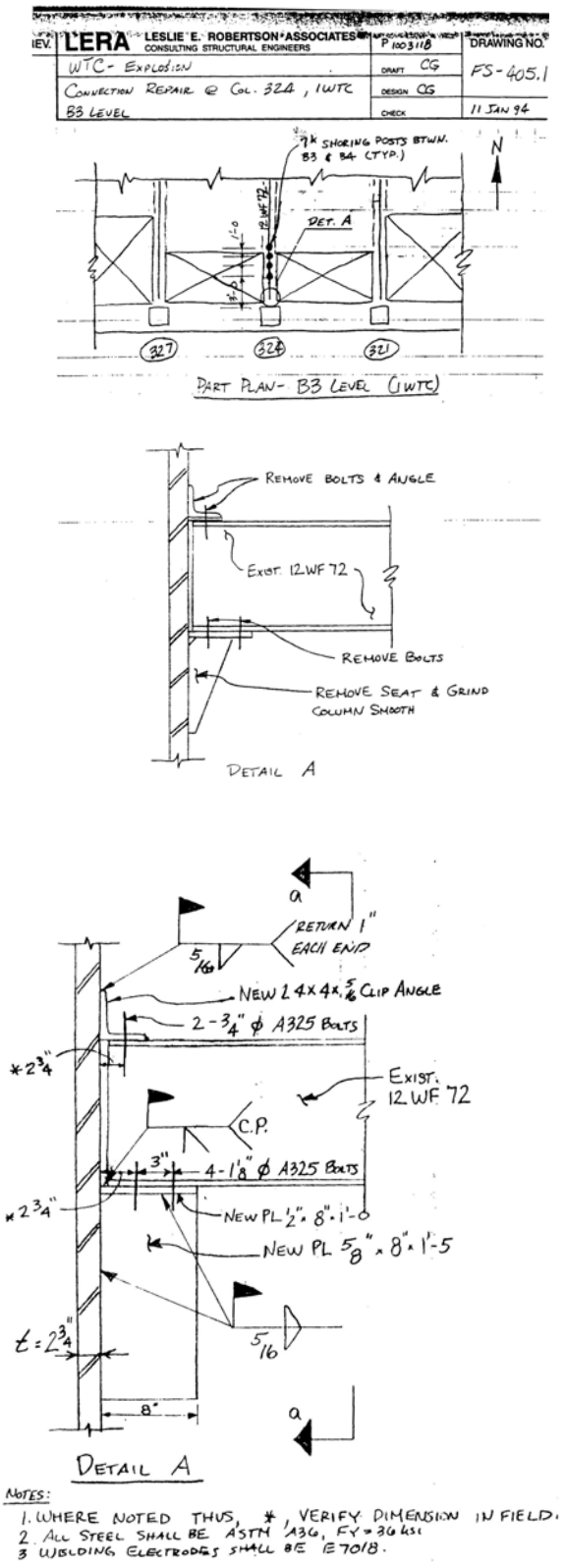

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Figure 4–8. Repair of damaged floor beam at Level B3 in WTC 1.

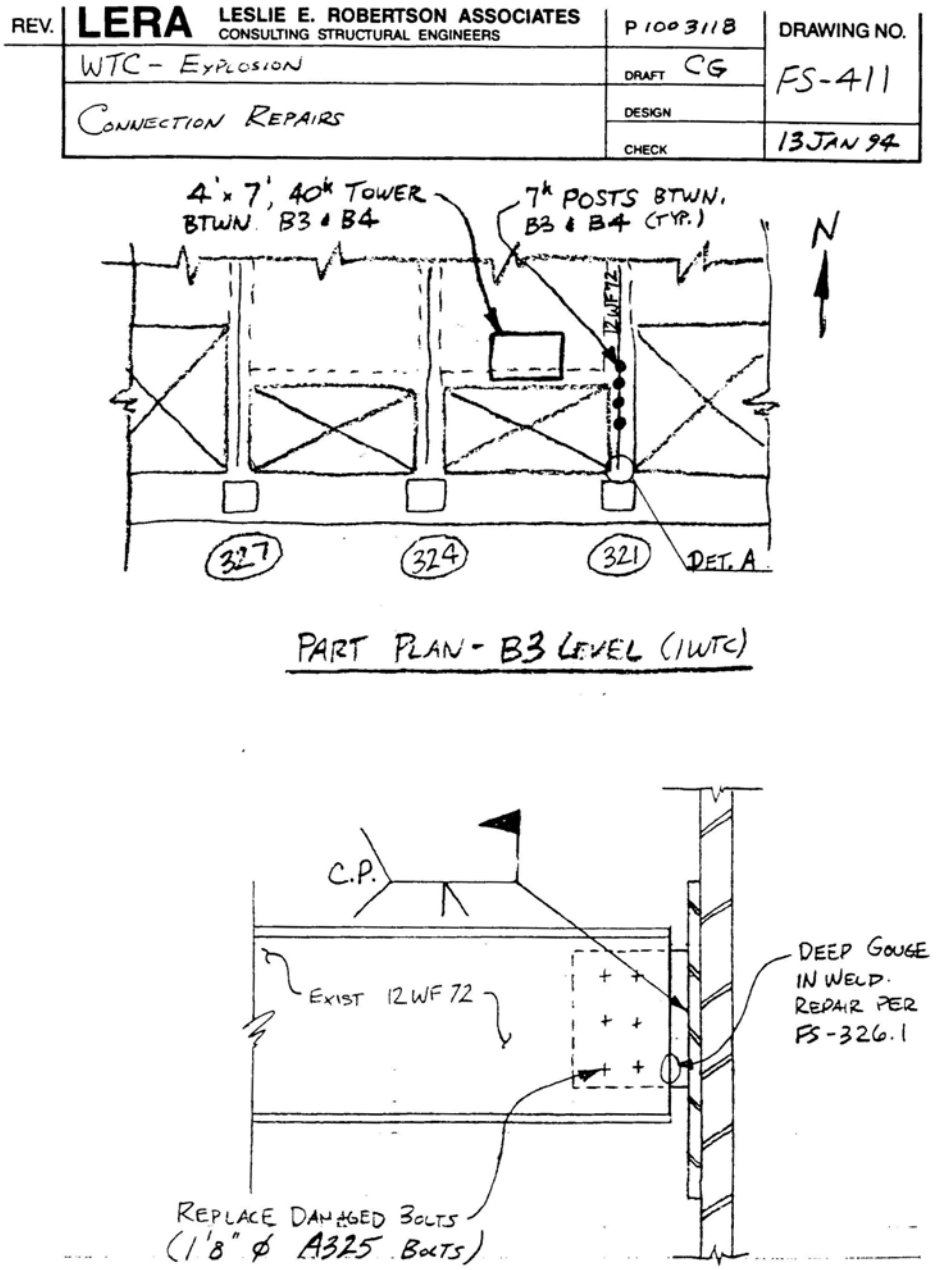

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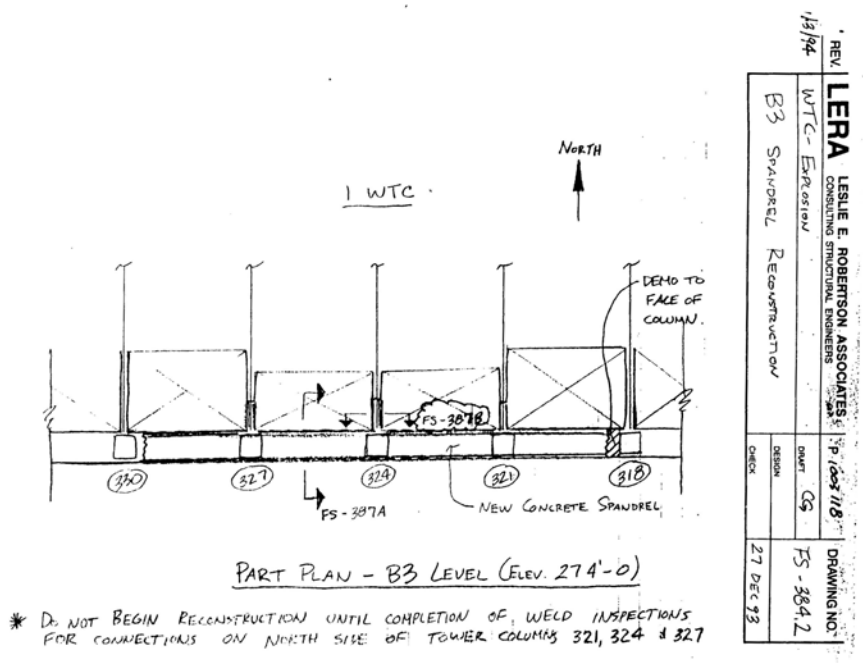
Figure 4–9. Repair of damaged floor beam at Level B3 in WTC 1.



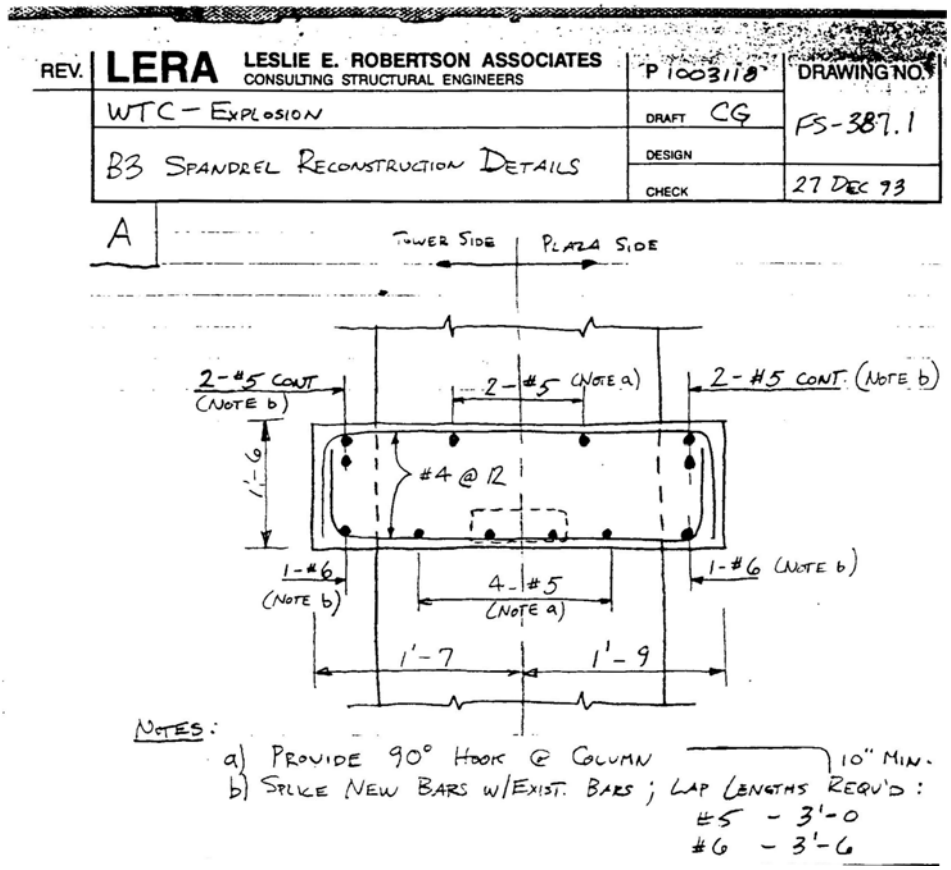


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Figure 4–10. Repair of damaged reinforced concrete spandrel beam at Level B3 in WTC 1.

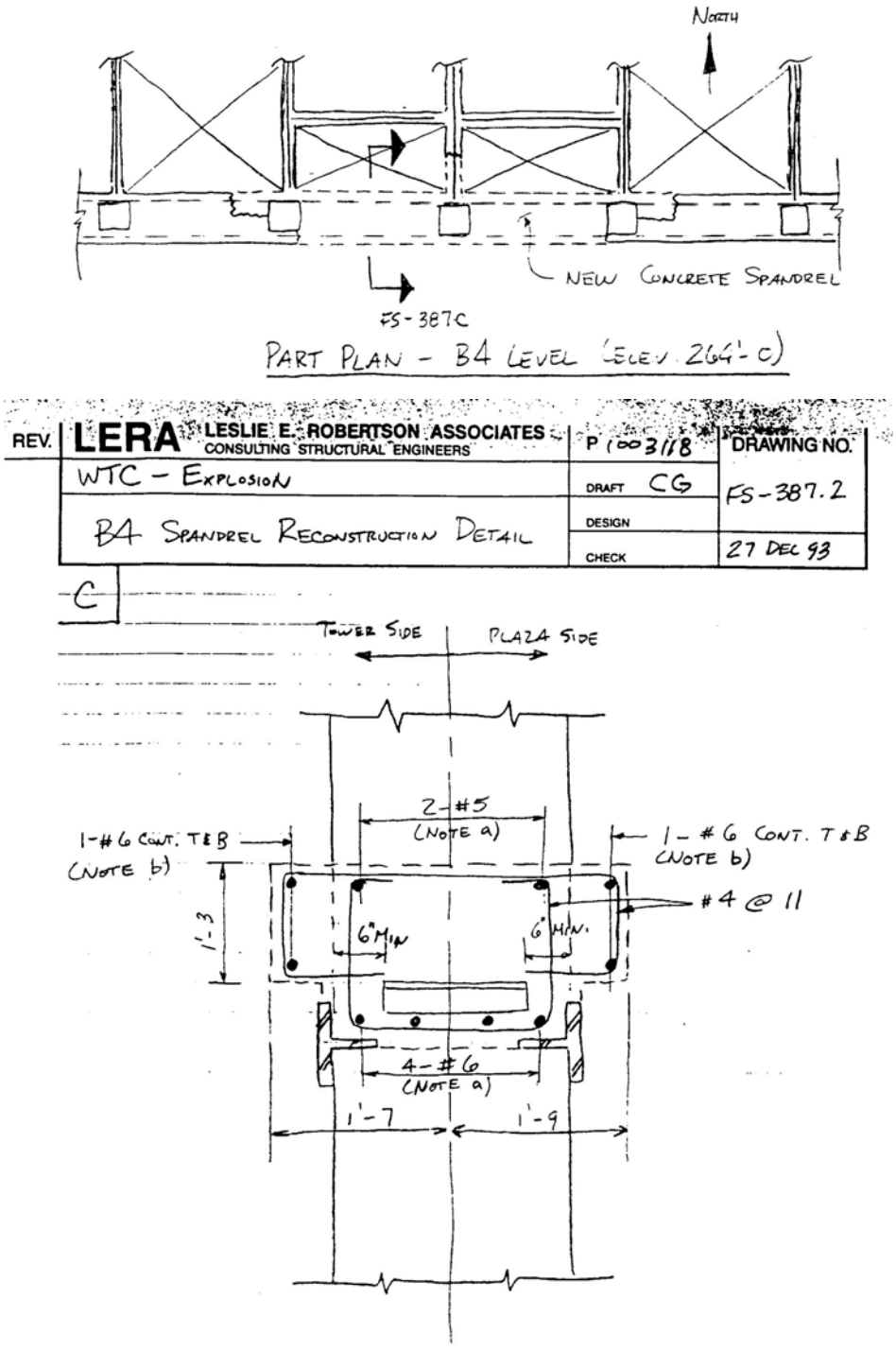

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Figure 4–11. Repair of damaged reinforced concrete spandrel beam at Level B4 in WTC 1.

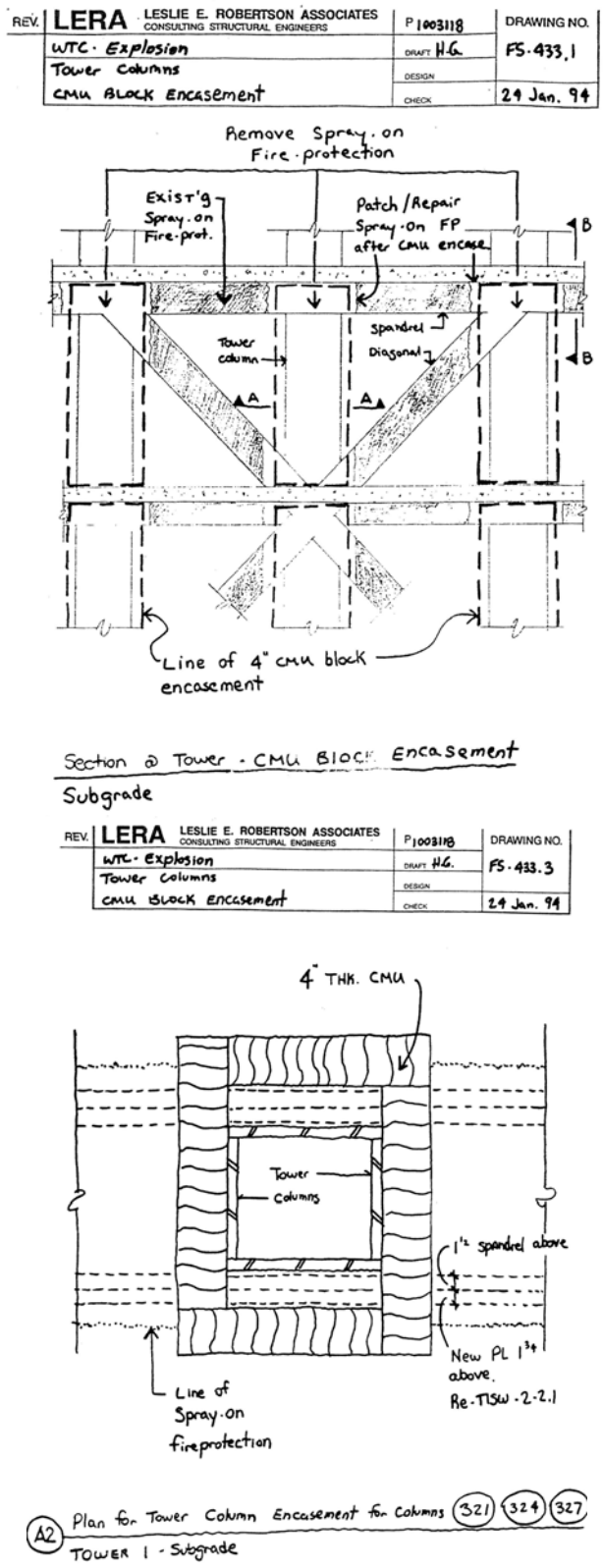

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Figure 4–12. Concrete masonry encasement of columns at subgrade levels in WTC 1.

Damaged concrete encasement around existing steel beams was also repaired as required. Figure 4–13 shows a typical reconstruction detail for a beam located at Level B2. The extent of concrete encasement reconstruction at Levels B1 and B2 is shown in the drawings that were prepared by LERA (LERA 1993c).

Other repairs were made to spandrel beams at Level B5 and to the connection between the floor beam and Column 357 at the Concourse Level (see Figs. 4–14 and 4–15, respectively).

Lucius Pitkin, Inc. was hired to perform a thickness survey of box columns by the ultrasonic method and an ultrasonic flaw detection survey of diagonal and beam weld repairs made at WTC 1 (Lucius Pitkin 1993). Ultrasonic thickness measurements were made at Columns 345, 348, and 351 on Level B1. Ultrasonic flaw detection measurements were made on full penetration butt welds of new diagonal bracing repairs at Columns 321, 324, and 327 at Levels B1 and B2. Additional measurements were made on butt and fillet welds of beam repairs at Columns 321 and 327 between Levels B1 and B2. Results of the thickness survey are given in Table 1 and Fig. 1 of the Lucius Pitkin report (Lucius Pitkin 1993). Results of the ultrasonic flaw survey are given in Figs. 2 through 4 of the same report. No conclusions were made in the report on the adequacy of the test results.

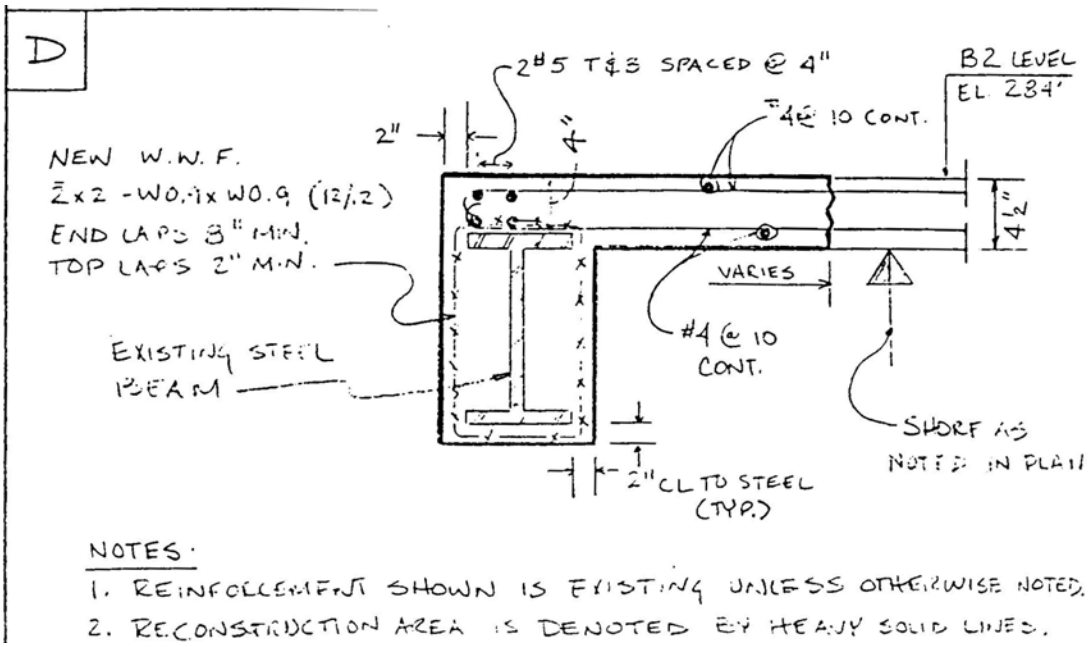

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Figure 4–13. Reconstruction details for existing encased steel beams in WTC 1.

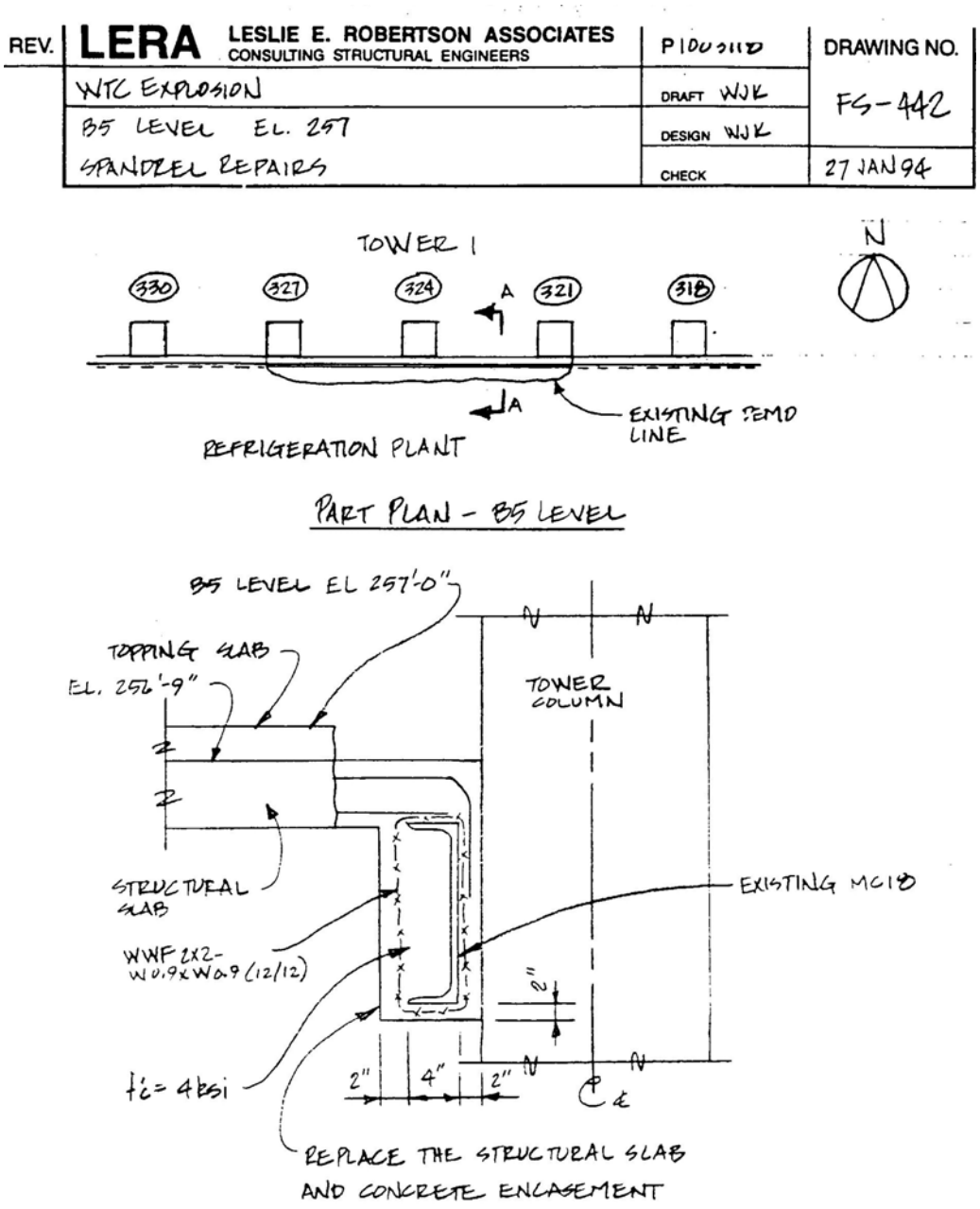

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Figure 4–14. Repair of encased steel spandrel beam at Level B5 in WTC 1.

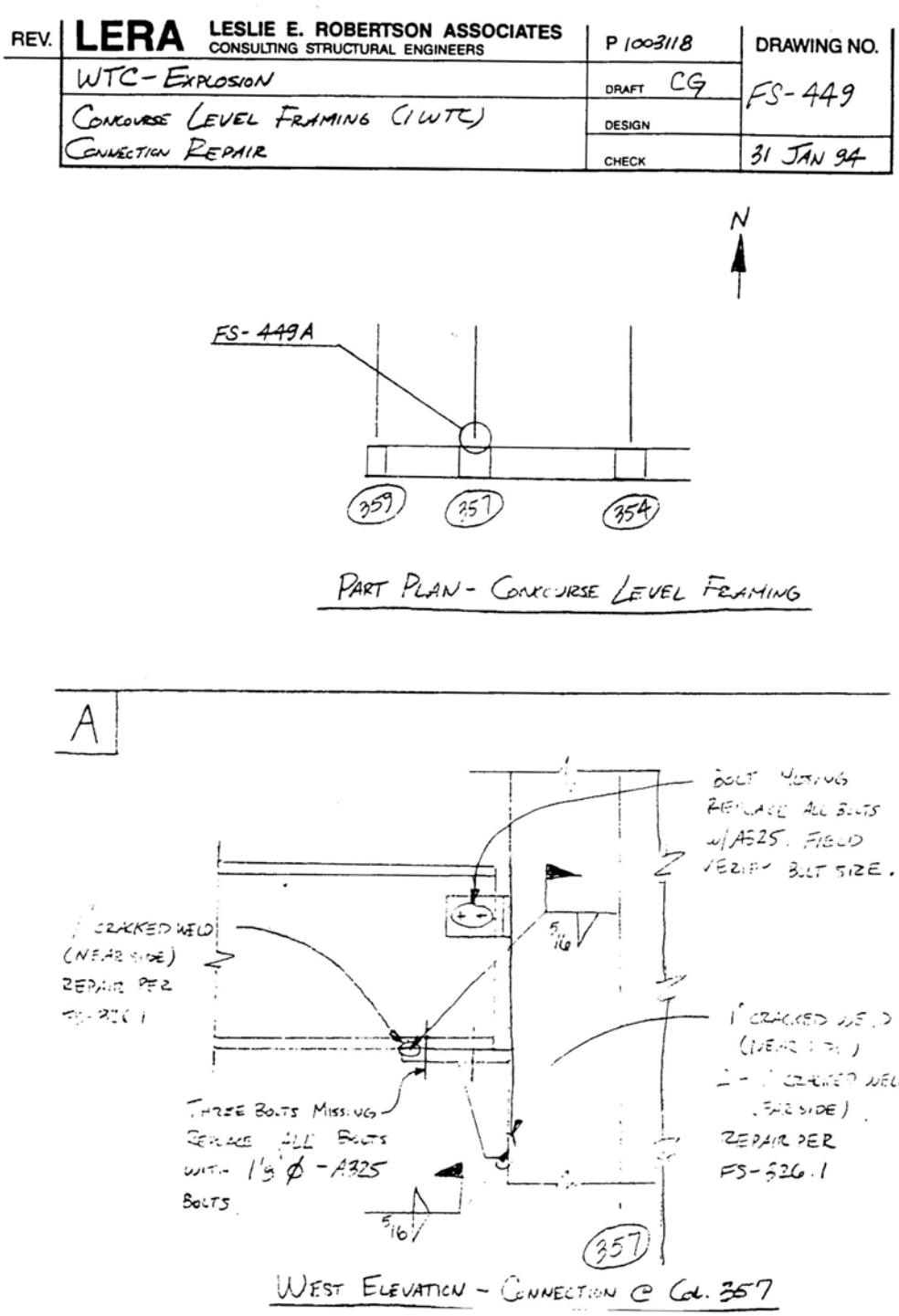

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Figure 4–15. Repair of beam connection at Concourse Level in WTC 1.

4.2.5 Other Modifications

An FM transmitter station was installed on the 110th floor in 1997 for WNYC-FM (W96-1171, PANYNJ, Newark). The structural engineer for this project was J. C. Westrick & Associates. The documentation for this modification includes: (1) the Tenant Alteration Application Review Request Form submitted to the Port Authority on behalf of the tenant, (2) Port Authority comments made on the project submittal, (3) J. C. Westrick & Associates comments in response to Port Authority comments, and (4) a letter dated January 14, 1997 from the Supervisor of the Tenant Alteration Application Unit of the Port Authority to the Vice President of Operations and Engineering at WNYC-FM stating that review on the project was complete.

In June of 2000, structural calculations were submitted by LERA for the WABC Control Room on floor 110 (W00-1180, PANYNJ, Newark). A new transmitter and ductwork were suspended from the existing floor system at this level. The documentation for this modification includes: (1) the Tenant Alteration Application Review Request Form submitted to the Port Authority on behalf of the tenant, (2) Port Authority comments made on the project submittal, (3) LERA comments in response to Port Authority comments, and (4) a letter of approval from the Port Authority dated May 30, 2001.

Although no major modifications were made to the existing structural members because of the two projects cited above, they illustrate that the guidelines set forth by the Port Authority for alterations to the structural systems of the WTC buildings were followed (see Chapter 2 of this report for information on the Port Authority guidelines for inspection, repair, and modifications).

4.3 MODIFICATIONS AND REPAIRS MADE TO WTC 2

4.3.1 Openings Made in Floor Slabs

Structural modifications involving openings made in the floor slabs are listed in Table 4–4,which includes a brief description of the work that was performed with respect to the modifications.

In all of the cases cited in Table 4–4, except for the 1987 case, general notes and drawings in the documents listed the codes, design criteria, and materials that were used in the design and the proposed sequence of construction. Structural calculations were included for the modifications made in 1993, 1998, and 1999 (floors 25 and 26). The design of the new structural members and a check of the capacities of existing structural members were included in the calculations.

For the modifications performed in 1997, the documentation includes the Tenant Alterations Application Review Request Form and comments from the Port Authority in regard to the submittal. Similar documents are included in the submittal package for the modifications performed in 1998 and 1999 (work done on 88th and 89th floors).

Smaller floor penetrations, the largest of which was 17 in. in diameter, were made on floor 110 in 1979 for Sage Gray Todd & Sims (LERA Box 8). The structural engineer was LERA.

4.3.2 Openings in Floor Slabs That Were Subsequently Closed

Openings in floor slabs that were subsequently closed are listed in Table 4–5. The design of the new structural members and a check of the adequacy of existing structural members were included in calculations in all cases.

Table 4–4. Openings made in floor slabs in WTC 2.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1979	77	Ebasco Inc.	SHCR	Slab openings were cut at nine locations in the northeast quadrant of the building along the north and east faces of floor 77. Framing channels were also installed.	LERA Box 8
1987	96	Yamaichi International	LERA	Slab opening was cut near columns 901 and 902 in the southeast quadrant near the core. New structural members were added.	LERA Box 10
1993	94-95	Fiduciary Trust	LERA	Slab opening was cut between columns 507, 508, 607, and 608 in the core for stair linking floors 94 and 95. New structural members were added.	W93-2179 PANYNJ (Newark)
1997	99-101	AON Risk Services	Gensler	Slab openings were cut for stairs linking floors 99, 100, and 101. No other information is provided.	WC97-2185-001 PANYNJ (Newark)
1998	99	AON Risk Services	The Office of James Ruderman	Slab opening was cut between columns 601, 602, 701, and 702 in the core on floor 99 for stairs leading down to floor 98. New structural members were added.	WC98-2212 PANYNJ (Newark)
1999	25, 26	Sun Microsystems	LERA	Slab opening was cut near column 901 in the core for new stair between floors 25 and 26. New structural members were added.	WTCI-69-L, SA0279, 0006
1999	88, 89	Keefe, Bruyette & Woods, Inc.	Cetra/Ruddy Inc.	Slab opening was cut for stairs linking floors 88 and 89. No other information is provided.	WC99-2114 PANYNJ (Newark)

Table 4–5. Openings in floor slabs that were closed in WTC 2.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1997	37, 38	Unknown	LERA	An escalator was removed between floors 37 and 38 near column 608. New floor deck and framing were added to close the opening.	WTCI-66-L
2000	95, 96	Fiduciary Trust	LERA	New beams and deck were added to frame existing opening between columns 901, 902, 1001, and 1002 in the core on floor 96. Existing framing was checked for new loads.	WTCI-66-L

4.3.3 Structural Members That Were Reinforced

A summary of the structural members that were reinforced in WTC 2 is given in Table 4–6. The Tenant Alteration Application Review Request Form is included in the documentation for the modifications performed in 1999.

Table 4–6. Structural members that were reinforced in WTC 2.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1993	96	Fiduciary Trust	LERA	A number of long-span floor trusses and their connections in the northeast quadrant of the building were reinforced due to additional loads from high-density mobile filing cabinets.	W93-2179 PANYNJ (Newark)
1999	81	Fuji Bank Limited	LERA	Documents reference adding reinforcement to existing two-way floor trusses to accommodate new UPS workspace. Documents do not specify the required amounts of reinforcement due to the new superimposed loads.	W99-2125 PANYNJ (Newark)

4.3.4 Other Modifications

In 1994, the slab in the elevator lobby on floor 90 (bounded by core columns 702, 703, 902, and 903) was repaired for Fiduciary Trust for some unknown reason (WTCI-66-L). LERA was the structural engineer for this repair, which consisted of demolishing and replacing a 5 in. lightweight aggregate concrete slab in this area.

4.4 MODIFICATIONS AND REPAIRS MADE TO WTC 7

A summary of the major modifications and repairs made to WTC 7 is given below. All modifications were to be made in accordance with the PANYNJ *Tenant Construction Review Manual* (see Chapter 2 of this report).

4.4.1 Modifications Made due to New Loading Requirements

Structural modifications due to new loading requirements are listed in Table 4–7. Included is a brief description of the work that was performed with respect to the modifications. In most cases, members were reinforced to accommodate floor loads that were greater than the loads for which these members were originally designed.

In all of the cases cited in Table 4–7, structural calculations were included on the check of the existing structural members and on the design of new structural members. The documents related to the 1988 modifications include comments made by the Tenant Construction Review Unit of the Port Authority in regard to the project submittal and responses from the structural engineer to the Port Authority on these comments. Similar documents are available for the modifications made in 1999 on the 40th floor, which

include a copy of the Tenant Construction or Alteration Application that was submitted to the Port Authority on behalf of the tenant.

Table 4–7. Modifications made due to new loading requirements in WTC 7.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1988	38	Salomon Brothers Inc.	Office of Irwin G. Cantor	Bottom and top cover plates were added to the existing W24x55 beams along column lines 37 and 40, and bottom cover plates were added to the existing W24x55 beams along column lines 30 and 35 to support new hanger loads.	W-7004 PANYNJ (Newark)
1989	24	General Auditing Office	Office of Irwin G. Cantor	Bottom cover plates were added to the existing W21x44 beam on column line 45 and the two adjacent W21x44 beams to the west of column line 45 to support additional load due to new file storage. The existing W36x135 girder framing between columns 76 and 79, which supported these beams, was also reinforced with a bottom cover plate.	W-8003 PANYNJ (Newark)
1989	47	Salomon Brothers Inc.	Office of Irwin G. Cantor	Bottom cover plates were added to the existing W16x31 beam along column line 2, the W16x26 beam along column line 3, and the W14x22 beams along column lines 4 and 5 to support additional mechanical equipment. The W33x130 girder on column line 56, which supported these beams, was reinforced with bottom and top cover plates.	W-7004 PANYNJ (Newark)
1990	11, 12	Spicer & Oppenheimer	Office of Irwin G. Cantor	Bottom cover plates were added to eight existing beams and girders in the northwest corner of the building on the 11th floor to support larger live loads. Similarly, bottom cover plates were added to three existing beams between column lines 48 and 49 and the girder between columns 70 and 73 on the 12th floor.	W-8005 PANYNJ (Newark)
1991	19	ITT Hartford	Office of James Ruderman	Bottom cover plates were added to existing W24x55 and W24x76 beams to support new files and shelves. Exact location of these beams could not be determined from the documentation.	W-8010 PANYNJ (Newark)
1992	12	Securities Exchange Commission	Office of Irwin G. Cantor	Bottom cover plates were added to eleven existing beams in the northwest corner of the building to support legal files. A new W12x19 beam was also added between two of the existing beams.	W92-7056 PANYNJ (Newark)
1992	18, 19	Equal Employment Opportunity Commission	Office of Irwin G. Cantor	Bottom cover plates were added to existing W24 beams on the 18th floor on column lines 31, 32, and 33 to support larger live loads.	WTCI-166-P Disk 3 W92-7150

Table 4–7. Modifications made due to new loading requirements in WTC 7 (continued).

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1993	28	Salomon Brothers Inc.	Office of Irwin G. Cantor	Eight additional shear studs were added to an existing W16x26 beam located in the mechanical/electrical room to support new equipment loads.	W93-7138 PANYNJ (Newark)
1993	7, 8	American Express Bank	Office of James Ruderman	A new W12x14 beam located on the west side of the building between column lines 7 and 8 was added on the 8th floor to support a new CMU wall.	W93-7233 PANYNJ (Newark)
1994	7 through 29	Salomon Brothers Inc.	Office of Irwin G. Cantor	Bottom cover plates were added to twenty-two existing beams between columns 5 and 25 on the south side of the building on each floor between levels 7 and 29 to support larger live loads. Similarly, bottom cover plates were added to eight beams on the east side of the building between column lines 31 and 37 on each of these floors.	WTCI-166-P Disk 4 W93-7232
1995	20	ITT Hartford	The Cantor Seinuk Group	Bottom cover plates were added to the existing W16x26 beams along column lines 23 and 25 to support new filing cabinets. Similarly, WT sections were welded to the bottom of the existing W16x26 beams that framed in between the above-mentioned beams. WT sections were welded to the bottom of the existing W16x26 beam east of column line 18 and the W16x26 beam on column line 19 to support new filing cabinets. Similarly, a bottom cover plate was added to the existing W16x26 beam east of column line 19.	W95-7153 WTCI-197-P
1999	37	Salomon Smith Barney	Gilsanz Murray Steficek	A new W16x40 beam was added between two existing W14x22 beams along column lines 76 and 77 to support a new high-density filing system.	W99-7134 PANYNJ (Newark)
1999	13	The Standard Chartered Bank	The Cantor Seinuk Group	Ten additional shear studs were added to an existing W4x55 beam to support additional loads from a new file room and a new UPS/LAN room. Exact location of this beam could not be determined from the documentation.	W99-7137-02 PANYNJ (Newark)
1999	40	Salomon Smith Barney	Gilsanz Murray Steficek	Four new W18x35 beams were added to support the new high-density files near column 76. WT4x20 sections were welded to the bottom of two existing W14x22 beams that supported the files. New W16x50 beams were connected below to the existing W36x135 girders that supported the beams in this area.	W99-7172 PANYNJ (Newark)

Table 4–7. Modifications made due to new loading requirements in WTC 7 (continued).

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
2000	31	Salomon Smith Barney	Gilsanz Murray Steficek	Top and bottom cover plates were added to an existing W27x94 beam between columns 77 and 80 to support a new high-density filing system. The existing beam connections were also reinforced with stiffened seat connections.	W00-7122 PANYNJ (Newark)
2000	38	Salomon Smith Barney	Gilsanz Murray Steficek	Bottom cover plates were added to existing W14x22 beams between columns 76 and 77 and between columns 77 and 78 to support a new high-density filing system. Also, the following existing girders were reinforced with bottom cover plates: (1) W36x135 between columns 76 and 79, (2) W27x94 between columns 77 and 80, and (3) W27x84 between columns 78 and 81.	W00-7224 PANYNJ (Newark)
2000	39	Salomon Smith Barney	Gilsanz Murray Steficek	New W14x53 beams were added under each rail of a new high-density filing system in lieu of reinforcing existing W14x22 beams between columns 76 and 77.	W00-7202 PANYNJ (Newark)

4.4.2 Openings Made in Floor Slabs

It is stated in PANYNJ (1997) that the 41st and 43rd floor slabs were completely removed on the east side of the building to accommodate the trading floors for Salomon Brothers Inc.

According to The Office of Irwin G. Cantor P.C. (1989), columns 76, 78, 79, 80, and 81 were reinforced with plates that ran from the top of the 39th floor to the underside of the 40th floor due to the removal of the floor slab at the 39th floor. Similarly, column 74 was reinforced with plates that ran from the top of the 43rd floor to the underside of the 44th floor due to the removal of the floor slab at the 43rd floor.

Structural modifications involving openings made in the floor slabs are listed in Table 4–8, including a brief description of the work that was performed with respect to the modifications.

Structural calculations on the design of new structural members and on the check of the existing structural members were included for the modification made in 1989 (3rd floor) and 1990.

4.4.3 Modifications Made to Beam Webs and Flanges

Modifications made to beam webs and flanges are summarized in Table 4–9 including a brief description of the work that was performed with respect to the modifications.

Table 4–8. Openings made in floor slabs of WTC 7.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1989	3, 4	Salomon Brothers Inc.	Skidmore Owings & Merrill	On the 3rd floor, openings were cut on the west, north, and east sides of the building. New framing was introduced around these openings. On the 4th floor, new openings and framing were introduced on the north side of the building.	WTCI-166-P, Disk 2
1989	3	Salomon Brothers Inc.	The Office of Irwin G. Cantor	Two 2 ft-6 in. by 3 ft-6 in. openings were cut near columns 24 and 25. New C8x11.5 framing members were added around the openings.	W-7005 PANYNJ (Newark)
1990	11	Spicer & Oppenheimer	Office of Irwin G. Cantor	A new stair opening was made between columns 77, 78, 80, and 81. New W12x16 beams were added around the opening.	W-8005 PANYNJ (Newark)
1994	43	Salomon Brothers Inc.	Skidmore Owings & Merrill	A new slab opening was made near column 71 in the core area. New beams were added around the opening.	W94-7746, WTCI-166-P, Disk 4

4.4.4 Other Modifications

A list of structural modifications that were made to WTC 7 prior to April of 1997 is given in Chapter IV, Section A(5) of the Facility Condition Survey Report for WTC 7 (PANYNJ 1997). The following is a summary of the modifications that are noted in that report:

- In the Convention Area on the 3rd floor between column numbers 45 and 48A, steel plates have bee installed around the perimeter of the room between the slab and the floor surface (behind the wall coverings and above the suspended ceiling). According to the PANYNJ report, these plates were installed to protect attendees at the Convention Center from the magnetic field generated from the ConEd Substation beneath the conference rooms. No documentation was located that provides any additional details on this modification.

- On the north side of the 5th floor generator room, masonry block walls were added to partition the eight transformer vaults installed for Salomon Brothers. The vaults were between columns 46 and 53. No documentation was located that provides any additional details on this modification.

- A penthouse was constructed on the 47th floor roof to house the chiller plant and the cooling towers for Salomon Brothers. The chiller plant was an enclosed steel-framed structure with corrugated steel walls. It was approximately 25 ft in height and took up about one-third of the square footage of the 47th floor roof. The cooling towers were supported on a steel frame and were enclosed by louvered walls on the north and south sides and by the chiller plant and the bulkhouse on the east and west sides, respectively. No documentation was located that provides any additional details on this modification.

The list of modifications in the PANYNJ report also included the removal of the floor slabs on floors 41 and 43 to accommodate the trading floors for Salomon Brothers, as noted in Sec. 4.4.2 of this report.

Table 4–9. Modifications made to beam webs and flanges in WTC 7.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference
1993	28	Salomon Brothers Inc.	Office of Irwin G. Cantor	Two 1 in. by 36 in. openings, located 3 ft apart, were cut into the web of an existing W24x55 beam (unknown location). Plates were welded on each side of the web along the upper and lower edges of the openings.	W93-7138 PANYNJ (Newark)
1993	4-7, 16, 21, 29, 38, 45	Salomon Brothers Inc.	Office of Irwin G. Cantor	Notches were cut in the bottom flanges of various beams on these floors to accommodate ductwork. Plates were welded to the upper side of the bottom flanges.	W93-7221, WTCI-166-P, Disk 2
1998	1	Mayor's Office of Emergency Management	The Cantor Seinuk Group	A notch was cut into the top flange of an existing beam (unknown location). Two plates, one on each side of the web, were welded under the top flange.	W98-1734, WTCI-166-P, Disk 5
1999	36-44	Salomon Smith Barney	The Cantor Seinuk Group	Two new openings (68 in. by 22 in. and 76 in. by 22 in.) spaced 3 ft-10 in. apart were cut into the web of the existing W24x62 beam framing into column 75. Horizontal and vertical stiffener plates were added on all sides of the openings. Also, a new WT15x74 section was welded to the bottom of the beam. The same size openings were made in an existing W27x94 beam on the 43rd floor, which was reinforced in a similar manner.	W99-7127 PANYNJ (Newark)
1999	42, 44	Salomon Smith Barney	Gensler	New web openings were cut in numerous beams along the north and east sides of the building.	W99-7127, WTCI-166-P, Disk 6

4.5 REFERENCES

LERA (Leslie E. Robertson Associates). 1993a. *The World Trade Center – The Explosion of 26 February 1993, Inspection Program, South Wall of Tower 1*. May. (WTCI-69-L).

LERA (Leslie E. Robertson Associates). 1993b. "WTC Structural Integrity Investigation, Visual Inspection – Spandrel Damage Assessment." July. (part of WTCI-160-STB).

LERA (Leslie E. Robertson Associates). 1993c. "Reconstruction of Tower A, El. 294-0 and 284-0," structural drawing RE-TA-1." December. (WTCI-456-STB).

Lucius Pitkin, Inc. 1993. *Examination of Box Columns and Diagonal Beam Repairs – World Trade Center*, New York, Report No. ME-4525 S1. December. (part of WTCI-67-L).

PANYNJ (Port Authority of New York and New Jersey). 1997. *Port Authority Facility Condition Survey Program – 7 World Trade Center*. Engineering Quality Assurance Division, Engineering Department. April. (WTCI-122-P).

The Office of Irwin G. Cantor P.C., "Salomon Brothers Inc. Base Building Modifications – 7 World Trade Center Structural Computations," January 1989 (W-7004, Port Authority, Newark).

Woodson, S.C., Davis, J.L., and Walton, B.A., 1993. *Observations of World Trade Center Damage*, Technical Report SL-93, US Army Corps of Engineers Waterways Experiment Station. September. (part of WTCI-67-L).

Appendix A
TENANT CONSTRUCTION REVIEW MANUAL – 1971

TENANT CONSTRUCTION REVIEW

THE PORT OF NEW YORK AUTHORITY

NEW YORK, N.Y.

P R E F A C E

THE FOLLOWING IS A PRESENTATION OF THE TECHNICAL FUNCTIONS OF THE TENANT CONSTRUCTION REVIEW. IT HAS BEEN PREPARED IN AN EFFORT TO CLARIFY UNDERSTANDING OF THE CONCERNS OF THE PERSONNEL IN THE TENANT CONSTRUCTION REVIEW UNIT.

TABLE OF CONTENTS

INTRODUCTION

This pamphlet has been prepared to facilitate the proper and expeditious execution of review work in the Tenant Construction Review Unit. It tries to achieve this by subdividing a job into trades and thus clarifying the possible scope of a project from functional and technical points of view. Detailed checklists based on Building Codes, prepared for each trade, cover the main areas of design and detailing that are expected to receive special attention. Finally, design, safety and field coordination criteria additional to Building Code requirements are listed under each trade.

It is hoped that this pamphlet will create a degree of consistancy in review work, and, will establish the basic minimum requirements which must be incorporated in the submitted plans and specifications.

Although New York City laws are predominantly used as basis, the check lists may be used for any facility in conjunction with the local code.

CITIES AND THEIR CODES

NEW YORK CITY

(1) N.Y.C. Building Code

(a) New Code, Effective December 6, 1968
(b) Old Code, Effective 1938
(c) N.Y.C. Electrical Code

(2) Rules of "The Board of Standards & Appeals" of N.Y.C.
(3) N.Y. State Labor Law

NEWARK (N.J.)

Building Code of City of Newark 1964, Title 7, incl. Appendix
N.J. State Plumbing Code

ELIZABETH (N.J.)

Standard Building Code of New Jersey including Supplements 1 and 2 with supplement parts A, B, C, D & F.
Plumbing Code of The City of Elizabeth

JERSEY CITY (N.J.)

Basic Building Code, 1965 Edition as published by Building Officials Conference of America , Inc., (BOCA)

TETERBORO AIRPORT

Boro of Teterboro:	Standard Building Code N.J.
Boro of Moonachie	National Building Code, 1967, Abbreviated
Boro of Little Ferry:	National Building Code, 1967
Boro of Hasbrook Heights:	Basic Building Code, 1965, (BOCA) Plumbing Code of Boro of Hasbrook Heights

ADDITIONAL CODES

Where applicable the following shall be referred to:

National Electrical Code; NFPA Standards; N.J. State Labor Law; and additional laws, rules and regulations adopted by the federal, state and local municipal agencies.

GENERAL REQUIREMENTS

1. Applicant shall submit a completed application form, supplied to him by PONYA, along with his design criteria and plans.

2. For any work done on a roof structure with a valid bond, an ~~a~~affidavit shall be obtained by the tenant from the insurer, to the effect that the terms of the bond have not been violated.

3. In order for the P.O.N.Y.A. to obtain the N.Y.C. Fire Department approval of the proposed fire alarm installation, three sets of the following information are required to be sent to the P.O.N.Y.A., via the tenant's Alteration Application

   a. A plot plan of the building showing the exact location of the fire alarm boxes and their relationship to site conditions, i.e. roads, sidewalk, fences, island, building exits, etc.

   b. Details of fire alarm pedestal, foundation, cable and duct installation, etc.

   c. Specifications for fire alarm equipement, cable, installation procedures, etc.

   d. The above may be submitted in the form of Contract Drawings, sketches and formal specifications, for proper transmittal by PONYA to the NYC Fire Department.

4. Before starting the sprinkler work, tenant shall file with PONYA resident Engineer, sprinkler drawings bearing the acceptance stamp ~~(s)~~ of:
   The Ins. Services Office of N.Y. & The Kemper
   The ~~Fire Insurance Rating Organization~~ of N.Y., ~~or, The Employers' Group of Insurance Companies~~, or, the insurance carrier.
   Insurance Group (for our buildings)

5. When an application is approved, two (2) sets of complete plans and specifications shall be submitted to PONYA. For new buildings and major applications one set shall be filed with the Building Department.

6. At the termination of construction a complete set of as built drawings, in cloth, shall be submitted to PONYA.

7. Each plan shall contain the registration number, seal, signature and address of Architect or Engineer who prepared the plans. Where the enforcement of this requirement with the Federal Agency could present difficulties, it is submitted that the following form of the comment should satisfy this requirement:

2.1

"Drawings shall bear the seal and signature of a Registered Architect or licensed Professional Engineer or the approved application should bear certification, by the Responsible Governmental Agency making this submission, that the plans were prepared in a manner consistent with the standards of professional practice established in the State of New York."

8. Contractors shall obtain PONYA permits for any welding and hot work, in addition to being licensed by the state or the municipality, where applicable.

9. In order to effectuate the policy of The Port of New York Authority, the owner of the premises to be altered, the Contractor shall comply with all provisions of federal, state, municipal, local and departmental laws, ordinances, rules, regulations, and orders which might affect the Contract and the performance thereof and those engaged therein, except where stricter requirements are contained in the Specifications or indicated on the Drawings, in which case the Contractor shall comply with the latter requirements. However, the Contractor shall not apply for any variance, license, waiver or permit of any kind in the name of or on behalf of the Port Authority.

FUNCTIONAL REVIEW

A functional review is a service to an Architect supplementing his feasibility study, reviewing his design criteria, acquainting him with PONYA interpretations of Building Codes and supplemental PONYA criteria where necessary. A functional review is a voluntary request on the part of an Architect. There will be no review of plans for extensive code

3. Protection of building areas exposed to fuel spillage and drainage.

4. PA requirements for carpets, furniture, etc.

Coordination with Airport Utilities

1. Electrical: Anticipated new power requirements shall be referred to the electrical reviewer.

2. Water supply: Coordination of any demand for chilled water, high temperature water, domestic water and high pressure sprinkler supply water with PA facilities, and the fire protection loop, shall be

Grouted & Filled Cell Masonry	Section 8
Anchorage	" 9
Miscellaneous Requirements	" 10
Veneer	" 11
Miscellaneous Structures & Systems	Section 12
REINFORCED MASONRY	RS 10-2
Concrete	Sub-Article 1004.0
Concrete Mixes	C26-1004.3
Short Span Concrete Floor and Roof Construction Supported on Steel Beams	C26-1004.8
REINFORCED CONCRETE - ACI 318-1963, Building Code Requirement, modified as specified in	RS 10-3
STRUCTURAL STEEL - AISC 1969 Specifications for the	

3. Inspection of the tensioning of high strength bolts where stresses in bolts are 50% or more of basic allowable values, Table 10-2.

4. Inspection of the connection of fittings to wire cables, except where proof-loading to not less than 55% ultimate capacity, Table 10-2.

II. ALUMINUM

3. Inspection of subgrade for footings, foundation piers, and foundation walls (notification to PONYA Resident Engineer at least 2 days prior to installation required unless department inspection is waived under C26-120.5), C26-1112.5.

4. Inspection of underpinning operations, construction and excavation of temporary or permanent cofferdams, caissons, braced excavated surfaces and other constructions or excavations affecting support of adjacent properties or buildings. (Plans required), C26-1112.6.

5. Evaluation of laboratory field tests for the verification of the magnitude of stabilized overburden pressure, C26-1103.4 (b), (c).

[redacted]

(Note that where foundation is to rest on, or be underlain by, nominally unsatisfactory bearing materials, a report based on soil tests, foundation analysis (including analysis of undisturbed samples), by architect of engir is required, C26-1103.5, C26-1103.5 (b) (2).)

VIII. MATERIALS, ASSEMBLIES FORMS AND METHODS OF CONSTRUCTION

CODE TEST METHOD Whenever the Building Code prescribes a method of testi such tests shall be made under the supervision of an ar or an engineer; or by a testing service or laboratory a to the PONYA Resident Engineer C26-106.2 (a) (1).

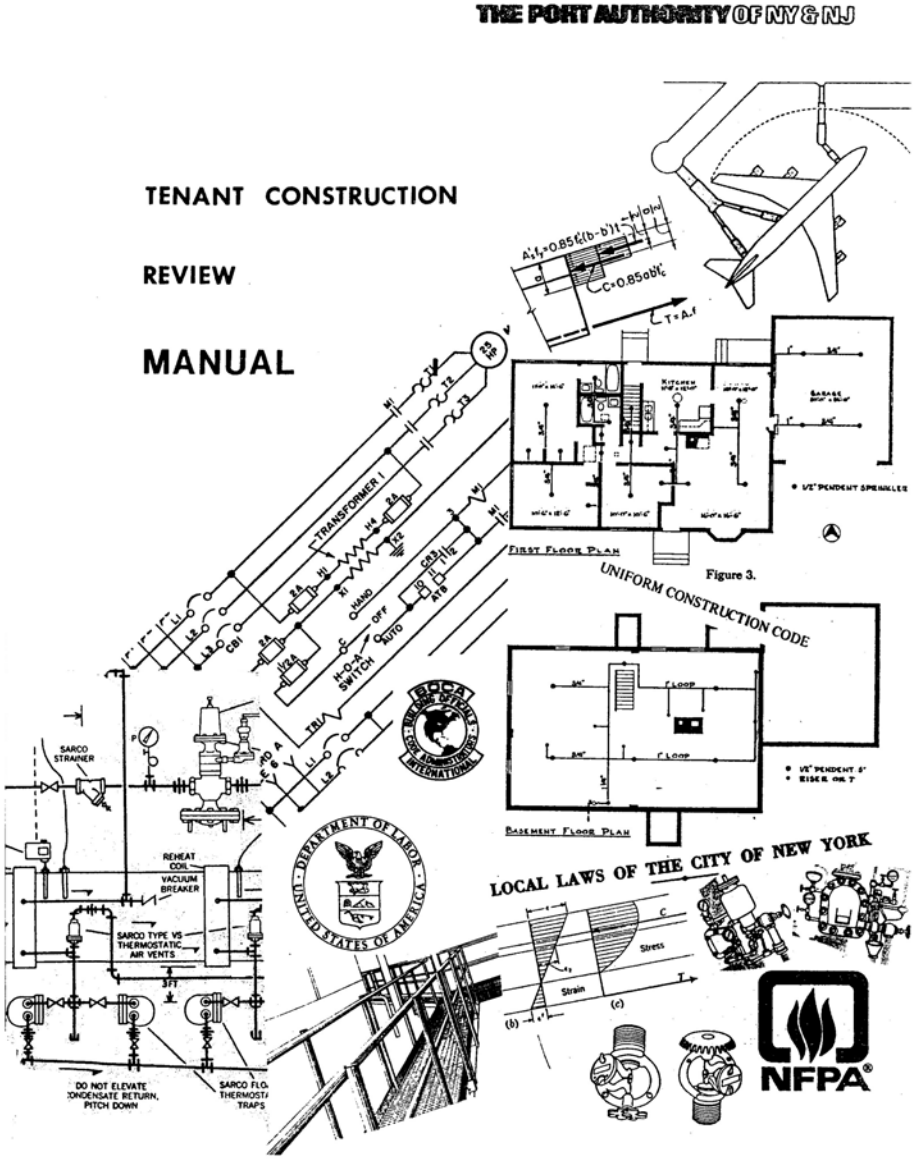
IX. INSPECTIONS DURING PROGESS OF WORK

The commissioner may accept signed statements by architects and engineers and supporting inspection and test reports without verifying insp or test by department inspectors, C26-120.5.

X. FINAL INSPECTION

The architect, engineer, or other person who supervised or superintend

Appendix B
TENANT CONSTRUCTION REVIEW MANUAL – 1979



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PREFACE

THE FOLLOWING IS A PRESENTATION OF TECHNICAL CRITERIA USED IN THE REVIEW OF TENANT CONSTRUCTION. IT HAS BEEN PREPARED IN AN EFFORT TO DEFINE THE CONCERNS OF THE TENANT CONSTRUCTION REVIEW UNIT

TABLE OF CONTENTS

INTRODUCTION

This pamphlet has been prepared to facilitate the proper and expeditious execution of review work in the Tenant Construction Review Unit. It tries to achieve this subdividing a job into separate disciplines and thus clarifying the possible scope of a project from functional and technical points of view. Detailed checklists based on Building Codes, prepared for each discipline, cover the main areas of design and detailing that are expected to receive special attention. Finally, design, safety and field coordination criteria additional to Building Code requirements are listed under each discipline.

It is hoped that this pamphlet will create a degree of consistancy in review work, and, will establish the basic minimum requirements which must be incorporated in the submitted plans and specifications.

CODES, RULES AND REGULATIONS

NEW YORK

(1) N.Y.C. Building Code

- (a) New Code, Effective December 6, 1968
- (b) Old Code, Effective 1938
- (c) N.Y.C. Electrical Code

(2) Rules of "The Board of Standards and Appeals" of N.Y.C.

(3) N.Y. State Labor Law
N.Y. State Energy Conservation Construction Code

NEW JERSEY

Since January 1977 all communities in the State are required to conduct their construction activities in accordance with the STATE UNIFORM CONSTRUCTION CODE which was made part of the New Jersey Administration Code (NJAC) as Chapter 23 of Title 5. Under the code the following subcodes have been adopted:

1. Building subcode - The BOCA Basic Building Code/1978

STANDARDS APPLICABLE IN ALL P.A. FACILITIES

1. Occupational Safety & Health Act (OSHA)
2. Federal Standard for Making Buildings Usable by the Physically Handicapped (P.L.-90-480) (ANSI A117.1)
3. Federal Floodproofing Regulations
4. F.A.A. - Standards (at Airports)

GENERAL REQUIREMENTS

1. Each application submitted must be accompanied by properly completed and executed application form, supplied to the tenant by the Port Authority.

2. For proper technical review besides the drawings, signed and sealed by the Registered Architect or the Professional Engineer, design criteria, specifications and calculations shall be submitted.

3. In order for the Port Authority to obtain the N.Y.C. Fire Department approval of the proposed fire alarm installation, three sets of the following information are required to be sent to the P.A., via the tenant's Alteration Application.

    a. A plot plan of the building showing the exact location of the fire alarm boxes and their relationship to site conditions, i.e., roads, sidewalk, fences, island, building exits, etc.

    b. Details of fire alarm pedestal, foundation, cable, installation procedures, etc.

    c. Specifications for fire alarm equipment, cable, installation procedures, etc.

    d. The above may be submitted in the form of Contract Drawings, sketches and formal specifications, for proper transmittal by P.A. to the NYC Fire Department.

4. Before starting work on sprinkler systems, dry chemical, Halon, or

7. Contractors shall obtain P.A. permits for any welding and hot work, in addition to being licensed by the state or the municipality, where applicable.

8. In order to effectuate the policy of the Port Authority of New York and New Jersey, the Tenant shall comply with all provisions of federal, state, municipal, local and departmental laws, ordinances, rules, regulations, and orders which might affect the contract and the performance thereof and those

FUNCTIONAL REVIEW

A Functional Review is a service to a tenant, when requested by him, supplementing his consultants' feasibility study, reviewing their design criteria, and acquainting them with specific pre-existing conditions of compliance with a Building Code or PANY/NJ criteria that would affect the proposed work. Functional Reviews shall be confined to fundamental concepts, items that may prohibit construction or substantially affect the design.

Submitted plans shall establish the applicable Codes and be accompanied by design criteria.

The scope of the Functional Review shall include, but not necessarily be limited to, the following items.

BUILDING CODE

1. Occupancy group and construction classification of the altered and adjacent areas.

2. Fire integrity of spaces in the building as it applies to shafts, rating of interior separations

4. Unusual structural conditions, including foundations, shall be referred to the structural reviewer.

5. Special mechanical or electrical problems affecting unusual environmental, energy or power commitments, or other deviations from Code provisions, shall be referred to the mechanical or electrical reviewer.

STRUCTURAL

A. PLANS, NOTES, SCHEDULES

Plans

1. Each plan shall contain the registration, seal, signature and address of the Architect or Engineer who prepared the plans. C26-110.2.

2. Structural plans shall contain the information required by the code. C26-110.2(b).

Notes

1. Where structural review is required, structural calculations shall be submitted.

2. Upon completion of the soils and foundation review, the structural reviewer shall take all soils and foundation documents to the Engineer of Soils for his review and comments.

3. Upon completion of the superstructure review, the structural reviewer shall take all superstructure documents to the Chief Structural Engineer for his review and comments.

4. Building frames shall be checked for stability and inhibition of side-sway and the effect of same on the slenderness ratio of the columns.

5. All materials, assemblies, forms or methods of construction and equipment that are subject to controlled inspection shall be listed on drawing. See Section 12 of this Manual.

6. Rules and Regulations listed on p. 5.4 shall also be referred to as required.

Schedules

B. CHECKLIST

The following is a checklist of the more significant code items with which the review will be concerned, but not limited to:

Loads

Dead Loads
Floor Live Loads
Live Loads for Sidewalks, Driveways & Railings
Roof Loads
Moving Loads
Partial Loading Conditions
Floor Live Load Reduction
Contributory Floor Areas
Wind Loads
Thermal Forces
Shrinkage
Distribution of Loads

Structural Work

General Requirements
Material & Methods of Construction
Inspection of Materials & Assemblies
Inspection of Methods of Construction
Use of Used & Unidentified Materials
Equivalent Systems of Design
Deferred Detailing
Combination of Loads
Load Tests
Fire Protection Requirements

Soils and Foundation

Depths of Foundations
Foundations at Different Levels
Slabs on Grades Construction
Borings
Probings & Geophysical Explorations
Foundation Loads
Classification of Soils Materials

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Administrative Requirements
Minimum Pile Penetrations
Minimum Spacing of Piles
Capping & Bracing of Piles
General Requirements for Installation of Piles
Allowable Axial Loads on Piles
Allowable Lateral Load

Pile Driving Operations

Equipment
Procedures

Pile Types

Timber Piles
Precast Concrete Piles
Cast-In-Place Concrete Piles
Compacted Concrete Piles
Steel "H" Sections
Concrete Filled Pipe Piles
Caisson Piles
Composite Piles
Underpinning
Stability

Inspection

Controlled Fills
Boring Operations
Piling; Installation and Testing
Subgrade for Footings, Foundation Piers & Walls
Support of Adjacent Properties or Building

Reports Required

Verification - Stabilized Overburden
Bearing Capacity of Nominally Unsatisfactory Bearing Material
Alternate or Similitude Method for Pile Load Verification
Substantiation of Higher Allowable Pile Loads

C. ADDITIONAL PORT AUTHORITY CRITERIA

Buildings designed and/or constructed by PANY/NJ that are being altered should be coordinated with the particular facility design group, especially for foundation requirements.

.5.3

RULES AND REGULATIONS RELATING TO STRUCTURAL ITEMS
(Applicable in N.Y.C.)

1. Rules and Regulations Relating to Resistance to Progressive Collapse Under Extreme Local Loads (Bldg. Dept.).

2. Rules and Regulations for the Design of Composite Construction with Metal Decks or Lightweight Concrete (Bldg. Dept.).

3. Rules Relating to Structural Designs Based on Electronic Computer Computations (Bldg. Dept.).

4. Rules and Regulations Relating to the Design and Installation of Curtain Wall Systems (Bldg. Dept.).

5. Rules for Application and Protection of Sprayed-On-Fireproofing (BSA Cal. #118-68-GR).

6. Rules and Regulations for Masonry Parapet Walls. (Bldg. Dept.)

7. Rules for Arc and Gas Welding and Oxygen Cutting of Steel Covering the Specifications for Design, Fabrication and Inspection of Arc and Gas Welded Steel Structures and the Qualification of Welders and Supervisors (BSA Cal. #1-38-SR).

8. Rules for Governing the Marking of Transparent Glass Doors and Fixed Adjacent Glass Sidelights (BSA Cal. #501-68-SR).

9. Rules for the Manufacture, Testing and Use of Concrete Masonry Units (BSA Cal. #639-40-SR).

5.4

MATERIALS, OPERATIONS AND EQUIPMENT

SUBJECT TO INSPECTION REQUIRED BY BUILDING CODE

The purpose of this section is to list some of the materials, operations and equipment which normally require the services of a licensed professional engineer in order to assure code compliance in conjunction with normal inspection procedures contained in Subarticles 106.0 and 107.0 of the N.Y.C. Building Code and Subchapter 2, sec. 5:22-2.6 of the New Jersey Uniform Construction Code.

MATERIALS

Concrete

Materials for all structural elements proportioned on the basis of calculated stresses 70 percent or greater, of the basic allowable values. Inspection includes making of preliminary tests for concrete and quality control and inspection at the batch plant.

Notes:

a. For general provisions relating to inspection see building code section and reference standards.

b. All structural materials subject to controlled inspection shall be tested and/or inspected at the place of manufacture and evidence of compliance shall be provided.

c. Mill, manufacturer's, suppliers' inspection and test reports will be accepted as evidence of compliance with the provisions of the code for all structural materials and assemblies not subject to controlled inspection.

OPERATIONS AND METHODS OF CONSTRUCTION

Steel

1. Welding operations and the tensioning of high strength bolts in connections where the calculated stresses in the welds or bolts are 50 percent or more of basic allowable values.

2. Inspection of the connection of fittings to wire cables, except where proof-loading to not less than 55 percent of ultimate capacity.

Concrete

1. Actual preparation of cylinders for strength tests.

2. The checking of all samples recovered for the purpose of strength tests for slump, admixtures, air content, unit weight, and temperature.

3. The checking of sizes and position of reinforcement.

4. The inspection of placement of concrete and maintenance of records and verification for:

    a. Temperatures
    b. Protections against excessive temperatures
    c. Curing
    d. Erection and connection of precast members
    e. Amount of water added in the field
    f. Tensioning of all prestressed elements
    g. Preplaced aggregate

5. Inspection for proper use of admixtures. Batch plant inspection required for all admixtures, other than air-entraining and water-reducing agents.

Aluminum

Inspection of welding operations where stresses in welds are 50% or more of basic allowable values.

Wood

Inspection of the fabrication of glued-laminated assemblies and of plywood components.

Reinforced Masonry

1. Fabrication of prefabricated units.

2. Placement and bedding of units; sizes of members, including thickness of walls and wythes; sizes of columns; the size and position of reinforcement, in place, and provisions for curing and protection against freezing for all reinforced masonry construction.

12.2

Unreinforced Masonry

Placement and bedding of units and sizes of members including thickness of walls and wythes; sizes of columns; and provisions for curing and protection against freezing for all masonry construction proportioned on the basis of structural analysis as described in the reference standard.

Soils and Foundations

1. Controlled Fills
2. Boring Operations
3. Piling; Installation and Testing
4. Subgrade for Footings, Foundation Piers and Walls
5. Support of Adjacent Properties or Building

Firestopping

Installation of all firestopping where required.

Fireproofing

All fireproofing other than the concrete encasement.

Notes:

a. For general provisions relating to inspection see appropriate building code sections and reference standard.

b. All construction operations designated for controlled inspection shall be inspected by the architect or engineer designated for controlled inspection during the performance of such operation.

c. Certification by the fabricator or erector, as applicable, will be accepted as evidence of compliance with the provisions of this code for all construction operations not subject to controlled inspection.

EQUIPMENT

Required ventilating systems including functioning of any required smoke detection and fire protection devices.
Refrigerating Systems
Boilers
Fuel Burning Equipment
Chimney Smoke Test (where applicable)
* Fire Standpipe System
* Fire Pumps
* Fire Alarm & Signaling System Electrical Test

12.3

* Sprinkler System
* Voluntary Ventilating System with required Smoke Detection and Fire Protection Devices
* Soil Percolation Test
* Plumbing and Gas Piping System

(* The test of this item shall be witnessed by a facility representative).

Notes:

a. For general provisions relating to inspection see appropriate building code sections and reference standard.

b. All equipment testing designated for controlled inspection shall be inspected by the architect or engineer designated for controlled inspection during the performance of such operation.

c. Certification by the manufacturer of equipment, as applicable, will be accepted as evidence of compliance with the provisions of this code for all equipment not subject to controlled inspection.

Appendix C
TENANT CONSTRUCTION REVIEW MANUAL – 1990

Engineering Quality
Assurance Division

TENANT CONSTRUCTION REVIEW MANUAL

March 1984
Revised March 1990

Engineering Department
THE PORT AUTHORITY OF NY & NJ

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A1	Specifications Governing The Flammability of Carpets.
A2	Specifications Governing The Flammability of Drapery And Curtain Materials.
A3	Specifications Governing The Flammability of Upholstery Material And Plastic Furniture.
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S1	Cement Plaster Ceilings.
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M2	Port Authority Bus Terminal North Wing - HVAC Criteria.
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F1	New York City Municipal Fire Alarm.
RFS-1	Airport Rampside Clearances.

SECTION 2 INTRODUCTION

This Manual is published to present the technical criteria to be considered by Tenants at Port Authority facilities in connection with construction work undertaken by a Tenant, which is in addition to other requirements under the agreement between the Port Authority and the Tenant. This Manual also covers the Port Authority Engineering Department scope-of-review of the design documents (plans, specifications, calculations and other documentation) submitted by Tenants in connection with proposed construction or alterations. It shall not be deemed to imply that there will not be additional reviews by other Port Authority Departments.

Reviews will not address the proposed aesthetic or functional aspects of the design.

Construction documents for Tenant alterations will be reviewed by the Engineering Department for compliance with applicable Codes and Port Authority Engineering Standards. In the absence of a specific code provision, this Manual sets forth the applicable standards to be followed by Tenants except as may otherwise be required of the Tenant. All design documents shall reflect the existing construction as well as the proposed work in order to determine compatibility with existing conditions at facilities.

In this regard a list of all documents and guidelines which the Facility has provided to the Tenant, and which affects the design, should become an integral part of the Tenant's contract document submission. If the subsequent review process will be aided by the inclusion of the construction documents itemized on this list, such documents should also be included in the submission.

The Tenant Construction Review Unit of the Engineering Department will review the Tenant Construction or Alteration Application submitted by the Tenant in accordance with the criteria included in this Manual. The responsibility for engineering design shall remain with the Tenant's Engineer or Architect preparing the design. The Tenant Construction Review Unit will not impose solutions to engineering problems but will comment on the design presented.

SECTION 3 GENERAL REQUIREMENTS

1. All proposed construction shall be submitted for reviev, in completed form, accompanied by a "Tenant Construction or Alteration Application," Form PA531, which shall be provided to the Tenant by the appropriate Port Authority line department.

   The line department shall specify to the Engineering Department, the technical disciplines to be reviewed for the submitted projects.

2. The design documents, such as drawings, reports, computations and specifications, required in connection with the proposed construction, shall be attached to and form a part of the Tenant Construction or Alteration Application, and shall reflect the existing construction as well as the proposed work, and be sealed and signed by the architect or engineer of record licensed to practice in the State in which the proposed construction is to be performed. The architect/engineer indicated on the Application shall be considered the A/E of record.

   Where the A/E of record submits documents prepared by other consultants, he is responsible for assuring that the documents from all the consultants are properly coordinated.

   Where other consultants have been acknowledged by the A/E of record, either in the Alteration Application or on the drawings, said consultants may seal and sign the documents they have prepared.

   Where the Tenant retains two or more independently functioning consultants, they each become an A/E of record for the scope of their work, for which each will be required to submit a separate Alteration Application, and each such consultant shall seal and sign the documents he submits.

   Responsibility for design or code compliance shall not be delegated to contractors.

3. Voluntarily installed systems, such as sprinklers, alarms, etc., shall comply with the provisions of the Building Codes for such systems.

4. Fire protection plans, as described in the New York City Building Code Section 27-228.1 (C26-124.1) et seq., shall be filed for review along with other design documents for construction projects in all the Port Authority facilities. After the approval of the project for construction, and before a certificate of occupancy is issued, one (1) copy of these plans shall be submitted to the manager of the facility where the project is located and two (2) copies shall be filed with the Quality Assurance Division of the Engineering Department.

5. In accordance with the policy of the Port Authority of New York and New Jersey, the Tenant shall comply with the provisions of all federal, state, municipal, local and departmental laws, ordinances, rules, regulations and orders that may affect the contract and all individuals involved therein. Where stricter requirements apply, i.e., those contained in the specifications or drawings, they shall be followed. The Tenant or his agents shall not apply for any variance, license, waiver or permit in the name of or on behalf of the Port Authority.

D. Special structural conditions, including foundations.

E. Special or unusual mechanical or electrical problems affecting environmental, energy or power requirements.

F. Deviations from Code provisions.

G. Existing structures shall be revieved for existing Code violations.

III. PANY/NJ CRITERIA

Note: See the subsequent sections of this Manual for more specific criteria.

A. Sprinklers in conveyor spaces inaccessible to firefighting equipment. Ceilings with lay-in panels are considered to be inaccessible.

B. Adaptation of Code and NFPA standards to loading bridges, hangars, terminal buildings, etc.

C. Protection of airport buildings from potential fuel spillage fires.

D. Requirements for draperies, furniture, etc.

E. PVC pipes, ducts, conduits and insulation for wires shall not be used within buildings.

V. COORDINATION WITH FACILITIES

A. Electrical: New power requirements shall be indicated.

B. Water supply: Coordination of any demand for chilled water, high temperature water, domestic water, high pressure sprinkler supply water, and connections to the fire protection loop, shall be fully described.

SECTION 6 STRUCTURAL

I. GENERAL

A. The scope of the structural reviev shall comprise compliance with the applicable Codes, standards, and design criteria listed below.

B. Computations shall be submitted with all structural plans.

II. CODES AND REGULATIONS

A. New York City:

1. New York City Building Code.

2. Rules and Regulations of the Department of Buildings, such as:

   a. Resistance to Progressive Collapse Under Extreme Local Loads.

   b. Design of Composite Construction with Metal Decks or Lightweight Concrete.

   c. Structural Designs Based on Electronic Computer Computations.

   d. Design and Installation of Curtain Wall Systems.

   e. Masonry Parapet Walls.

B. New Jersey:

New Jersey Uniform Construction Code (NJUCC).

C. City of Yonkers:

The Uniform Fire Prevention and Building Code of New York State.

III. STANDARDS

AASHTO American Association of State Highway and Transportation Officials.

AREA American Railway Engineering Association.

V. PORT AUTHORITY DESIGN CRITERIA

A. All structures, including those in New York State, shall be designed for earthquake Zone 2 forces. BOCA provisions shall apply, unless more stringent local laws are adopted.

B. Roof Snow Load in New Jersey:

In calculating snow loads, BOCA "Ground Snow Load" shall be 25 psf.

C. Ceilings:

1. Cement plaster ceilings - see Attachment S1.

2. Lightweight ceilings in New Jersey - see Attachment S2.

3. Lightweight ceilings in WTC - see Attachment S3.

D. Vehicular Traffic (Airports):

1. Elevated roadways shall be designed for seismic forces according to the "Guide Specifications for the Seismic Design of Highway Bridges" by AASHTO, or the relevant State DOT standards for earthquakes, whichever is stricter.

2. The minimum loading for departure and arrival ramps servicing passenger terminals shall be HS 15-44. Use AASHTO design. All other ramps servicing cargo facilities or road overpasses: AASHTO design using HS20 minimum loading.

E. Highway Signs and Luminaries:

Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals; American Association of State Highway and Transportation Officials (AASHTO).

F. Loading Bridges (Airports):

1.	Minimum Live Loads:	Floor (LL) - 40 psf or a concentrated load of 300 lbs. Roof (RLL) - as per local code.
2.	Minimum Wind loading (WL):	12.5 psf lateral for the extended (operational) mode (combined windward and leeward pressure). 25 psf lateral for the retracted (stowed) mode (combined windward and leeward pressure).

3. Minimum Load Combinations:

   a. Extended: DL + LL + RLL
      DL + LL + 1/2RLL + WL
      DL + WL

   b. Retracted: DL + RLL
      DL + RLL + WL
      DL + WL

4. Minimum Stability Factors: Overturning 1.5
   Sliding 1.5
   Uplift 1.5

5. Codes (except where stricter requirements are noted):

   a. New York City - New York City Building Code.

   b. New Jersey - The Construction Code (BOCA).

V. DETAILS OF STRUCTURAL REVIEW

The following are representative of details reviewed:

A. The design calculations shall include but not be limited to:

1. Design criteria and applicable Codes.

2. Reference Standards.

3. Materials.

4. Type of construction and foundations.

5. Design loads; including wind and other existing forces.

6. Machinery and equipment loads in excess of 1000 lbs. including an evaluation of any potential vibration.

7. Allowable soil bearing capacity.

8. Pile type and capacity.

9. Design analysis and drawings of all connections other than AISC standard framed or seated beam connections.

10. Analysis and sketches of expansion joints.

11. Design of bracing systems and rigid joints.

12. Wind drift and deflections.

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13. Ponding.

14. Computer print-outs and users' manuals.

15. Investigation of superimposed loads from adjacent construction on structure and foundation.

16. Investigation of existing structural system and foundations under additional loads due to alterations.

17. Where it has been established that post-construction settlements of foundations are to be monitored, the monitoring program, the limits of such differential settlement that the structure can tolerate, and the

C. Specifications:

1. Shall clearly define the scope of work and materials required for the contract.

2. Shall include limitations, restrictions or conditions due

SECTION 14 MATERIALS, OPERATIONS, AND EQUIPMENT APPROVAL AND INSPECTION

I. GENERAL

The purpose of this section is to outline:

A. The requirements for acceptance (approval) of materials, assemblies, forms, methods of construction, and the intended use of equipment.

B. The requirements for inspection of materials and assemblies and construction.

II. CODES AND REGULATIONS

A. New York City:

1. New York City Building Code and its Reference Standards.
2. New York City Fire Prevention Code and Directives.
3. New York City Electrical Code.
4. New York City Local Laws.
5. Rules of the Board of Standards & Appeals (BS&A).
6. New York State Labor Laws.
7. New York State Multiple Dwelling Laws (Hotels).
8. New York State Energy Conservation Construction Code.
9. Directives and Memoranda of the Department of Buildings.

B. New Jersey:

1. New Jersey Uniform Construction Code, its bulletins and the sub-codes (BOCA, etc.) with their Supplements and Reference Standards.
2. Applicable Flood Controls.
3. New Jersey Uniform Fire Code.

C. The City of Yonkers:

The Uniform Fire Prevention and Building Code of New York State.

III. NEW YORK CITY

A. Approval/Acceptance of Materials, Equipment, etc.:

No material, assemblies, forms, method of construction, equipment, machinery and devices will be acceptable for the intended use unless:

1. Accepted by the Code test method by the Materials and Equipment Acceptance (MEA) division of the Office of the Commissioner of the Buildings Department of New York City.

2. Or approved by the New York City Board of Standards and Appeals (BS&A).

Resolutions of MEA or BS&A shall be submitted for review along with other review documents. Manufacturers' or distributors' letters shall not be acceptable.

The above requirements are abstracted from New York City Building Code Sections C26-106.1, 106.2, 107.1 and 107.2.

B. Inspection:

Controlled Inspection (Code Sections C26-106.3 and 107.3):

Controlled fill .....

Underpinning C26-1112.6

Concrete ..... Code Tables 10-1, and 10-2

Precast Concrete .....

IV. NEW JERSEY

A. Approval/Acceptance of Materials, Equipment, etc.:

Acceptance of materials, assemblies, equipment, forms, methods of construction, etc., shall be based on authenticated reports from approved agencies indicating compliance with accepted engineering practice. See BOCA Building Code Section 1300, BOCA Mechanical Code Section 4.02.0, and the Appendix A of these Codes for approved agencies and testing standards.

Note: The P.A. Engineering Department has accepted approvals from the New York City Board of Standards & Appeals (BS&A) and Material and Equipment Acceptance (MEA). See III.A above.

B. Inspection:

Construction Control - as per NJUCC 5:23-2.21(c):

1. The tenant shall assign a "responsible person in charge of the work" (RPIC), who shall be responsible for:

   a. Review and approval of all documents pertaining to the construction phase.

   b. Verification of all controlled materials.

   c. Special inspection of critical construction components (see list in paragraph 2 below).

   d. Necessary services to determine that the work is proceeding according to the approved documents.

   e. At the completion of work, the RPIC shall submit a report to the P.A. attesting to the satisfactory completion of the project, including a list of deviations from the approved documents.

2. The following is the list referred to in the requirement

a. Foundations:

i. Boring operations.....BOCA, Section 1203.1

ii. Subgrade for foundations.

iii. Controlled fill.

iv. Piling (installation, testing, cut-off and tip elevations).....Section 1213.12

v. Support of adjacent properties.

vi. Underpinning.

vii. Foundations and walls up to grade prior to backfilling.

b. Structure:

i. High strength bolts - see BOCA Building Code Table 1308.3.2.

ii. Welds.

iii. Concreting operations - see BOCA Building Code Table 1308.4.4.

c. Plumbing:

3. The contractor shall, at the completion of the construction, certify that the construction has been executed in substantial accord with the approved documents, with all pertinent deviations specifically noted.

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THE PORT AUTHORITY OF NEW YORK & NEW JERSEY

M E M O R A N D U M

To: W. Biancamano, R. Catlin, P. Ciano, E. Chalom, G. Doherty, E.K. Farrely, W. Fife, P. Galya, R. Goode, G. Jensen, J. Kau, J. Miller, M. Ronis, S. Smolenski, E. Takla, V. Volpicelli
From: Ennala Ramabhushanam
Date: October 23, 1990
Subject: TENANT CONSTRUCTION REVIEW MANUAL - AMENDMENT #1

Copy To: A. Brociner, P. Cooper, V. Dovletian, E. Fasullo, M. Poliacof, O. Suros, TCRU Staff

Listed below are the pages of the Tenant Construction Review Manual with. The that are amended and must be replaced by the pages attached he

IV. PORT AUTHORITY DESIGN CRITERIA

A. All structures, including those in New York State, shall be designed for earthquake Zone 2 forces. BOCA provisions shall apply, unless more stringent local laws are adopted.

B. Roof Snow Load in New Jersey:

In calculating snow loads, BOCA "Ground Snow Load" shall be 25 psf.

C. Ceilings:

1. Cement plaster ceilings - see Attachment S1.

2. Lightweight ceilings in New Jersey - see Attachment S2.

3. Lightweight ceilings in WTC - see Attachment S3.

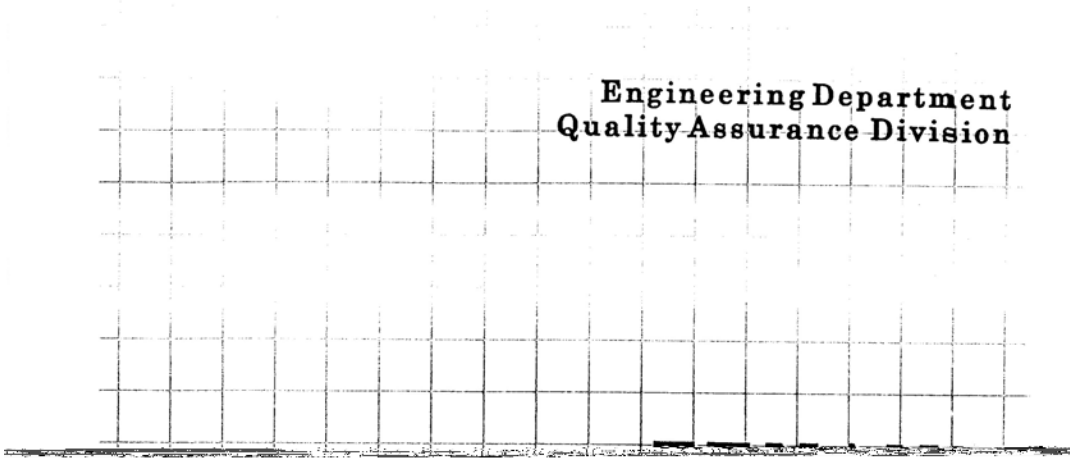
* 4. For the suspension of lightweight ceilings to resist earthquake forces see ASTM E580.

D. Vehicular Traffic (Airports):

1. Elevated roadways shall be designed for seismic forces according to the "Guide Specifications for the Seismic Design of Highway Bridges" by AASHTO, or the relevant State DOT standards for earthquakes, whichever is stricter.

2. The minimum loading for departure and arrival ramps

Appendix D
TENANT CONSTRUCTION REVIEW MANUAL – 1997



SECTION 1

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Historical Notes:
First published 1971, Rev. 1979; updated March 1984, Rev. March 1990.

LIST OF ATTACHMENTS

A1	Standard for Interior Plastic Signs
A2	Specifications Governing the Flammability of Drapery and Curtain Materials in Unsprinklered Areas.
A3	Specifications Governing the Flammability of Upholstery Material and Plastic Furniture in Unsprinklered Areas.
A4	Specifications Governing the Flammability of Plastic Laminate and Wood Veneer Furniture.
S1	Plaster Ceiling Design Standards.
S2	Lightweight Ceiling Design Criteria.
S3	Modifications to the New York City Building Code Earthquake Loads.
C1	Civil Standard Details.
C2	Protection of Underground Pipes.
M1	Port Authority Bus Terminal - HVAC Design Criteria
E1	Port Authority Bus Terminal - Electrical Design Criteria.
F1	New York City Municipal Fire Alarm.
RFS-1	Airport Rampside Clearances.

SECTION 2

INTRODUCTION

This Manual presents the technical criteria to be followed by Tenants, and their architectural and engineering consultants, at all Port Authority (PA) facilities in connection with construction work undertaken by a Tenant. These technical criteria are in addition to other requirements contained in the lease agreement between the Port Authority and the Tenant. This Manual also covers the Port Authority Engineering Department's scope-of-review of the design documents (plans, specifications, calculations and other documents) submitted by Tenants in connection with proposed construction or alterations. It shall not be deemed to imply that there will not be additional reviews by other Port Authority Departments.

The Design Standards (Tenant Construction Review) Unit of the Engineering Department's Quality Assurance Division will review the Tenant Construction or Alteration Application submitted by the Tenant in accordance with the criteria contained in this Manual. The responsibility for architectural and engineering design shall remain with the Tenant's Architect or Engineer (A/E) of record. The Design Standards Unit will not impose design solutions but will only comment on the design presented.

Reviews will not address the proposed aesthetic or functional aspects of the design.

Construction documents for Tenant construction or alterations will be reviewed by the Design Standards Unit for compliance with all applicable Codes and Port Authority Technical Standards. In the absence of a specific code provision, this Manual sets forth the applicable standards to be followed by Tenants except as may otherwise be required. All design documents shall reflect the existing construction as well as the proposed work in order to determine compatibility with existing facility conditions.

In this regard, a list of all reference documents and guidelines which the Facility has provided to the Tenant, and which affect the design, should become an integral part of he Tenant's contract document submission. If the review process will be aided by the inclusion of these reference documents, such documents should also be included in the submission.

SECTION 4

CONCEPTUAL REVIEW

I. GENERAL

At the Tenant's request, a Conceptual Review will be performed to supplement the consultants' feasibility studies. These reviews will inform the consultants of established design criteria, pre-existing conditions that determine code compliance, and Port Authority requirements affecting the proposed work. The conceptual review shall be limited to fundamental concepts and items related to the criteria in this Manual that may significantly affect the design. The review will not address aesthetics or

E. Special or unusual mechanical or electrical problems affecting environmental, energy, or power requirements.

F. Deviations from Code requirements.

G. Existing structures shall be reviewed for existing Code violations.

III. **PANY/NJ CRITERIA**

See the subsequent Technical Sections of this Manual for specific criteria.

IV: **COORDINATION WITH FACILITIES**

A. Electrical: New power requirements shall be indicated.

B. Water supply: Coordination of any demand for chilled water, high temperature hot water, domestic water, high pressure sprinkler supply water, and connections to the fire protection loop, shall be fully described.

C. Any work affecting fuel lines shall be indicated.

SECTION 6

STRUCTURAL

I. GENERAL

A. The scope of the structural review shall comprise compliance with the applicable Codes, standards, and design criteria listed below.

B. Computations shall be submitted with all structural plans.

II. CODES AND REGULATIONS

A. New York City:

1. New York City Building Code.

2. Rules of the City of New York, Title 1, Department of Buildings.

B. New Jersey:

New Jersey Uniform Construction Code (NJUCC).

C. City of Yonkers:

New York State Uniform Fire Prevention and Building Code.

III. STANDARDS

AASHTO	American Association of State Highway and Transportation Officials.
AREA	American Railway Engineering Association.
ANSI/EIA/TIA-222-E	Structural Standards for Steel Antenna Towers and Antenna Supporting Structures.

IV. PORT AUTHORITY DESIGN CRITERIA

A. In the absence of provisions for earthquake design in the New York State Uniform Fire Prevention and Building Code, the New York City Building Code Shall be used for earthquake design in the City of Yonkers.

For modifications to the New York City Building Code Earthquake Loads, See Attachment S3.

B. Floors in certain areas of the Port Authority Bus Terminal South Wing are of light weight low strength concrete construction. Concrete anchors are not permitted in these light weight slabs for the attachment of hangers for supporting ducts, utilities, ceilings, and other miscellaneous loads. These loads shall be supported directly from floor beams or supplementary framing connected to the floor beams. Information regarding the locations of the light weight slabs can be obtained from the Facility Tenant Liaison Office.

In areas where concrete inserts are permitted, only approved type stainless steel anchors rated for shock and vibration loads and elevated temperature shall be used.

C. Ceilings:

1. Plaster Ceiling Design Standards - see Attachment S1.

2. Lightweight Ceiling Design Criteria - see Attachment S2.

D. Vehicular Traffic:

1. Elevated roadways shall be designed for all loadings, including seismic effects, in accordance with the AASHTO "Standard Specifications for Highway Bridges" and the relevant State DOT Standards. In New Jersey, roadways providing access to interstate freight shall be designed for HS 25 loading.

2. The minimum loading for the departure and arrival ramps servicing airport passenger terminals shall be HS 15-44

AASHTO highway loading. All other ramps servicing cargo facilities or road overpasses shall be designed for HS20 AASHTO highway loading.

E. Highway Signs and Luminaries:

Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals; American Association of State Highway and Transportation Officials (AASHTO).

F. Aircraft Loading Walkways (Airports):

1. Minimum Live Loads: Floor (LL) - 40 psf or a concentrated load of 300 lbs. Roof (RLL) - as per local code.

2. Minimum Wind Loading (WL) 12.5 psf lateral for the extended (operational) mode (combined windward and leeward pressure). 25 psf lateral for the retracted (stowed) mode (combined windward and leeward pressure).

3. Load Combinations:

a. Extended: DL + LL + RLL
DL + LL + 1/2RLL + WL
DL + WL

b. Retracted: DL + RLL
DL + RLL + WL
DL + WL

4. Minimum Stability Factors:

Overturning	1.5
Sliding	1.5
Uplift	1.5

6-3

V. **DETAILS OF STRUCTURAL REVIEW**

The following are representative of items reviewed:

A. The design calculations shall include but not be limited to:

1. Design criteria and applicable Codes.
2. Reference Standards.
3. Materials.
4. Type of Construction and foundations.
5. Design loads, including wind and other forces.
6. Machinery and equipment loads in excess of 1000 lbs. Including an evaluation of any potential vibration.
7. Allowable soil bearing capacity.
8. Pile type and capacity.
9. Design and details of all connections other than AISC standard framed or seated beam connections.
10. Location and details of expansion joints.
11. Bracing systems and moment-resisting frames.
12. Deflections and wind drift.
13. Ponding.
14. Investigation and superimposed loads from new construction on existing structure and foundation.
15. Investigation of existing structural system and foundations under additional loads due to alterations.
16. Where it has been established that post-construction settlements of foundations are to be monitored, the

monitoring program, the limits of differential settlement that the structure can tolerate, and the necessary adjustments shall be submitted for review.

B. Drawings shall include, but not be limited to, the following information:

1. Applicable Code and Reference Standards.
2. Materials.
3. Design live loads, wind, and other forces.
4. Machinery, equipment, and other concentrated loads in excess of 1000 lbs. Including footprints or support layout(s).
5. Allowable soil bearing capacity.
6. Pile type, capacity, and minimum tip elevation.
7. Column schedule showing accumulated design load at each level for dead and live loads.
8. Stress diagram(s) for trusses.
9. Datum and ground water elevations.
10. Typical moment connection details.
11. Details of non-standard connections.
12. Construction sequence.

C. Specifications shall include, but not be limited to:

1. The scope of work and materials required for the construction or alteration.
2. Limitations and restrictions due to the existing conditions and/or requirements for the methods of construction or staging.

ATTACHMENT S3

MODIFICAITONS TO THE NEW YORK CITY BUILDING CODE EARTHQUAKE LOADS

Revise Table No. 23-P of RS 9-6 by:

a. Adding after II.1.b.
"c. Overhead Signs .. .. 2.00";

b. Adding after II.3.
"4. Anchorage for suspended ceilings weighing more than 4 psf without the weight of light fixtures .. .. .. 0.75";

c. Adding after III.1.
"2. Elevator and counterweight guardrails and supports 1.25"

"3. Sprinkler piping[5] .. .. 2.00"

"4. Gas and high hazard piping .. .. .. 2.00"

"5. Other piping[6] .. .. 0.67"

"6. HVAC ducts[6] .. .. 0.67"

d. Adding the following notes after Note 4 at the bottom of the table:

"5. The design of seismic restraints for sprinkler piping in compliance with NFPA 13 using a design acceleration of 0.15 is acceptable in lieu of compliance with these provisions.

6. Seismic restraints are not required for any of the following conditions for other pipe systems of HVAC ducts:

i. Piping or ducts suspended by individual hangers 12 inches or less in length from the top of the pipe or ducts to the supporting structure.

ii. Piping in boiler and mechanical rooms which has less than 1-1/4 inches inside diameter.

S3-1

iii. Piping in other areas which has less than 2-1/2 inches inside diameter.

iv. Ducts which have a cross-section area less than 6 square feet."

SECTION 14

MATERIALS, OPERATIONS, AND EQUIPMENT APPROVAL AND INSPECTION

I. GENERAL

The purpose of this section is to outline:

A. The requirements for acceptance (approval) of materials, assemblies, forms, methods of construction, and the intended use of equipment.

B. The requirements for inspection of materials, assemblies, and construction.

II CODES AND REGULATIONS

See the Technical Sections of this Manual

III. NEW YORK CITY

A. Approval/Acceptance of Materials, Equipment, etc.:

No material, assemblies, forms, method of construction, equipment, machinery, and devices will be acceptable for the intended use unless:

1. Accepted by the Code test method by the Materials and Equipment Acceptance (MEA) Division of the New York City Department of Buildings.

2. Or, previously approved by the New York City Board of Standards and Appeals (BS&A).

MEA or BS&A resolutions of approval shall be submitted for review along with other review documents. Manufacturers' or distributors' letters are not acceptable. The above requirements are abstracted from New York City Building Code, Sections 27-130, 27-131, 27-134, and 27-135.

B. Inspection:

Controlled Inspection (Code Sections 27-132 and 27-136)

1. All materials, equipment, and construction designated by the Code for "controlled inspection" shall be inspected and/or tested to verify compliance with the Code.

2. Controlled inspection shall be made and witnessed by or under the direct supervision of a registered architect (RA) or professional engineer (PE), retained by the tenant and acceptable to the architect or engineer responsible for the plans. The inspecting RA or PE shall be independent of the contractor.

3. All items subject to controlled inspection shall be listed on the title sheet of the plans, or the sheet immediately following.

The following list contains items subject to controlled inspections, as well as the items' relevant Code sections, where applicable. Effort has been made to make this list as inclusive as possible. Other items subject to controlled inspection, as required by NYC Building Code, that have been omitted in this list must also comply.

Borings or test pits	27-720
Piles	27-721
Subgrade for foundation	27-723
Controlled fill	27-679(a)
Underpinning	27-724
Concrete	Code Tables 10-1, 10.2
Formwork	27-1035(b)

Steel:	
i. Welding	Code Table 10.2
ii. H.S. bolts	Code Table 10-2
iii. Cable fittings	Code Table 10-2
Aluminum, welding	Code Table 10-2
Laminated wood	Code Table 10-2
Masonry	Code Table 10-2
Exterior Wall Insulation and Finish Systems	27-335.1(c)13
Firestopping	27-345(h)
Spray-on fireproofing	27-324(f)
Heating and combustion ..... equipment	27-793(a), 27-794(b)
Ventilation systems	27-779, 27-780
Refrigeration systems	27-781
High pressure systems	Department of Buildings, Rules Section 20-02(b)(2)(i)
Chimney smoke vent	27-856(e), 27-879(b)
Welding of gas distribution piping	RS-16, P115.8(h)
Curtain/Panel Wall	Rules of the City of New York, Title 1, Department of Buildings, Chapter 32.

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Structural integrity during ..... construction operations	Rules of the City of New York, Title 1, Department of Buildings, Rules, Chapter 16.

IV. NEW JERSEY

A. Approval/Acceptance of materials, Equipment, etc.:

1. Acceptance of materials, assemblies, equipment, forms, methods of construction, etc., shall be based on certified test reports from approved agencies. See BOCA Building Code Chapter 17 and BOCA Mechanical Code Chapter 4, as amended by New Jersey Uniform Construction Code (NJUCC).

   Note: Approvals from the New York City Material and Equipment Acceptance (MEA) Division are acceptable. See Paragraph III.A.1.

2. See NJUCC, Section 5:23-4.26 for certification of building elements, such as trusses, fire walls, fire separation walls, wall panels, pre-stressed/prefabricated floor or roof panels and pre-engineered structural frames.

B. Inspection:

Construction Control - as per NJUCC Section 5:23-2.21(e):

1. The tenant shall assign a "responsible person in charge of the work" (RPIC), who shall be responsible for:

   a. Review and approval of all documents pertaining to the construction phase.

   b. Verification of all controlled materials.

   c. Special inspection of critical construction components (see list in paragraph 2 below).

d. Necessary services to determine that the work is proceeding according to the approved documents.

e. At the completion of work, the RPIC shall submit a report to the P.A. attesting to the satisfactory completion of the project, including a list of deviations from the approved documents.

2. All items subject to "special inspection," stated in item B.1.c, shall be listed on the title sheet of the plans, or the sheet immediately following.

The following is a list of items subject to "special inspection of critical construction components." Effort has been made to make this list as inclusive as possible based on the current codes adopted by the NJUCC. Other construction items subject to "special inspection" as required by these codes that have been omitted in this list must also comply:

a. Inspection of Fabricators ..... BOCA, Section 1705.2 as amended by NJUCC.

b. Steel Construction:

i. Material Receiving ..... BOCA, Section 1705.3.2.

ii. Erection:
Installation of High strength bolts..... BOCA, Section 1705.3.3.1.

Welding ..... BOCA, Section 1705.3.3.2.

Details ..... BOCA, Section 1705.3.3.3.

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c. Concrete Construction:

i.	Materials	BOCA, Section 1705.4.1
ii.	Installation of Reinforcing and Prestressing Steel	BOCA, Section 1705.4.2.
iii.	Formwork	BOCA, Section 1705.4.3.
iv.	Concreting Operations...	BOCA, Section 1705.4.4.
v.	Inspection during Prestressing	BOCA, Section 1705.4.5.
vi.	Manufacturer of Precast Concrete	BOCA Section 1705.4.6.
vii.	Erection of Precast Concrete	.BOCA Section 1705.4.7.

d. Masonry Construction ..... BOCA, Section 1705.5.

e. Wood Construction ..... BOCA, Section 1705.6

f. Foundations:

Prepared fill	BOCA, Section 1705.7
Pile foundations	BOCA, Section 1705.8

	Pier foundations	BOCA, Section 1705.9
g.	Wall panels and veneers	BOCA, Section 1705.10
h.	Sprayed fire resistive materials	BOCA, Section 1705.12
i.	Exterior insulation and finish systems	BOCA, Section 1705.13.
j.	Special Cases	BOCA, Section 1705.14

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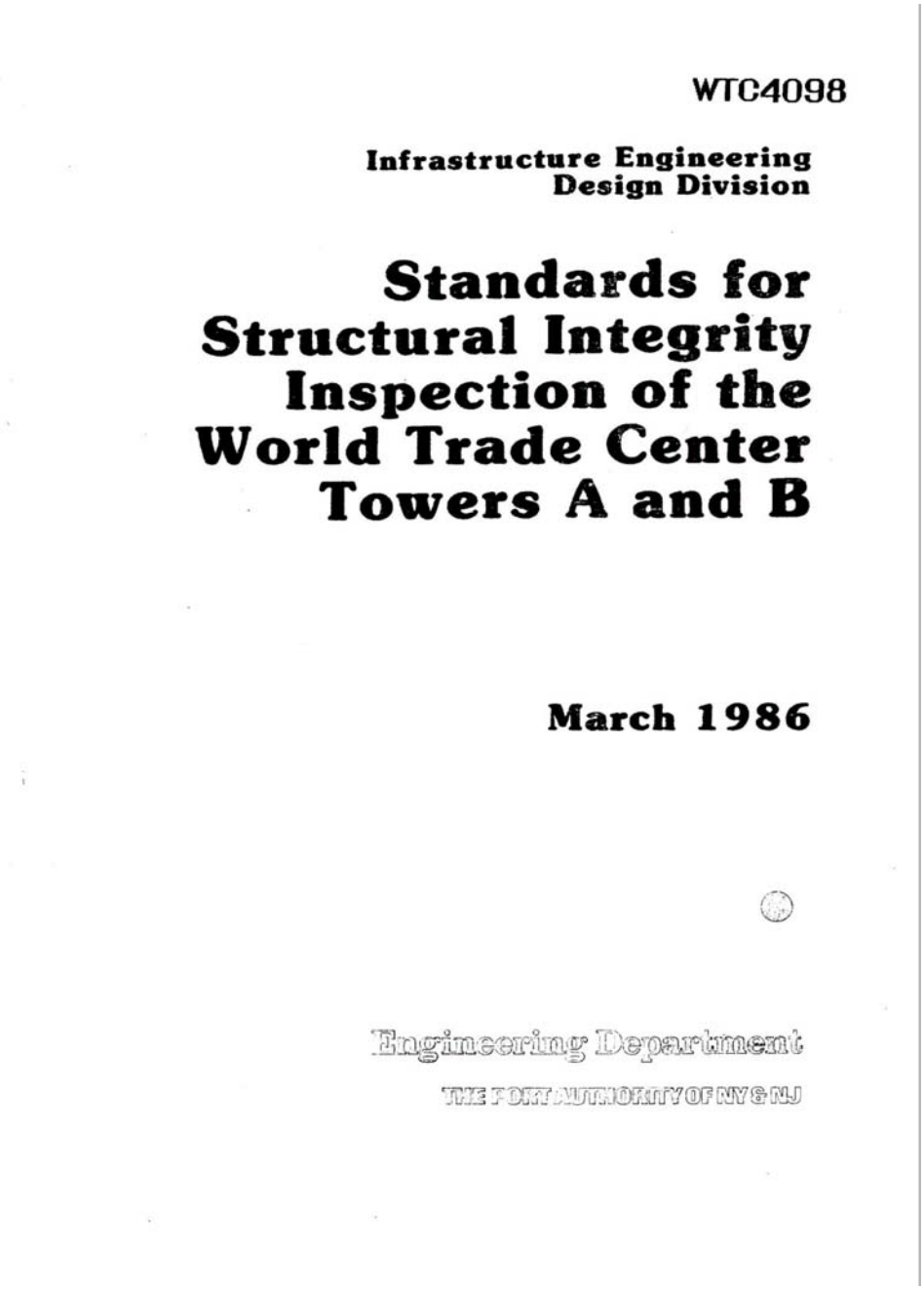
Appendix E
STANDARDS FOR STRUCTURAL INTEGRITY INSPECTION OF WTC TOWERS A & B



WTC4098

Infrastructure Engineering
Design Division

Standards for Structural Integrity Inspection of the World Trade Center Towers A and B

March 1986

Engineering Department

THE PORT AUTHORITY OF NY & NJ

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File: P802
March 1986

WORLD TRADE CENTER - BUILDINGS 1 AND 2

STRUCTURAL INTEGRITY STANDARDS

LESLIE E. ROBERTSON ASSOCIATES

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I. INTRODUCTION

A. Purpose, Character and Scope of the Program

These Standards are designed to assist the Port Authority in the evaluation of the on-going structural integrity of the twin towers of the World Trade Center, New York. To date, the towers have performed well, and maintenance costs are reported to be as anticipated. Further, tenant complaints of structure motion, perhaps the largest single predicator of excessive swaying motion, are reported to be negligible. Still, should degradation of the structural system take place with time, remedial action is essential. These Standards, then, are designed to anticipate degradation, should it occur, and to allow for systematic repair.

The Standards make use of three separate approaches to the providing of a suitable framework for the monitoring of the structural integrity of WTC 1 and WTC 2...the two 110-story towers of the World Trade Center:

1. First Approach - Statistical Inspections

Under the first, periodic statistical visual inspections of selected structural components in higher-potential trouble areas will be made. It is proposed that, initially, this work be accomplished by qualified outside consultants under PANYNJ management. In the future, where this course is judged to be advantageous this task can be performed by PANYNJ in-house personnel. The periodic inspections will be supplemented by occasional visual inspections made possible by the exposure to view of structure during tenant remodeling or general maintenance work. Every opportunity should be used to take advantage of these more-or-less random exposures of the structural system. Occasional inspections would be done in-house where the involved area is not large enough to justify the use of an outside consultant.

2. Second Approach - Reports

In the second approach, various reports are examined as possible symptoms of underlying structural problems. Maintenance reports of non-structural repairs, water leakage and tenant complaints about unusual building movement, vibration or noise are examples of such reports.

3. Third Approach - Continued Measurements

In the third procedure, the performance of systems within the structure is evaluated through the continuing measurement of movement or deformation, using appropriate tests and instruments. These systems range in size from relatively small individual components repeated many times throughout the buildings, to an entire tower structure.

The accumulated inspection reports and measured test data in time will form a chronological record which can be consulted in assessing the significance of observed structural conditions or measurements. The periodic inspection procedure is adapted from the Port Authority Engineering Department "Standards for In-depth Structural Integrity Inspection of Buildings." The other sections of the program are designed to respond to needs dictated by the nature of the specific structures and the building occupancy, and so are unique to these towers.

B. Feedback and Revision

It is anticipated that feedback from the application of the program may generate changes in procedure and scope. These Standards then, are viewed as an evolving system, to be amended as needed.

II. GENERAL DESCRIPTION OF THE BUILDINGS

The two tower buildings rise more than 1,400 feet above their foundations, 1,438 feet for WTC 1 and 1,432 feet for WTC 2. The TV mast raises that height to 1,800 feet for WTC 1. Each tower has 111 floors, 116 framed levels including below grade service levels, with nearly one acre of space on a typical floor.

The towers were the first in the new family of very tall buildings to use the exterior walls as a thin tubular shell in structural steel; the tubular shell cantilevers from its foundations to supply all of the needed resistance to wind and earthquake forces and to stabilize the core against lateral buckling. Lateral strength is attained in this way without the need for conventional rigid-frame construction, and the story height is reduced to 12 feet. Gravity loads are carried by core and exterior columns.

Different grades (yield points) of steel were used to equalize the dead load stresses and shortening of the very tall columns while accommodating imposed loads from wind and gravity. The major trusswork spanning the railroad tracks also used a variety of steel grades to produce uniform deflection. A rooftop space frame in each tower controls the expansion and contraction due to unequal column temperatures, and provides also a "root" for the 362 foot high TV mast now atop WTC 1 (provisions for a similar tower are incorporated into WTC 2).

The prefabrication of structural components was developed to a point never before achieved in high-rise buildings:

- The tubular shell of the outside walls is made up of nearly 6,000 wall panels, generally 36 feet by 10 feet, three stories high and encompassing three columns in width, which were stacked one above the other, the column ends field bolted together, and the spandrels field bolted to the spandrels of adjacent panels. In this way field welding was held to a minimum in these members and connections subject to stress reversal from wind excitation. Some wall units were 56 feet by 10 feet and weigh as much as 54 tons.

- The prefabricated floor units in the typical tenant floors of each tower were generally 20 feet wide, with 60 foot and 36 foot lengths on different sides of the building; each floor unit contained steel deck and electrical raceways. Double trusses span the 60 foot and 36 foot directions; alternating perpendicular deck support members and transverse trusses form an integral part of the prefabricated floor unit. The double truss webs extend above the deck to provide composite action with the concrete, which was cast after installation of the prefabricated floor units. The transverse trusses were conne

The site has miscellaneous fill and debris over the old riverbed, with the ground water level averaging about 5 feet below existing grade. A slurry wall system embedded in rock was used on the site perimeter to permit dewatering and excavation to rock for the project foundations without damaging adjacent structures. Rock anchors stabilized the wall during excavation. The perimeter wall system participates in the carrying of lateral wind forces from the plaza down to rock.

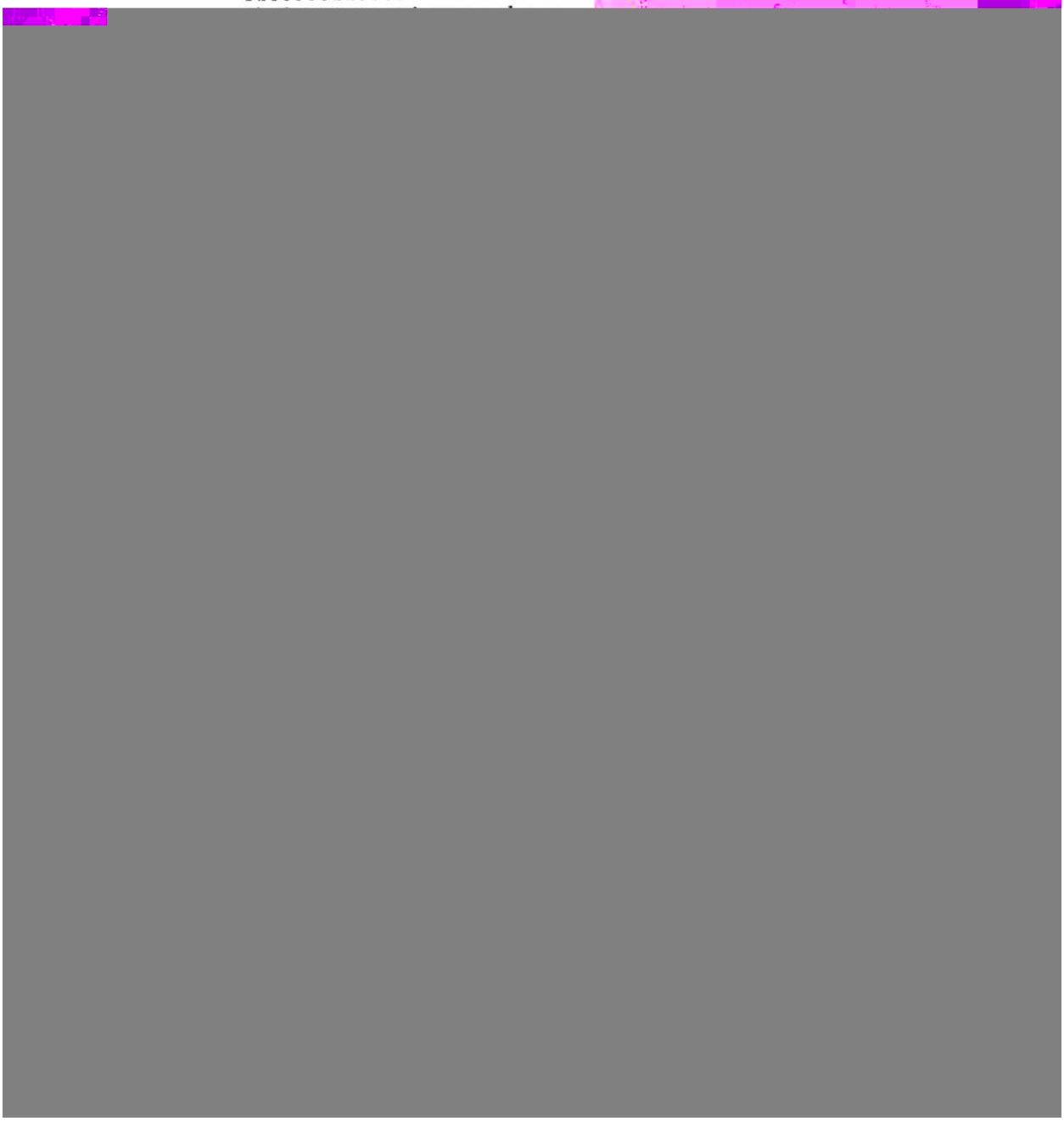
III. PRINCIPAL STRUCTURAL SYSTEMS AND ELEMENTS

A. Structural Systems

The exterior walls are framed with closely-spaced columns and deep

forces and r

In both towers the space frame from Floor 107 to the Penthouse Roof is formed by the addition of structural steel diagonals along the core column lines in the orthogonal directions to create with the columns and beams a network of intersecting trusses. This system mobilizes the interconnected structure to



Core framing carries a level of redundancy associated with the bending rigidity of so-called "simple" connections. This redundancy, while not easily amenable to calculation, is of the same order as is found in conventional steel buildings.

D. Dampers

As part of the development of structural systems for the twin towers a desire to improve the damping characteristics of these systems was both recognized and satisfied. A new damping system was developed by LERA, making use of viscoelastic materials manufactured by 3M Company. This product, later incorporated into Columbia Center (Seattle) and now planned for incorporation into several other buildings, is designed to reduce the swaying motion of the towers. The damping systems are not needed for structural integrity, but rather to reduce the perception of structure motion by building tenants. Individual dampers are not significant to damping performance as it is the summation of all dampers that contributes to the whole. Acc

IV. INSPECTION PROGRAM

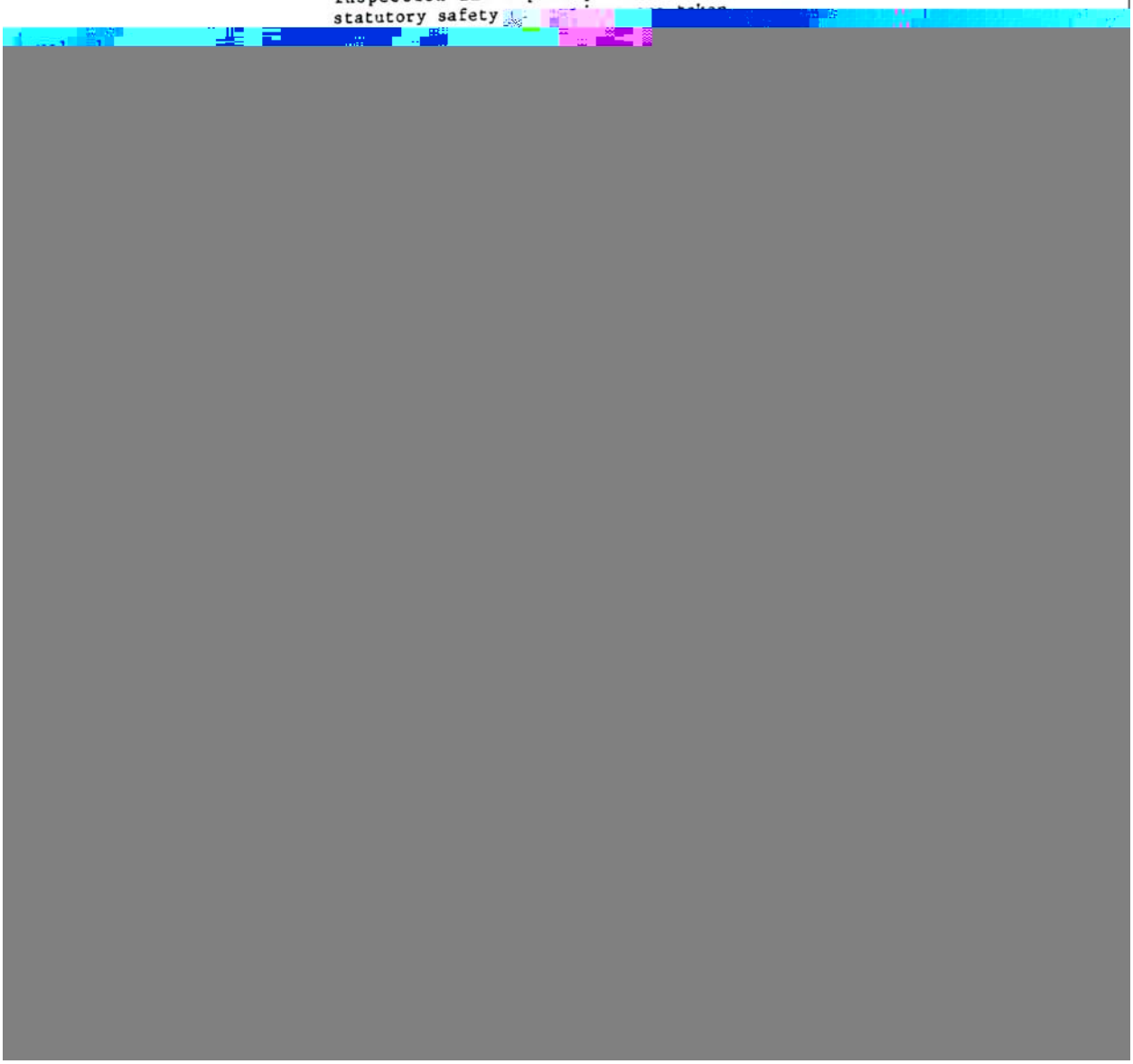
A. Visual Inspections

Since the concurrent visual inspection of the entire structure or even a major portion of it is not a practical goal, a statistical approach is followed. This approach involves the sampling of those components and systems which are more important to structural integrity, and at locations with a relatively higher potential for occurrence of defects

Where signs of water leaks suggest the probability that water has entered a box column, use a borescope to examine the internal surfaces of the column at base, cap, or diaphragm plates at the levels immediately below.

1. Periodic Inspections (Remarks apply to both towers unless noted specifically for only one)

   a. For the structural integrity inspection program for the TV antenna mast on top of WTC 1, see Appendix A. Make certain that none of the antennas on the mast will be operating during the inspection and repair procedures and that other proper and statutory safety




g. For the locations of the column and spandrel intersections and
"tree" junctions described below, refer to "Exterior Wall to
Floor 9 Elevations," Ap

2. Occasional Inspections, Monitoring of Reports

When general repairs or tenant remodeling involve removing ceilings, partitions, finishes or other cover, a thorough inspection should be made of the steel framing and connections and the concrete while they are exposed to view or und

2. Natural Frequencies - TV Mast

Install accelerometers and amplifiers within the heated enclosure of the 350 foot high TV antenna mast on top of WTC 1, at a level about 2/3 of the height of the mast above its base, to be connected to recorders within the building. One accelerometer is to be oriented to respond to N/S displacements and another to E/W displacements. Periods of vibration of the mast in each direction are to be recorded once a month, along with wind speed and direction.

4. Visco-Elastic Dampers

The testing program for the visco-elastic dampers should continue, consisting of:

a. Continuous measurement and recording of WTC 1 building movements of 3 or more inches, with concurrent wind speed and direction, at least until the end of 1985, and longer to the extent that funds are available.

b. 12 visco-elastic damping units are to be removed from WTC 1 annually and tested by 3M, using 4 units from each of 3 floors, from Zones 1, 2, and 3, replaced by damping units from WTC storage. Testing is to include temperature effects and shear strength.

c. A continuous log of tenant complaints on core noise and building sway will be kept.

5. Plumbness and Level

Plumbness and level surveys should be timed to coincide with periods of low wind speed and moderate temperature, as in the early morning hours in August.

a. Make building plumbness and floor level checks semi-annually for each tower. Investigate plumbness by measuring the offsets from a vertical laser beam, projected up from the bott[illegible] to the shaft walls of Freight Elevator No. 50, at 20 story intervals, establishing permanent measurement stations on each wall. Accuracy of the order of 3/4 inch (20 mm) is desired at the top of the shaft, with proportionately greater accuracy at the lower levels.

b. Establish 16 bench marks on the floor slab at Floor 70 of each tower, one at each corner and mid-point, adjacent to the exterior wall and adjacent to the core boundary as defined by the core columns. Measure the elevation of the remaining bench marks relative to one located near a corner of the core, using an engineer's level. Accuracy of levels should be to about 1/16th inch (1.5 mm).

V. INSPECTION PERSONNEL - IN-HOUSE

A. Inspection Supervisor

The Supervisor of the Structural Integrity Inspection of the Buildings is under the direction of the Engineer of Design, Infrastructure. The Supervisor is responsible for planning and directing the inspection, and preparing the report. The Supervisor should possess the following minimum qualifications:

1. Licensing

Professional Engineering license in New York or New Jersey specializing in Structural Engineeri

C. Inspector Qualifications

The field inspection crew members should be adequately qualified so as to be capable, after receiving moderate guidance on the initial run, of operating the program without detailed supervision. The most important qualifications for a field inspector are acute observation skills, common sense, strong motivation and persistence in carrying out any necessary follow-up procedures. The inspectors should be prepared to find serious defects rather than to assume that no problems exist. Where situations beyond the inspector's area of competence are encountered, guidance by supervisors should be sought.

As a minimum, the inspector should:

- be able to climb steel and function comfortably at great heights and in difficult positions;
- be a high school graduate or equivalent, with commensurate reading, verbal and written communication skills;
- read and understand construction drawings and other documents;
- letter legibly and be able to sketch technical details;
- be able to operate a camera;
- have a working knowledge of the use of measuring devices, such as rulers, tapes, gages, protractors and calipers; and
- exhibit a proper concern for safety while inspecting.

It is also desirable, but not mandatory, that the inspector have some prior experience in related work, such as high steel construction, structural maintenance or inspection, or surveying.

VI. OUTSIDE CONSULTANTS AND SUPPLIERS OF SPECIAL SERVICES

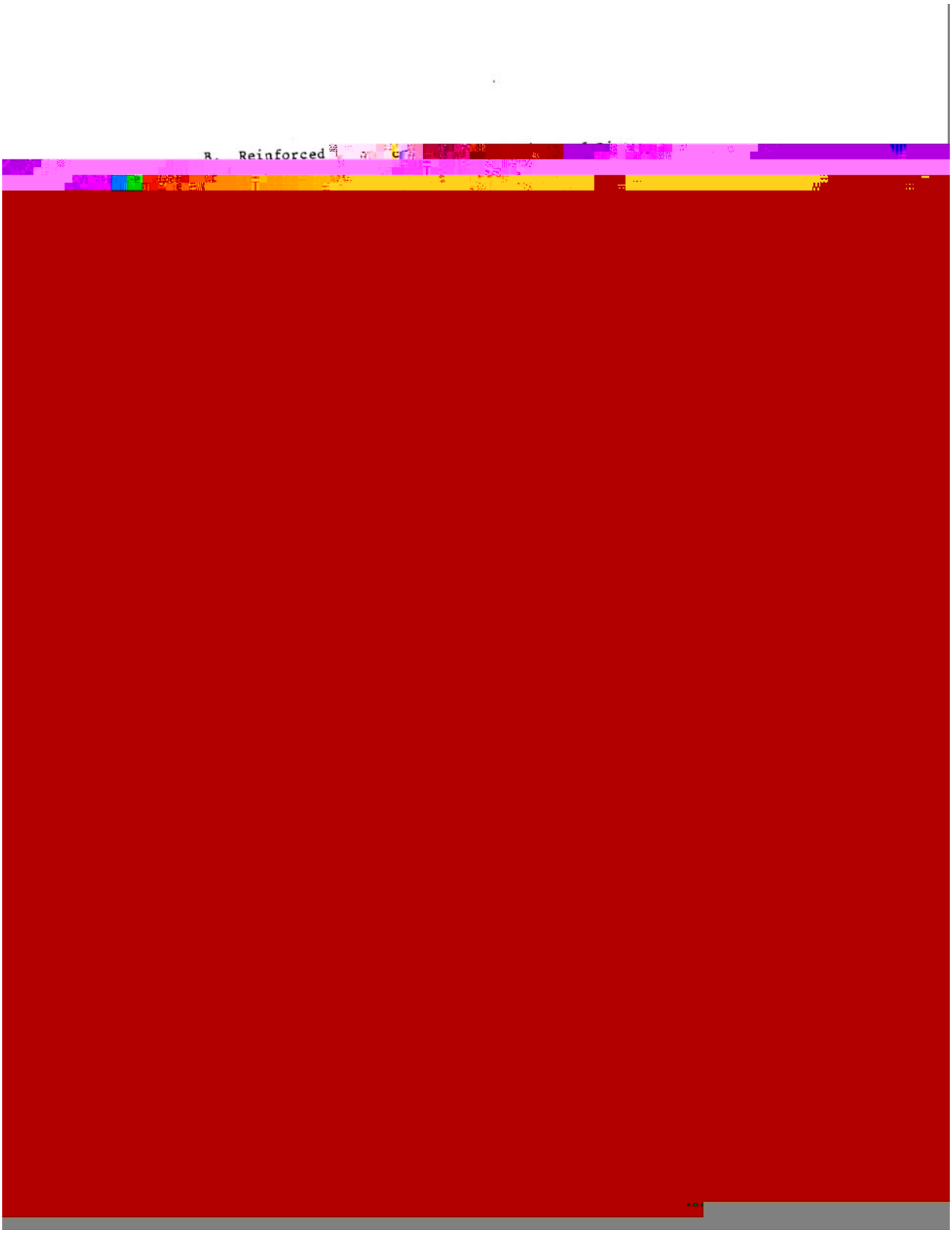
The consulting firm engaged to carry out periodic visual inspections, or to accomplish tasks requiring special skills and use of specialized equipment should assign a Supervisor who is a professional engineer licensed in New York or New Jersey and should have the ability to perform the work as demonstrated by a minimum of five years experience in the design and the field supervision of projects of comparable size and complexity. The personnel assigned to the project should possess, as a minimum, qualifications equal to those listed in "Inspection Personnel - In-house."

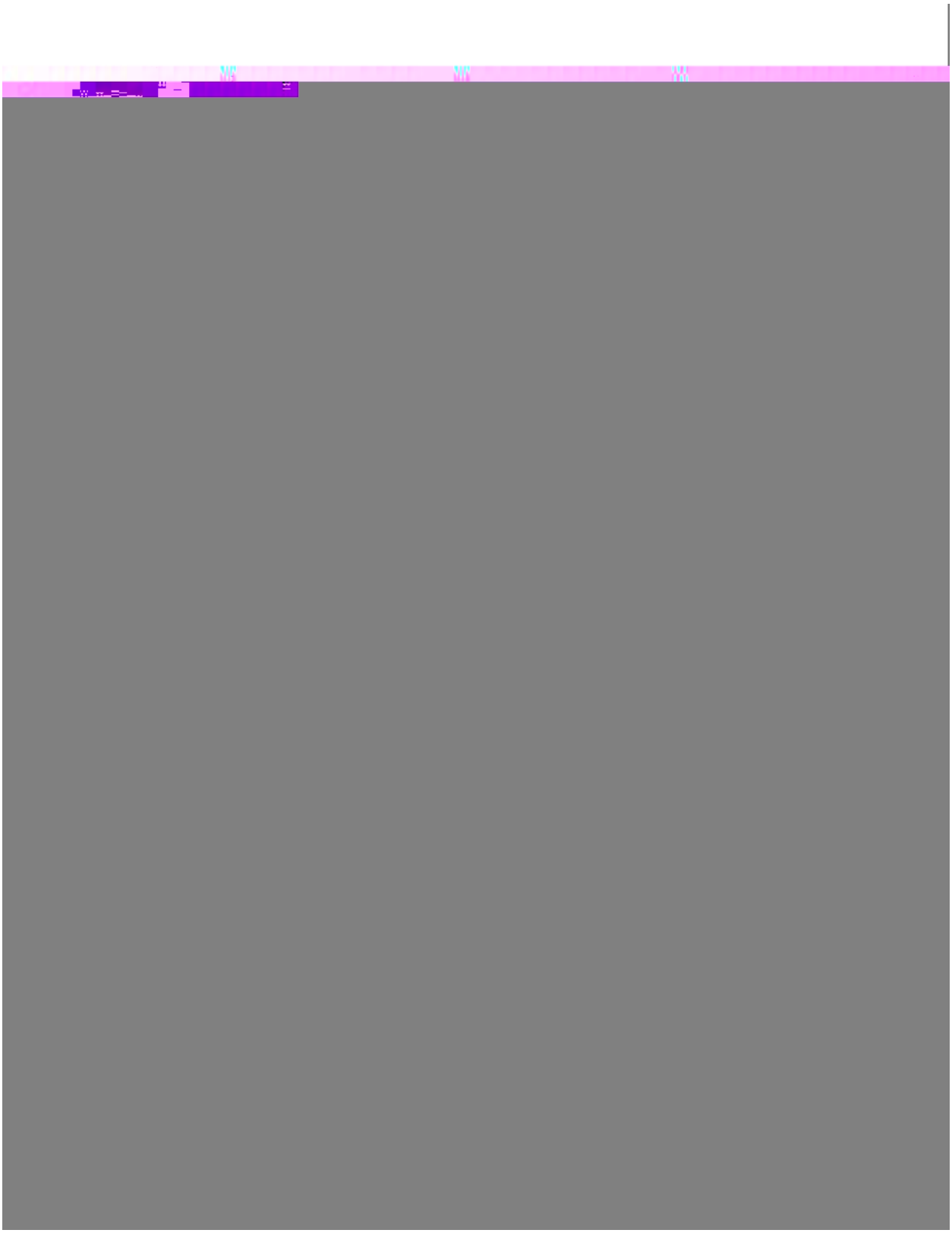
Before selection, the consultant should submit to PANYNJ a listing and description of comparable projects completed, and a list of the people to be assigned to the project with a resumé of experience and other qualifications for each.

VII. RECORD-KEEPING AND FOLLOW-UP PROCEDURE

The defects and signs of distress listed below are to be noted and recorded wherever encountered in elements falling into these categories.

A. Structural Steel Defect [redacted]





D. Measurements and Test Records

1. Periods of Vibration, Towers and Mast

Tower vibration and on-site wind speed and direction measurements are being logged each month for each tower. The periods of vibration for N/S and E/W translations and for torsional movements should be determined for each tower and for the TV mast. Should comparison of the vibration periods with previously recorded data for towers or mast reveal a statistically significant deviation, the relevant data need be called to the immediate attention of the Engineer of Design, Infrastructure.

2. Floor Systems

The floor vibration measurements resulting from the "heel drop" tests should be compared with prior measurements for similar floor structure zones, where available. In the event that the frequency or the damping ratio deviates from previously recorded values, data need be forwarded immediately to the Engineer of Design, Infrastructure.

3. Additional Data

In conjunction with the floor truss visco-elastic damper testing carried out by 3M, records of WTC 1 building movements of 3 or more inches with corresponding wind speed and direction measurements will be kept at least until the end of 1985. In addition, logs of tenant complaints on core noise, building sway, and the like will continue to be kept, listing date, tenant's location, and nature of complaint.

4. Plumbness and Level

Data obtained from the semi-annual plumb and level surveys are to be compared to previous records to monitor possible building lean or floor tilt.

E. Periods of Vibration

Since a reduction in stiffness of a structural system is symptomatic of deterioration or damage, vibration period measurements are used to monitor stiffness. To interpret the significance of measured changes in vibration period of the system, it is necessary to take into account changes in weight of the system, for which purpose an initial tabulation of weight must be made, and a log of weight changes kept. To facilitate evaluation of future measurements, the initially measured value of the period T, in seconds, can be plotted

VIII. EXCLUDED WORK

This standard is focused on structural steel and on reinforced concrete.

The following components are outside the scope of this standard and have been excluded:

Glass & Glazing
Facade Panels
Ceilings
Partitions
Elevators
Stairs
High-pressure steam equipment
High-voltage electrical equipment
etc.

IX. REFERENCES

1. Infrastructure Design Division, Engineering Department, PANYNJ: "Standards for In-depth Structural Integrity Inspection of Buildings," Port Authority of New York and New Jersey, October 1984.

2. U.S. Department of Transportation: "Bridge Inspector's Training Manual 70," U.S. Government Printing Office, 1970.

3. AASHTO: "Manual for Maintenance Inspection of Bridges," American Association of State Highway and Transportation Officials, 1983.

4. AWS: "Welding Handbook," Volume 1, Seventh Edition, American Welding Society, 1976.

5. Research and Development Division, Engineering Department, PANYNJ: "Measurement of the Dynamic Response of WTC Tower 'A' Under Wind Loads," Report No. 79-5, May 1979. Report No. 81-7, June 1981.

6. "Investigation of Aging Effects, World Trade Center Dampers," Robertson, Fowler & Associates P.C., October 1, 1984.

7. "Viscoelastic Damping Units," Report No. DU-1, Skilling Helle Christiansen Robertson, July 17, 1967.

APPENDIX A

STRUCTURAL INTEGRITY PROGRAM
TELEVISION ANTENNA MAST

I. INTRODUCTION

A. History

As of this writing, the 350 foot tall television antenna mast on top of ONE WORLD TRADE CENTER is approximately 5 1/2 years old. Erection of the antenna was completed in November, 1979 and activation of the first commercial broadcasting in June, 1980.

Maintenance work and interim inspections, to date, have been performed primarily by television station personnel maintaining broadcast antenna units and PANYNJ maintenance personnel furnished under contract by Broadway Maintenance Corporation.

B. Scope of Program

This document is prepared to assist in the specifying of visual and non-destructive testing of the antenna with the goals of providing reasonable assurance to PANYNJ that the antenna is performing safely as a structure, as well as to assist in identifying preventive maintenance which should be performed on a scheduled basis.

This program consists of four sections:

1. Structural Steel Antenna Elements
2. High Tensile Bolts and Studs
3. Weatherproof Enclosure
4. Radomes

Structural integrity inspections should be performed on a continuing basis, as weather and operational restrictions permit. Every effort should be made to perform a complete review of the mast structure within the weatherproof enclosure each year; the balance of the program should be done at least once every three years.

C. Additional Work

Remaining for development and appending to this program are record keeping documents and integrity review procedures such as specific ultrasonic testing procedures, sampling locations and sampling percentages. Integrity inspections should be documented by diagrams, sketches and photos to the maximum extent practicable in order to amplify the written description of each integrity inspection.

D. Safety

Both integrity inspection personnel and maintenance personnel should verify that good housekeeping practices are fully in effect in order to minimize or eliminate conditions conducive to fire hazards, falling, electrocution and the like.

II. STRUCTURAL STEEL ANTENNA ELEMENTS

A. Visual Inspection for Corrosion

Inspect each of the 18 tower sections, the tapered section and the channel 4/5 pole for freedom from corrosion. Use high intensity portable light source to assist viewing of structure.

1. Verify freedom from corrosion of all structural parts by visual inspection.

2. Record all locations where paint failure or corrosion are observed.

3. Record all locations, and extent of each such location, where structural parts cannot be directly viewed due to obstructions such as radome, conduits, antenna elements, weatherproof enclosure elements, lack of access, or other condition. Describe conditions preventing visual evaluation of each obstructed location.

4. To the extent possible, view portions of antenna obstructed from direct visual observation by use of appropriate fiber-optic viewing devices.

5. View those portions of antenna structure not accessible for clear viewing from within by direct access to the outside surfaces by appropriate means such as access by boatswain's chair.

B. Visual Inspection for Soundness of Base Metal and Welds

Inspect each section, the tapered section, and the channel 4/5 pole for sound base metal and sound welds.

1. Simultaneous with visual inspection for corrosion, verify freedom of all visible surfaces of base metal and of welds from cracks or other unacceptable discontinuities such as excessive pitting from corrosion, defects at weld ends, especially at access holes, chamfers and the like. Record all findings, even where apparently insignificant, for comparision with future observations.

C. Ultrasonic Inspection for Soundness of Base Metal

Inspect each section, the tapered section, and the channel 4/5 pole for sound base metal and sound welds.

1. Test solid round antenna mast vertical members by intensity method (sending and receiving transducers) and pulse transit time method (pulse-echo method) to assure freedom from cracking, especially in vicinity of structural welds and welds for mounting antennas and related parts. Transducer surfaces should be curved to fit the surface curvature of the part tested.

2. Test pipe members using pulse transit time method (pulse-echo method) with transverse sound waves to assure freedom of base metal from cracking or other discontinuities, especially in vicinity of structural welds and of welds for mounting antennas and related parts.

3. Test plate steel and rolled steel shapes with transverse or longitudinal waves, as appropriate, in locations as appropriate.

4. Locations of testing should be selected initially on the basis of review of fabrication drawings for the individual antenna structure sections and structural elements. Additional test locations should be selected in response to the results of the complete visual evaluation of the antenna structural steel.

5. UT equipment should be calibrated in accord with the appropriate ASTM, AWS and ASME standards. Additionally, it may be wise to prepare special calibration specimens representative of full size structural elements, so as to determine the best frequency and transducer size and geometry for providing meaningful and reproducible test results.

6. Thoroughness of UT examination for the bottom 101 feet of antenna structure should be based on the highest practicable sampling percentage because this length of antenna has been demonstrated more sensitive to temperature effects on material properties than the antenna sections above (Teledyne Technical Report TR-2315). Based on generated information, it may be possible to justify reduced sampling percentages for periodic scheduled UT integrity checks after study and evaluation of records of actual test results and observations. Fortunately, this portion of the antenna structure is available for examination on a far more continuous basis than the portion of the antenna above Elevation 101 (top of Section AC-10).

7. Record all significant ultrasonic indications (even though not of rejectable level) for comparison with results of future tests in the same location.

D. Water

Inspect all locations in antenna structure to assure that no location can pond or entrap water accumulations. The examination will require a preliminary review of each of the antenna structure fabrication drawings followed by visual examination of each part of each antenna section/element in the field.

III. HIGH TENSILE BOLTS AND STUDS

A. Corrosion

Inspect each bolt or stud connecting antenna sections or members within antenna sections for freedom from corrosion.

B. Cracks

Inspect each stud accessible and each bolt both large enough and accessible for freedom from cracks, especially at the root of threads.

C. Structural Integrity Check Items

1. Corrosion

Verify freedom from corrosion of all projecting bolt heads, nuts, washers and thread run-outs. Report for prompt maintenance (cleaning and painting) all bolt and stud parts where paint failure has occurred or rusting is in progress.

2. Use of Borescope

To the extent possible, view all portions of bolts and studs not accessible for direct viewing by use of fiber-optic viewing devices.

3. Ultrasonic Testing

Ultrasonically examine all studs and those bolts of sufficient size which can be reached for UT examination using longitudinal wave equipment. By comparison with results from appropriate calibration and reference specimens, verify that studs and bolts are free from cracking, especially in threaded and thread run-out zones.

Longitudinal wave testing probes should be selected for size and frequency on special calibration specimens representative of at least the threaded length plus a few inches of unthreaded rod to establish the type of ultrasonic response to be expected from the threaded lengths of bolts and studs.

IV. WEATHERPROOF ENCLOSURE

Purpose of these procedures is to assure maximum corrosion protection of antenna structural and system elements. Corrosion due to water penetration or due to excess humidity within weatherproof enclosure must be prevented. Temperature within weatherproof enclosure must be reliably assured to remain above 75°F (30°C) as recommended in Teledyne Technical Report TR-2315.

Detailed review should be made of the temperature maintained within the antenna structure below Elevation 101 (top of Section AC-10) since the date of installation.

A. Temperature and Humidity

Maintain accurate records of interior temperature and humidity.

B. Paint

Verify integrity of exterior painting system.

C. Seals

Verify integrity of exterior sealing systems against water penetration.

D. Weatherproofing System Integrity Check Items

1. Details around outrigger supports extending from tapered antenna base section to support microdish platforms.

2. Continuity and soundness of watertight seal welds for closure (cap) plates on top of AC-1, AC-7 and AC-10 and around sleeves penetrating closure plates.

3. Continuity and soundness of exterior caulking system (DYmeric by Tremco).

4. Soundness and continuity of seal welds and gaskets at joints in weatherproof closure steel wall plates, steel boots and FRP boots.

5. Protection from (and freedom from) rust for bolts, nuts, threaded studs, washers, bars and the like connecting sections to adjacent sections or to supports on antenna.

6. Use drawings TV-I, TV-O, TV1-TV2, TV50-TV58, TV111, TV121, TV131, TV141, TV151, TV161, TV171, TV181, TV191, and TV192 as guides in performing weathertightness check.

V. RADOMES

A. Connections

1. FRP radome sections end and edge connections.

2. FRP radome assembly connections to supporting structure.

B. FRP Shells

1. Condition of FRP shells in individual FRP radome sections.

C. Radome Integrity Check Items:

While the majority of radome integrity checks involve features within the radomes, the bolt heads and Belleville washers are on the outside surface of the radomes, the surface from which in-place retightening or replacement of radome assembly bolts and tensioning washers must be accomplished, if found necessary. Checking of radome connecting bolts will require the use of a boatswain's chair or other means of access to the outside of the antenna.

1. Examine each radome section to section connecting bolt and Esna elastic floating stop-nut assembly, bolt by bolt. Stop-nuts should be holding connecting bolts tight with sufficient tension to provide necessary clamping force in joints and splices between radome sections. Degree of tightness of each floating nut and bolt assembly should be checked. Corrosion or lack of corrosion of stop-nut assemblies should be determined.

2. Examine each radome section for freedom from cracking or other signs of potential distress. Pay special attention to zones around bolt holes near edge, and end lap splices of radome FRP sections.

3. Check condition of bolts connecting radomes to FRP Extren braces and support arms, as well as bolts connecting radome supports to structural steel supports. Check condition of Extren supports and braces.

APPENDIX B

FIBER OPTIC BORESCOPE SUPPLIERS

Addresses of some Fiber-Optic viewing instruments suppliers are:

Lenox/Fort
Lenox Instrument Company, Inc.
111 East Luray Street
Philadelphia, PA 19120
Telephone: (215) 324-4543

Reichert Fiber Optics
Warner-Lambert Technologies, Inc.
122 Charlton Street
Southbridge, MA 01550
Telephone: (617) 765-9744

American ACMI
Divison of American Hospital Supply Corporation
300 Stillwater Avenue
P.O. Box 1971
Stamford, CT 06904
Telephone: (203) 238-8654
(203) 357-8300

Olympus Corporation
Industrial Fiber Optics Department
4 Nevada Drive
Lake Success, NY 11042-1179
Telephone: (516) 488-3880

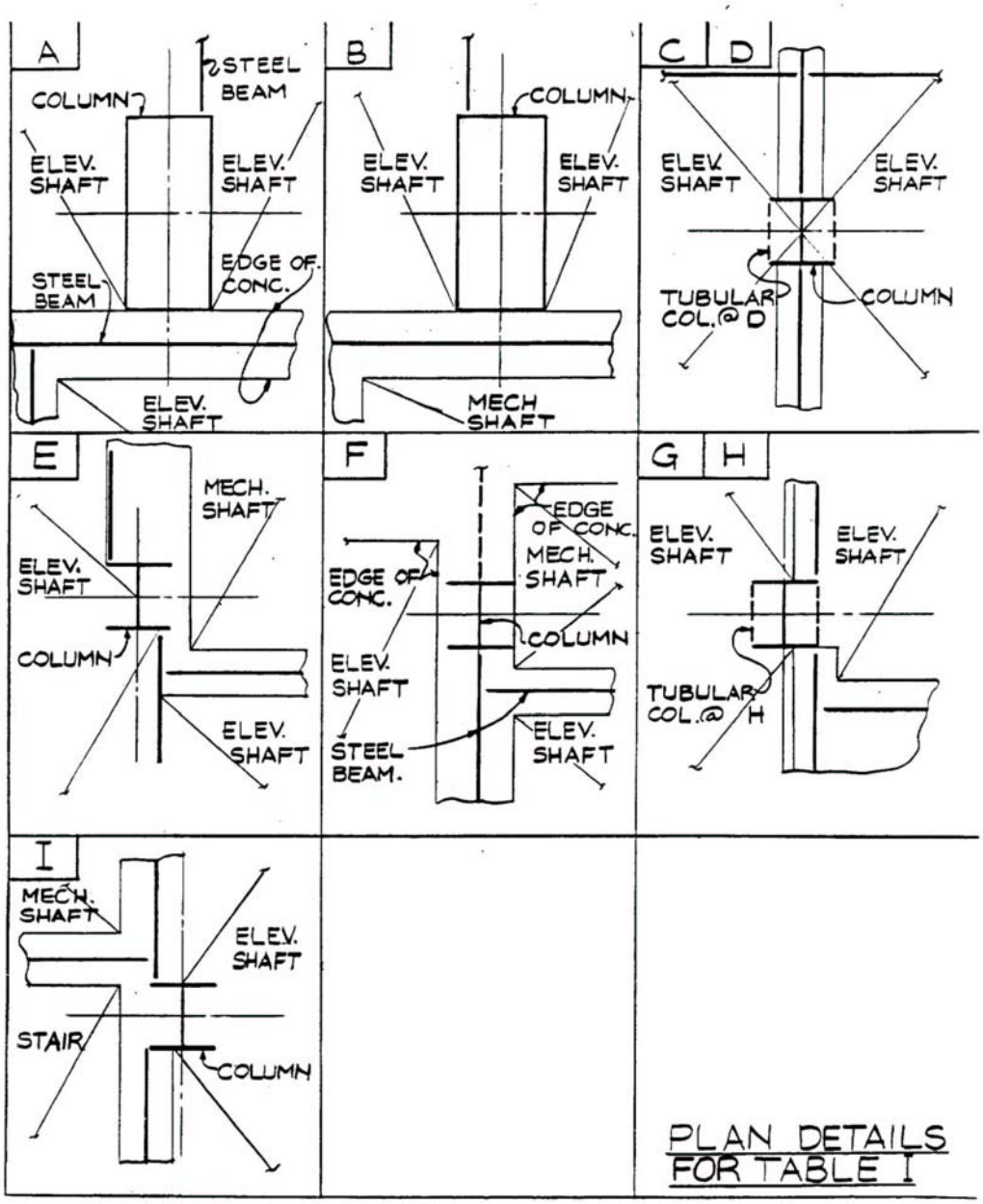
APPENDIX C

TABLE I: ECCENTRICALLY-BRACED COLUMNS IN ELEVATOR SHAFTS

COLUMN NUMBER	FLOORS	SIMILAR DETAIL	REMARKS
602	1 to 33, 43 to 68	A	
603	32 to 42, 44	B	
	El. 294	B	WTC 1 only
606	17 to 23, 25, 26, 44, 61, 62	B	
607	1 to 17, 44 to 55	A	
	El. 294	A	WTC 2 only
702	1 to 7	D	
	8 to 33, 44 to 68	C	
703	78 to 82, 94 to 101	E	
	106, 107, 108	F	
707	1 to 7	D	
	8 to 17, 44 to 55	C	
802	78 to 94	C	
803	78 to 94	H	
	95 to 101	G	
805	78 to 106	I	
806	78 to 87	C	
902	3 to 8, 32 to 42	B	
	43	B	WTC 2 only
907	7	B	
	1, 2	B	WTC 2 only

Notes:

1. Refer to paragraph IV. A.1.d.
2. Floor listings such as "3 to 8" are inclusive.
3. Listings apply to WTC 1 and WTC 2 unless noted otherwise.
4. At the Intermediate Level above Floor 1 and at Floor 8, inspect all columns in the elevator shafts.
5. For typical detail plans A through I, see the following page.



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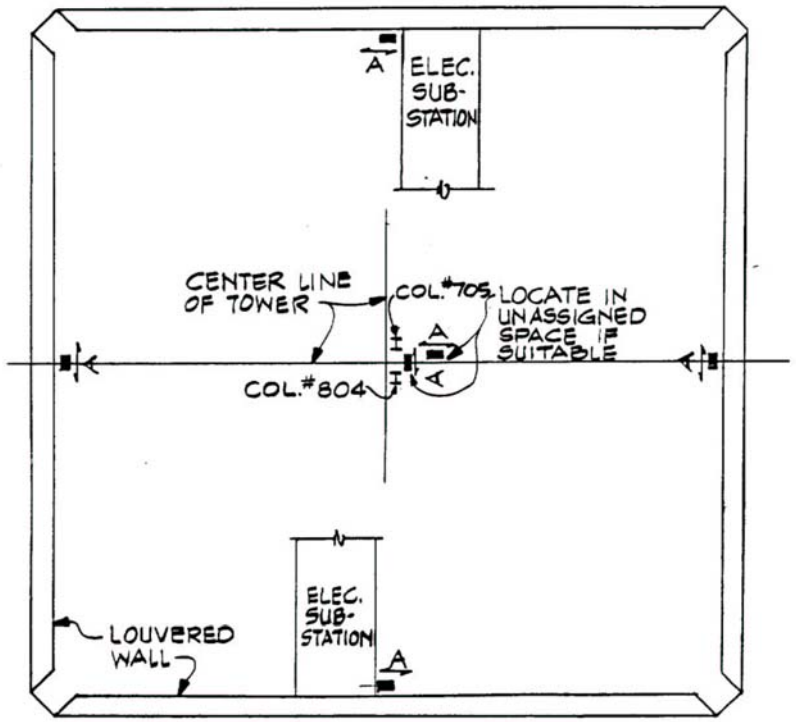


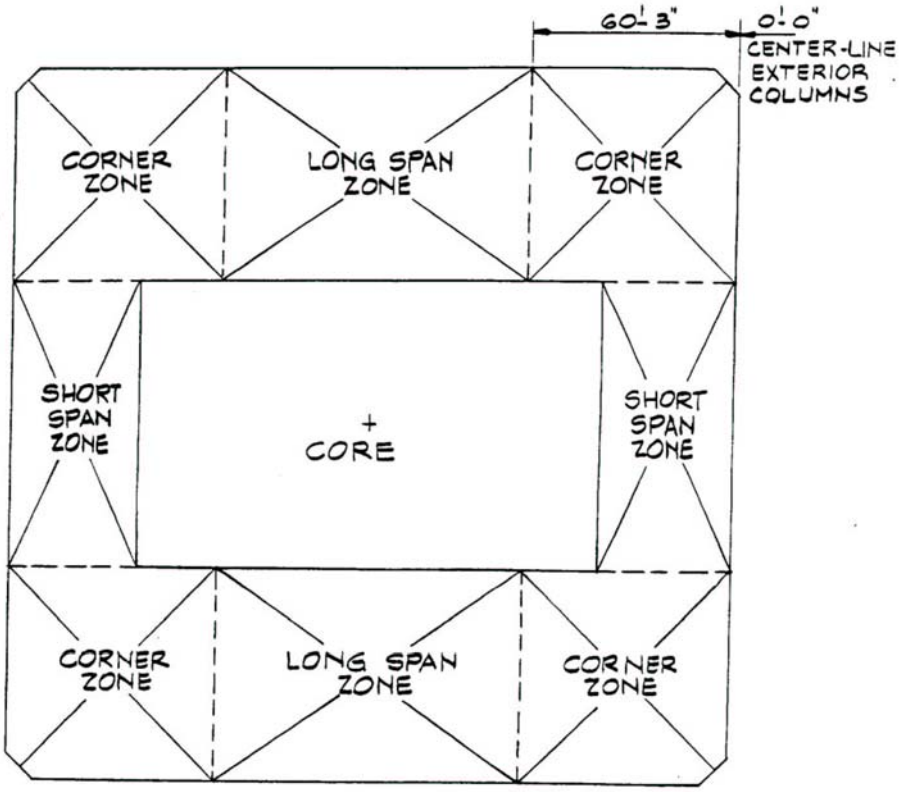
75TH FLOOR PLAN
MECHANICAL EQUIPMENT ROOM
2 WTC

SUGGESTED LOCATIONS OF ACCELEROMETERS
FOR MEASUREMENT OF TOWER NATURAL FREQUENCY

FIGURE 1

NOTES:

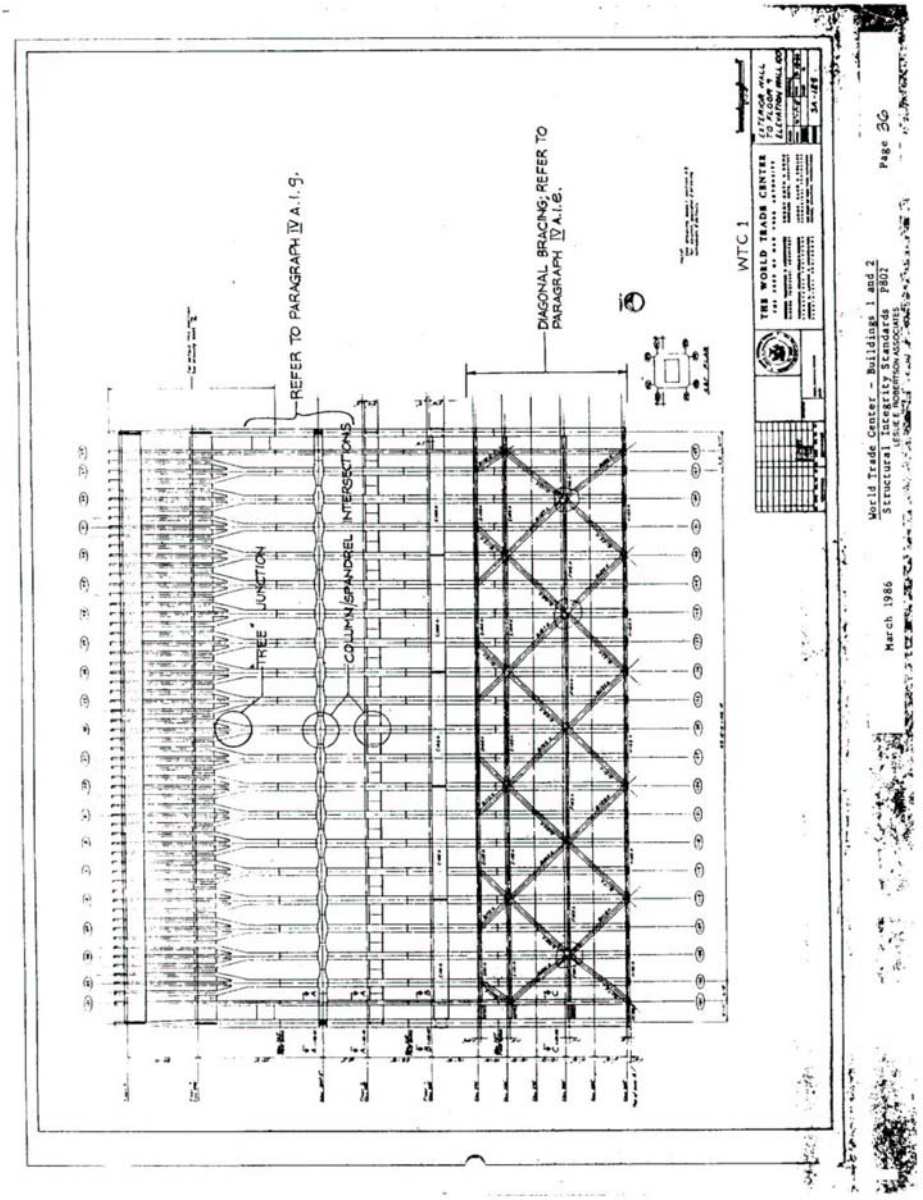
1. REFER TO PARAGRAPH IV.B.1.
2. SUGGESTED ACCELEROMETER LOCATIONS ARE SHOWN THUS: $\frac{A}{\blacksquare}$ ARROW DESIGNATES DIRECTION OF MOTION TO BE RECORDED.
3. VARY THE LOCATIONS AS REQUIRED TO CLEAR MECHANICAL EQUIPMENT AND MAINTAIN ACCESS TO THE ACCELEROMETERS.



TYPICAL TENANT FLOOR PLAN
ZONES FOR FLOOR NATURAL FREQUENCY MEASUREMENT

FIGURE 2

NOTE: REFER TO PARAGRAPH IV.B.3.


REFER TO PARAGRAPH IV A.I.9.
DIAGONAL BRACING; REFER TO PARAGRAPH IV A.I.8.
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JUNCTION
COLUMN/SPANDREL INTERSECTIONS
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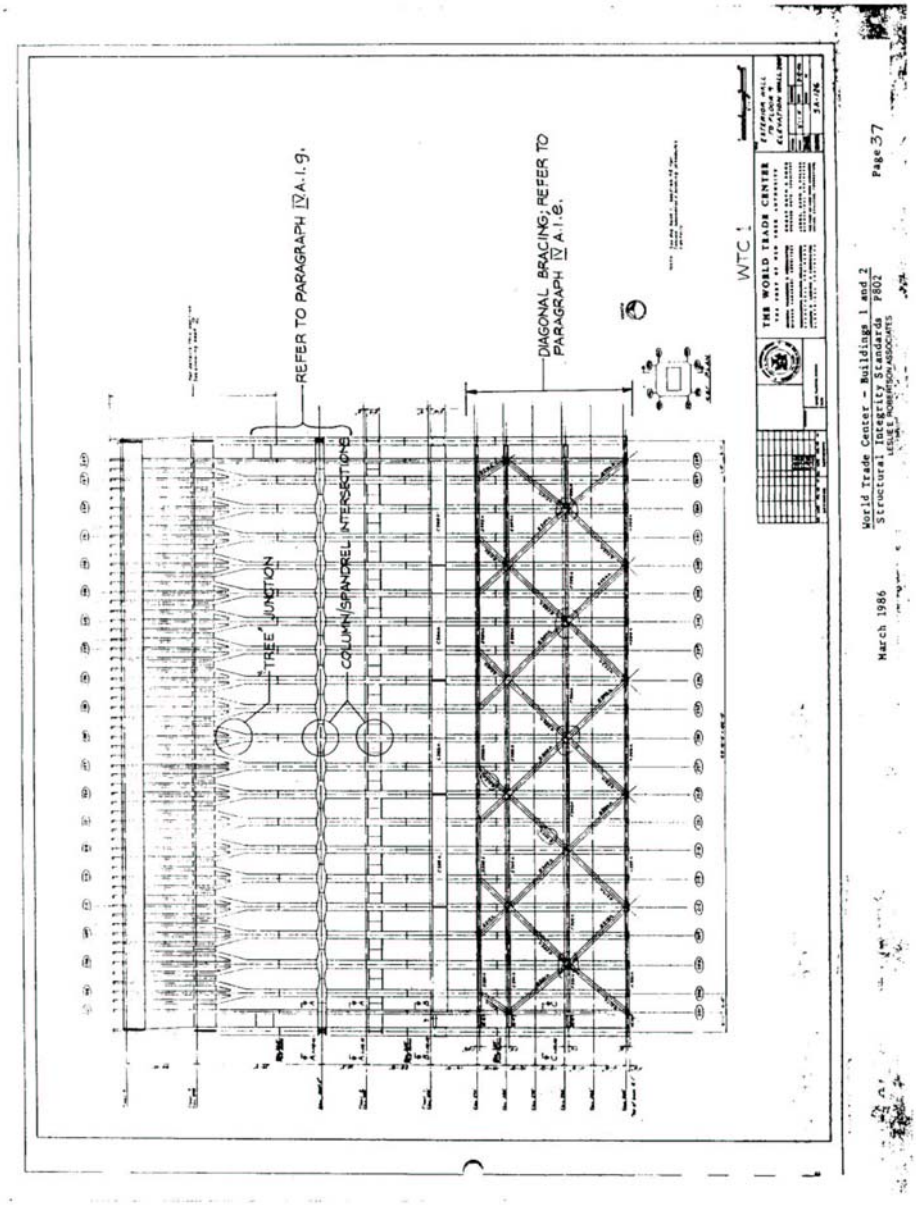
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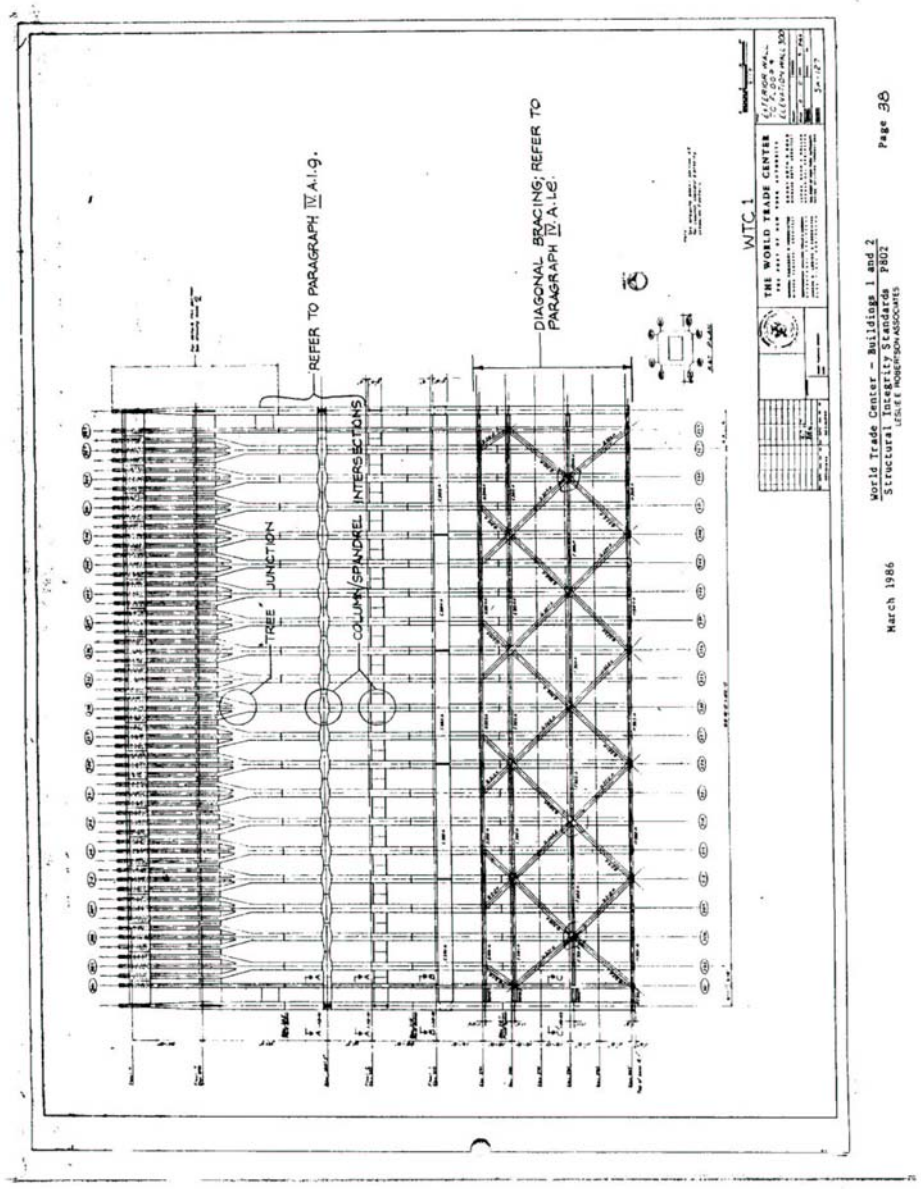
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DIAGONAL BRACING; REFER TO PARAGRAPH IV A.1.e.
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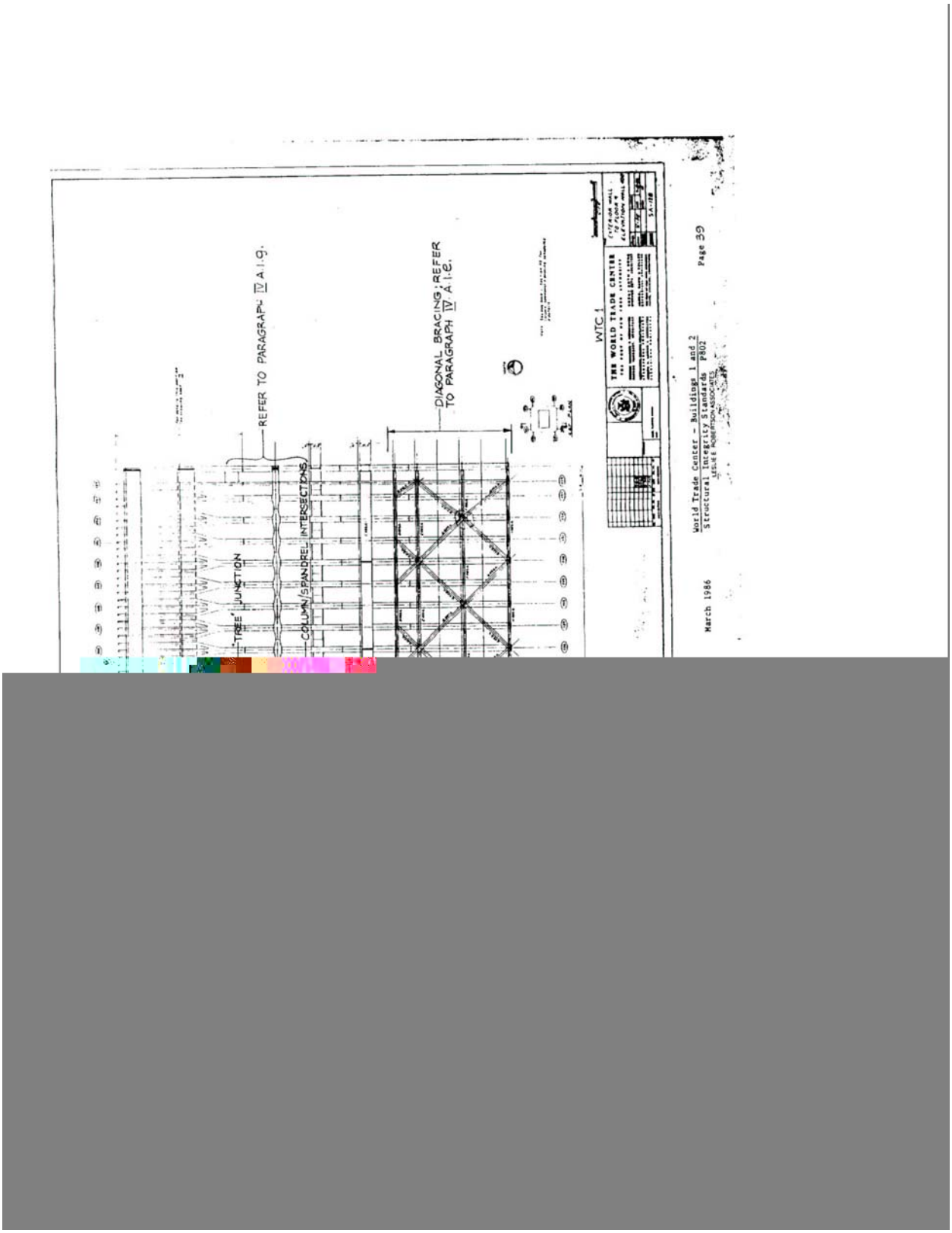
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DIAGONAL BRACING; REFER TO PARAGRAPH IV A.1.e.
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REFER TO PARAGRAPH IV A.1.g.
INTERSECTIONS)
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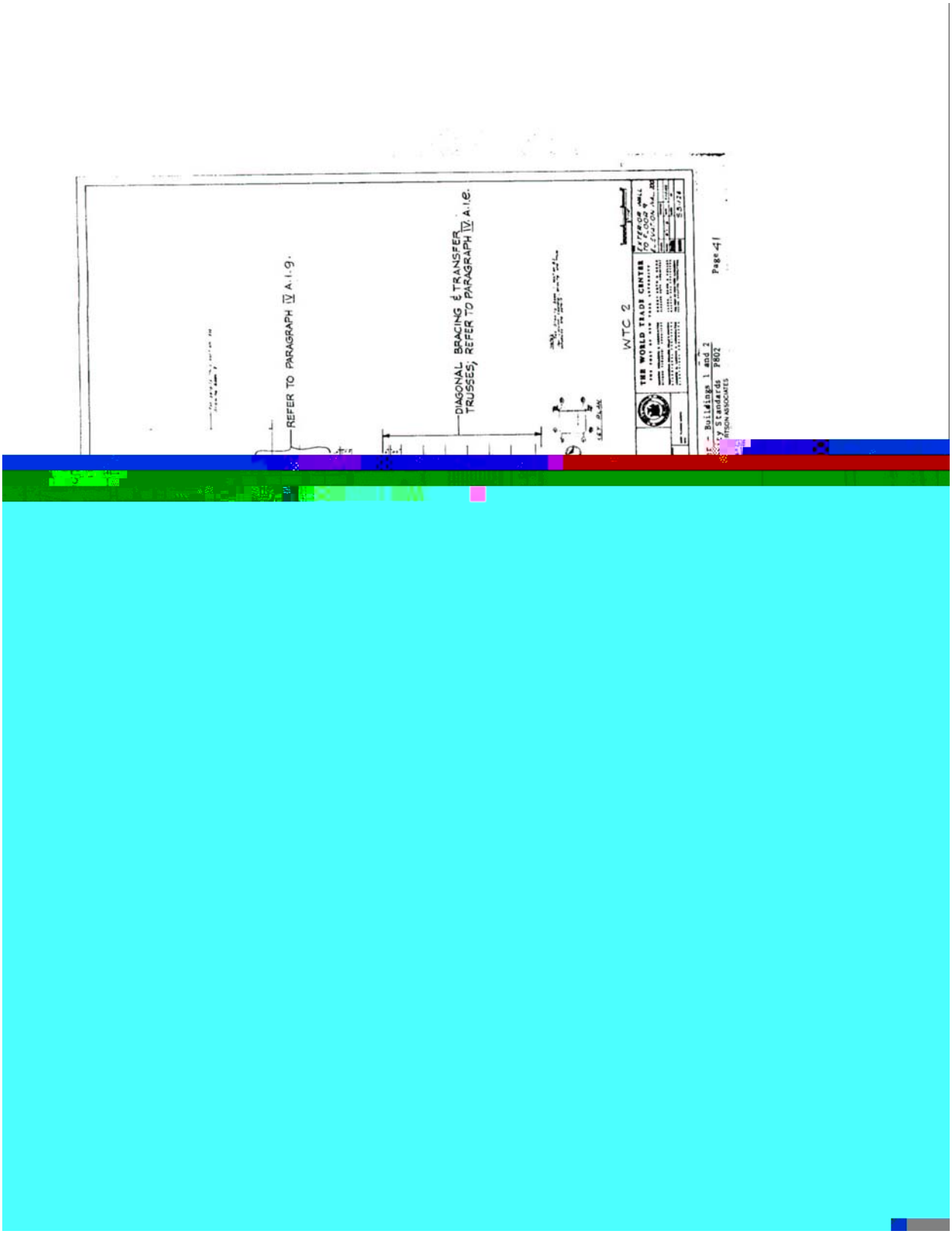
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DIAGONAL BRACING & TRANSFER TRUSSES; REFER TO PARAGRAPH IV A.1.e.
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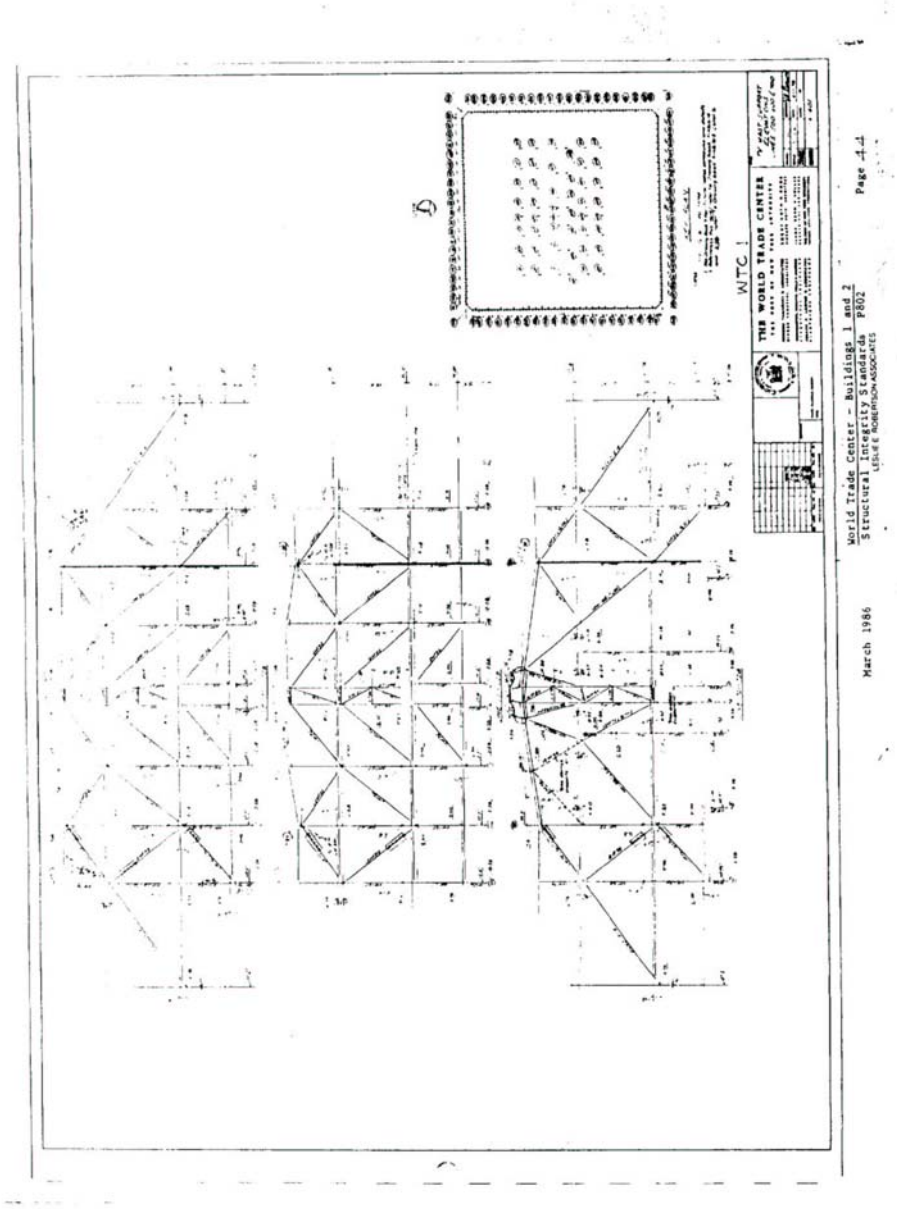
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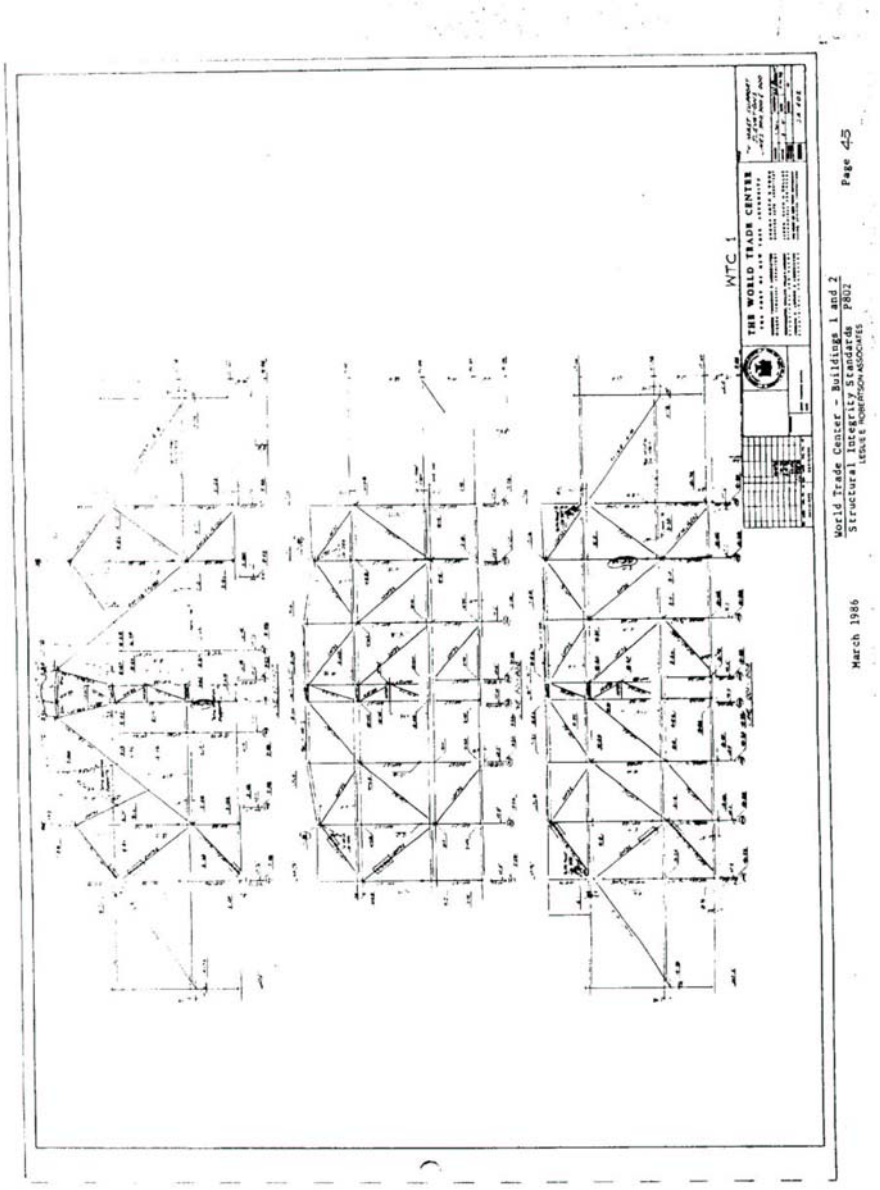
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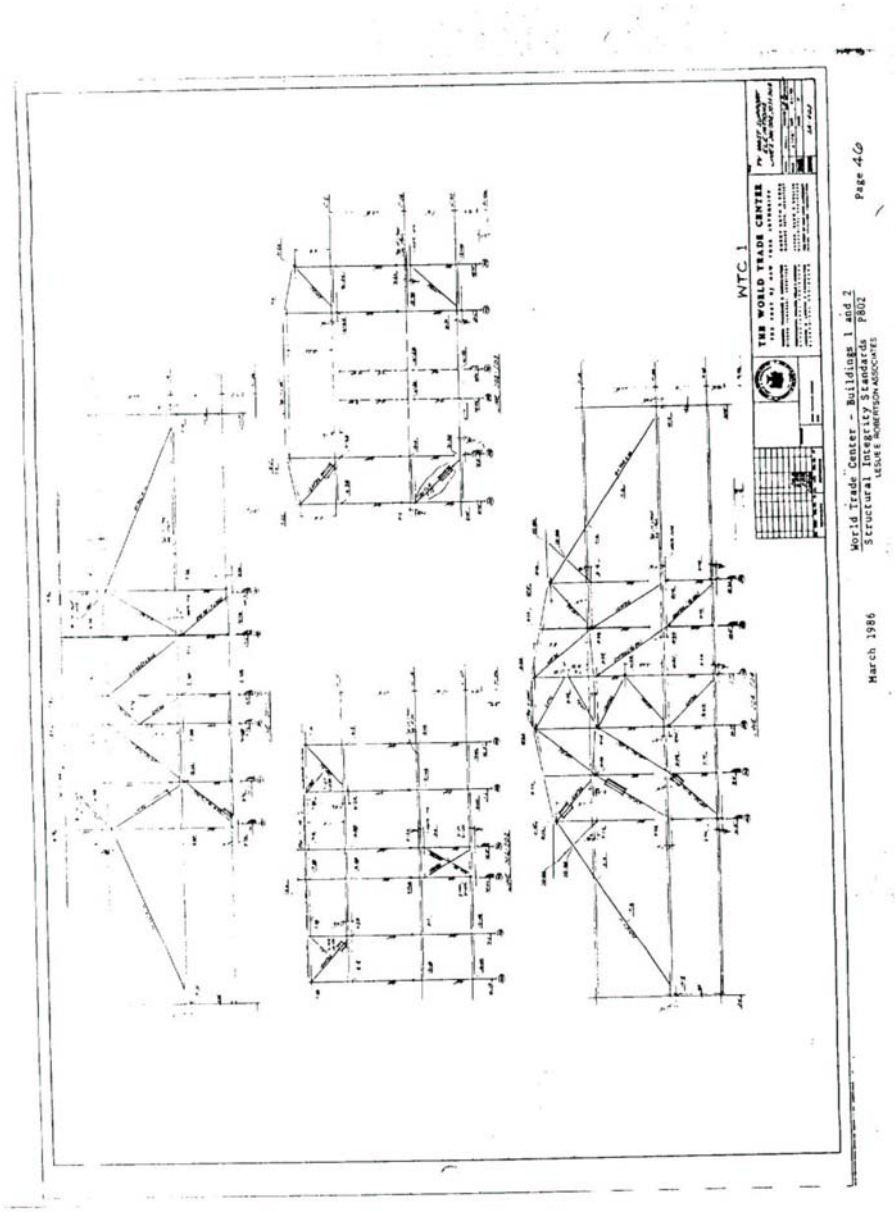
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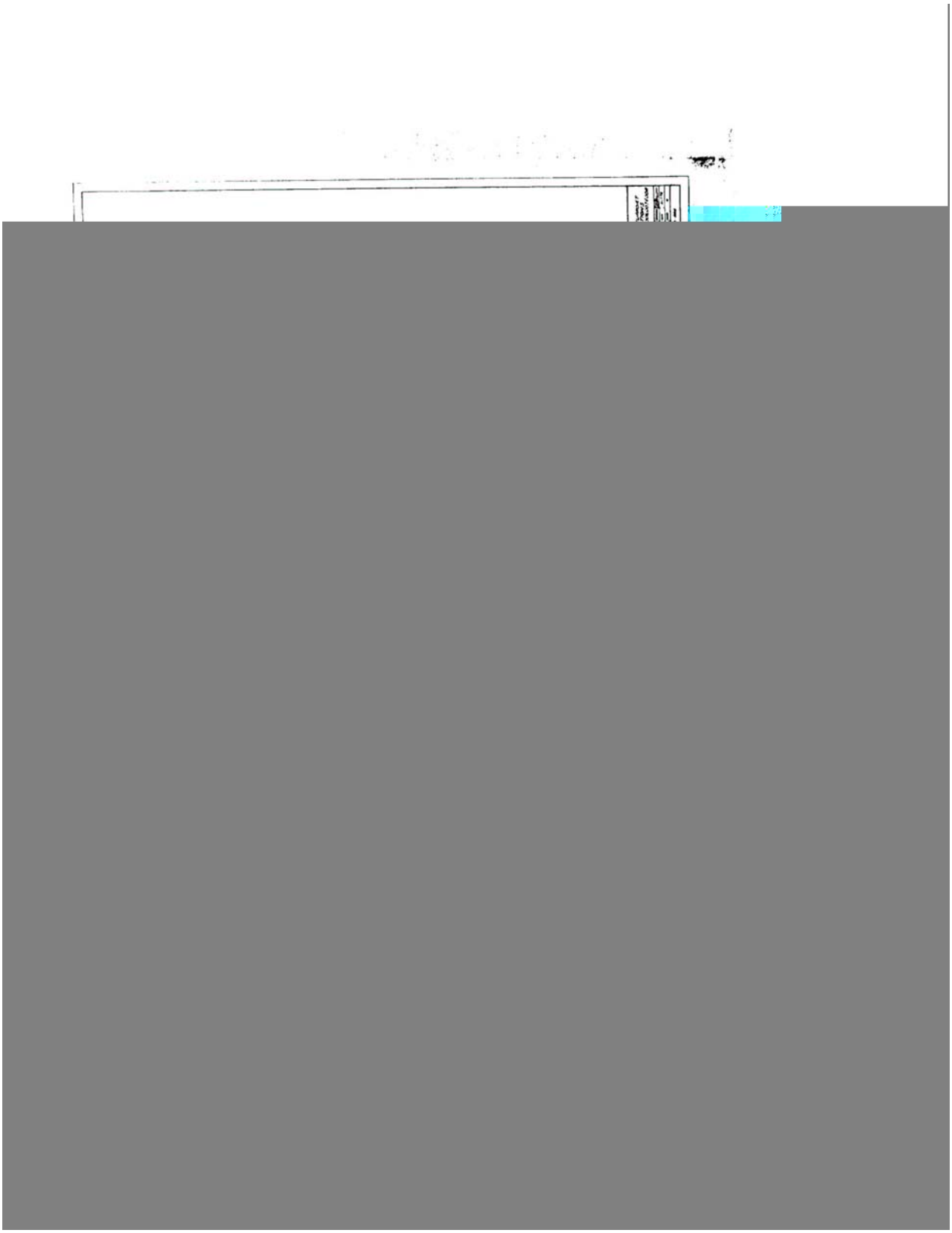

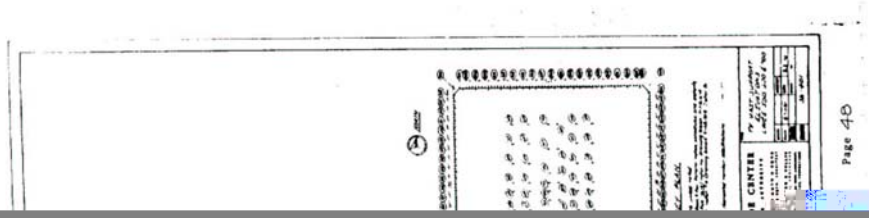
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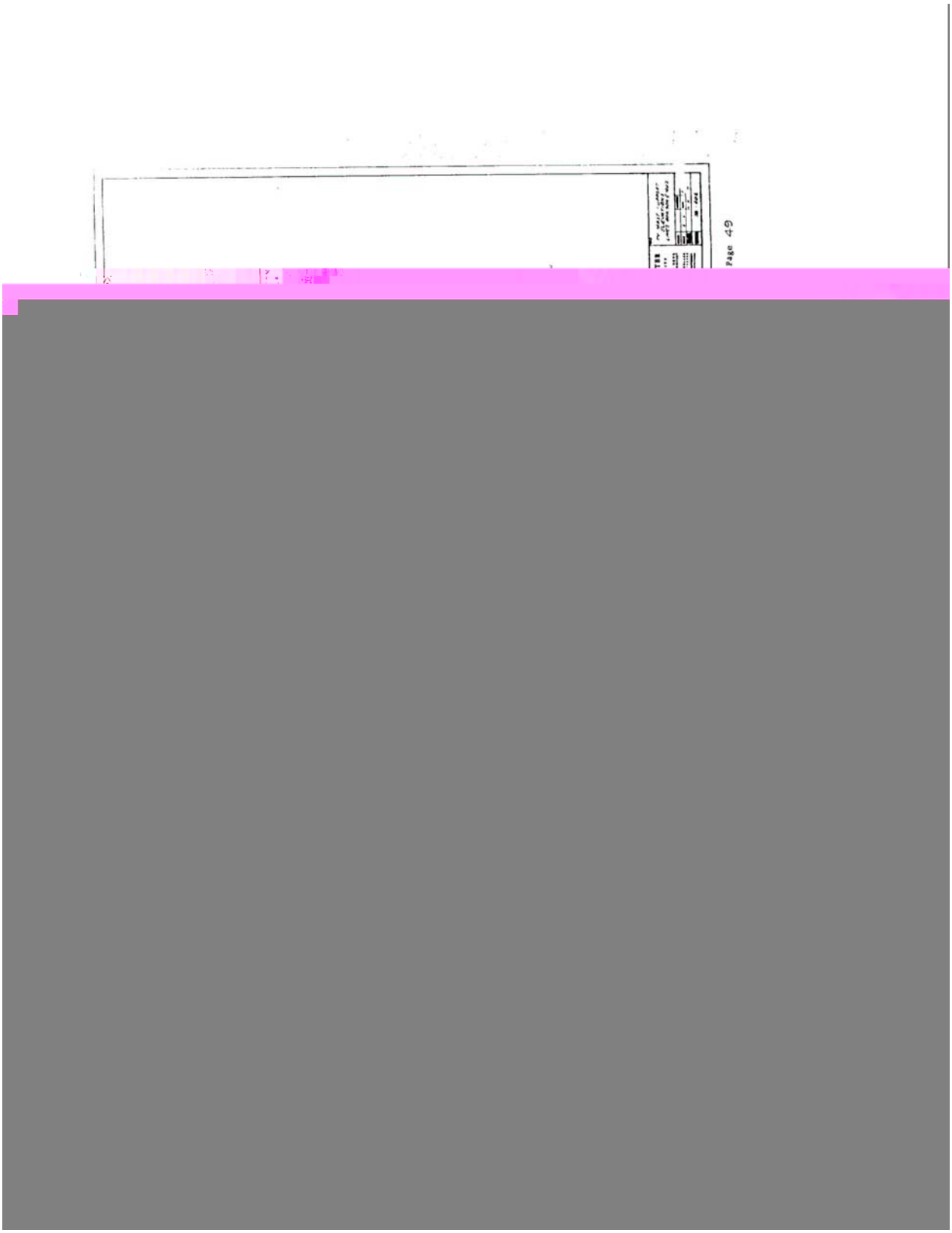

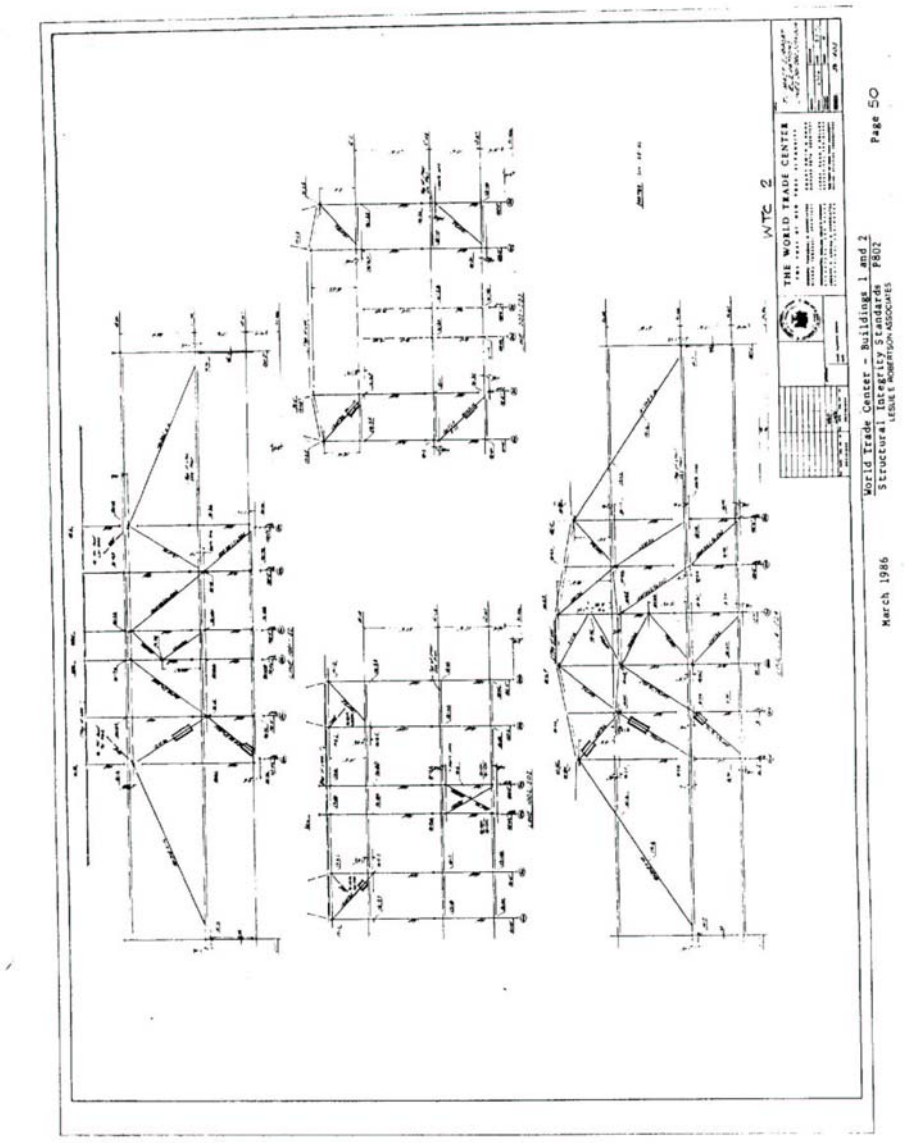
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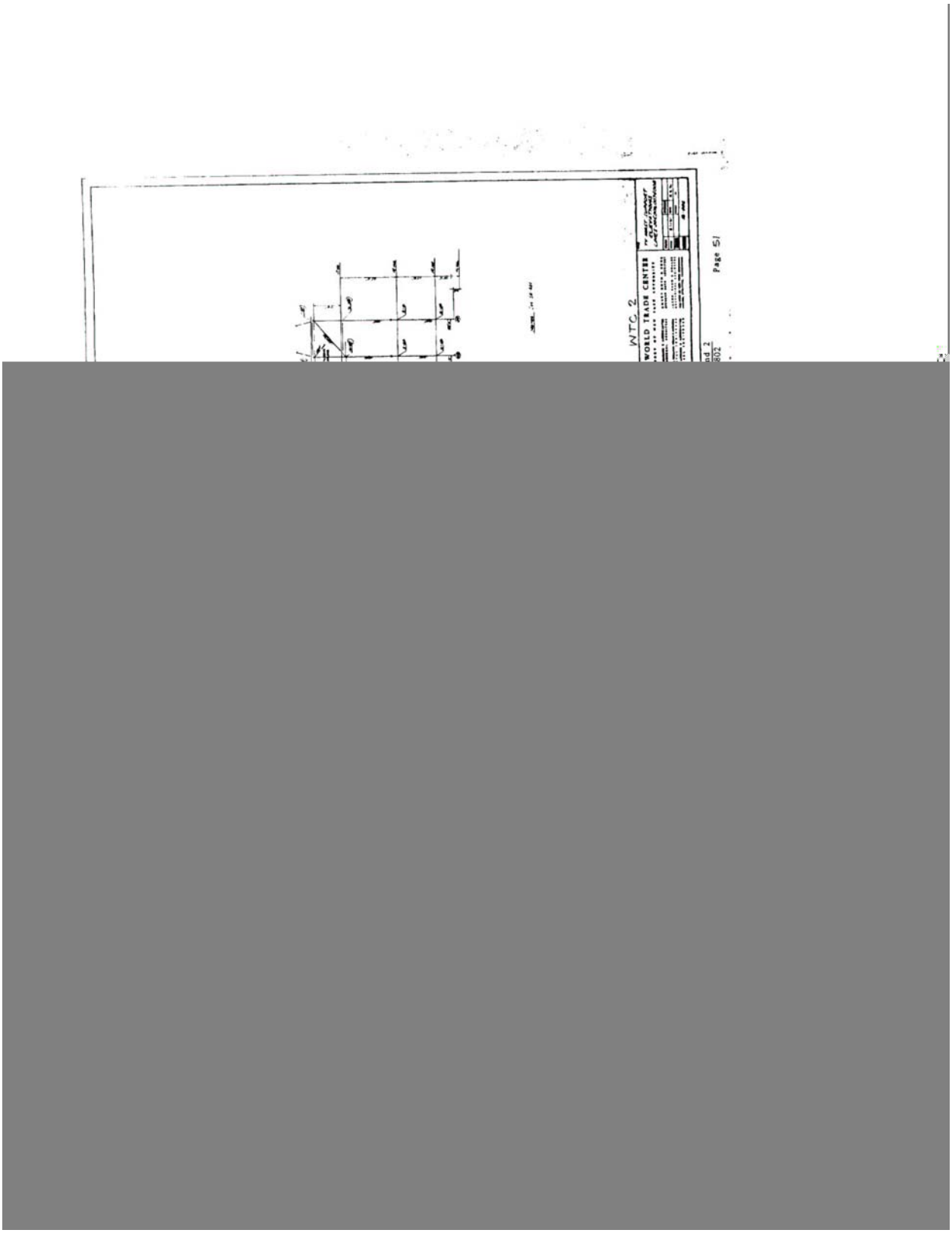
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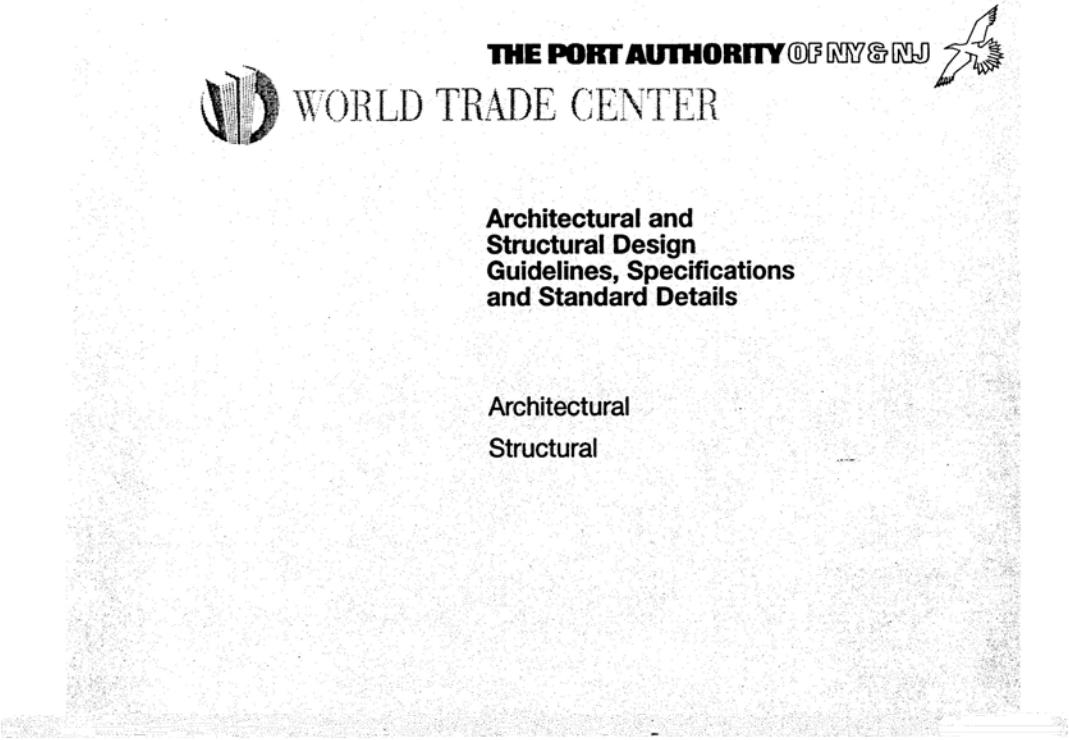
Appendix F
ARCHITECTURAL AND STRUCTURAL DESIGN GUIDELINES, SPECIFICATIONS, AND STANDARD DETAILS



February 27, 1998

THE WORLD TRADE CENTER
DESIGN GUIDELINES

STANDARDS FOR ARCHITECTURAL AND STRUCTURAL DESIGN

STANDARDS FOR ARCHITECTURAL AND STRUCTURAL DESIGN

TABLE OF CONTENTS

ARCHITECTURAL DESIGN GUIDELINES

A. GENERAL

The following is a guide for the architectural design requirement and criteria for tenant alterations at the WTC. The scope of the architectural review shall be to ensure compliance with the applicable codes, standards, and WTD Design Criteria.

1. ADA Compliance

All tenant spaces must conform to the latest design criteria established by the Americans with Disabilities Act (ADA), and Local Law # 58. A note specifying compliance should appear in each set of drawings. These requirements include but are not limited to the following:

a) HARDWARE - All hardware must conform to ADA requirements. Lever type knobs and panic bars are recommended for all doors.

b) ACCESS/CORRIDOR DIMENSIONS - All spaces within the tenant area must be equally accessible to the handicapped as specified by the ADA.

c) STROBES - All areas must be furnished with strobe lights (visual alarms). These strobes must be connected to the floor Class 'E' alarm system. See details in the Fire Alarm Design Guidelines.

d) TOILETS - Plans and elevations of the toilet for disabled people shall clearly show all critical dimensions as per ADA requirements.

2. Asbestos

A leasehold may contain vinyl asbestos floor tiles (VAT) which were installed

The tenant is required to submit documentation of the project once completed.

b) The tenant may retain the services of the World Trade Center Call-in abatement contractor. In this case the tenant must submit a written

B. WALL AND CEILING CONSTRUCTION

The WTD has available for the tenant's architect/engineer standard reference details which show examples of the depth and clarity of information required to be shown on the drawing for the construction of various wall and ceiling types. See attached WTC Standard Architectural and Structural Details.

1. Core Walls

All core wall shall have a 2-hour fire rating as required by the NYC Building Code.

2. Demising Walls

Walls separating tenants shall have a minimum 1-hour fire rating unless otherwise indicated by occupancy/use group.

3. Corridor Walls

Corridor walls shall have a fire-resistance rating of 2-hour as required by WTC and have a self-closing swinging type doors 1-1/2 fire resistance-rating.

4. Ceiling Construction

On tower floors with double trusses the WTC requires the suspended ceiling to be installed as detailed on the Standard Architectural Details STR-10 through STR-14 attached. All other areas and special installations must meet the requirements of the New York City Building Code.

A BS&A or MEA resolution of approval is required for ceiling tiles.

5. WTC Standard Ceilings

The new building standard suspended ceiling in public corridors is, 24" X 24" X 3/4" mineral fiber lay-in tile, Ultima RH90, beveled tegular, No.1782 for 9/16" slotted tee grid, by Armstrong.

C. MATERIALS AND METHODS OF CONSTRUCTION

No material, assemblies, forms, method of construction, equipment, machinery and devices will be acceptable for the intended use unless:

Accepted by the Code test method by the Materials and Equipment Acceptance (MEA) division of the Office of the Commissioner of the Buildings Department of New York City.

OR

Approved by the New York City Board of Standards and Appeals (BS&A)

Resolutions of MEA or BS&A shall be submitted for review. Manufacturers' or distributors' letters will not be acceptable.

1. Floor Coverings

The architect or engineer-of-record is required to obtain, certify, and supply for review documentation that the carpet has been tested by an independent laboratory (approved by the City of New York), showing the complete test data results in accordance with the New York City Building Code. Manufacturer's or supplier's data is unacceptable.

Carpet and carpeting assemblies shall not be installed in stairways designed to meet building code exiting requirements.

Carpets should be (but are not required to be) installed utilizing the "tackless" method which allows easier removal under the tenant's restoration obligation. The padding should be cemented to the subfloor at the perimeter with a "release" adhesive. Adhesives in all instances must be non-flammable. If rubber padding is used, all seams must be taped.

The tenant is required to provide all necessary access to trench header ducts and junction box cover plates for under floor conduit systems. If access is not provided, the tenant assumes all costs associated with the pulling-back, removing, and reinstalling of the carpet.

2. Raised Floor Systems

All raised floor systems must have a BS&A or MEA Resolution capable of withstanding the imposed loads.

For a raised floor not more that 10" in height, a minimum of 1-1/2" clearance is required between the edge of the raised floor and the induction unit (IU) enclosure. For furniture or a raised floor more than 10 " in height, a minimum of 6" clearance shall be maintained between the edge of the raised floor and the front of the induction unit enclosure. Additional removable floor grilles should be installed on the edge of the raised floor in front of the induction unit. See

Architectural Detail ARCH-17 for installation of raised floors which meet at the perimeter induction units.

3. Window Treatments

The WTC standard window covering is a horizontal blind, brushed aluminum finish, with 1" slats.

4. Transparent Glass and Fixed Adjacent Glass Sidelights

Transparent glass walls are required to be marked as per BS&A Rule 501-68-SR, Rules for Governing the marking of Transparent Glass Doors and Fixed Adjacent Glass Sidelights Rule. (See Attachment "A" to these guides)

5. Fire Shutters

Where spaces are provided with automatic fire shutters used to maintain the fire-rating, a safe means of egress shall be provided for persons who may remain inside the space after the grill is closed due to fire emergency. This additional egress must be in accordance with code requirements.

6. Fabric and Vinyl Wallcoverings

All fabric and vinyl wall coverings must have a copy of the BS&A or MEA resolutions submitted for approval.

D. SPECIALTY ROOMS AND EQUIPMENT

1. Storage Areas

Provide appropriate fire separations according to occupancy classification as per the NYC Building Code.

2. Computer Rooms

See the Mechanical and Fire Protection Guidelines for inclusion of Pre-action and Halon fire suppression systems.

E. CONTROLLED INSPECTIONS

All materials, equipment, and construction designated by the Code for "controlled inspection" shall be inspected and/or tested to verify compliance with the Code. Controlled inspections shall be made and witnessed by or under the direct supervision

of a registered architect (RA) or professional engineer (PE) retained by the tenant and acceptable to the architect or engineer responsible for the plans. The inspecting RA or PE shall be independent of the contractor.

F. SIGNAGE

1. Office Tenants

The World Trade Center will provide each tenant with one door sign and directory listings in the main lobby, skylobby and on the tenant's floor. Each tenant is entitled, by lease to a 12" X 12" acrylic door sign engraved with the company name and suite number.

Tenants who desire a non-standard door sign must first obtain approval of the WTD's Tenant Services Unit before proceeding with any such installation. The maintenance, repair, replacement, etc. of non-standard door signs, is the sole responsibility of the tenant.

G. FINAL SUBMITTAL

All alterations made to tenant spaces must have "AS BUILT" drawings submitted to the Tenant Alterations Unit of the World Trade Department upon completion of the job. Such AS BUILTS shall be submitted in the form of one complete set of Mylar reproducible drawings stamped AS BUILT and signed and verified by the consultant of record and the contractor and one (1) cadd disk (3-1/2", 1.44 mega Bytes floppy).

The architect shall state in the general specification the submission of such AS BUILTS

H. RETAIL AND PUBLIC SPACE TENANTS

See "Interim Tenant Design Criterial" for aesthetic criteria in public spaces at the World Trade Center.

STRUCTURAL DESIGN GUIDELINES

A. GENERAL

Before starting any design work, the tenant's consultants must perform a field inspection of all pertinent areas to verifythat they have the latest information about all structural elements. This includes information about truss reinforcement, if any, stair openings in slab and core-hole locations..

All calculations and construction drawings shall be submitted to the Port Authority for review and approval, and must be signed and sealed by a professional engineer or registered architect who must be licenced to practice in the state of New York.

Whenever calculations are submitted, a statement shall be made next to the seal on the cover sheet that "the professiona seal and signature affixed hereon is all inclusive for the full contents of this document." Alternatively, a separate seal and signature on each individual calculation sheet will also be acceptable. Four sets of calculations will be submitted with the first submission, and four copies of each revised sheet in any required subsequent submissions.

B. CALCULATIONS, LOADS, AND DESIGN PARAMETERS

The proposed floor loads shall be compared with the allowable design loading. Drawing STR-01 shows the allowable loading for a typical tower floor and also indicates limitations on the dimensions of concentrated loads. The design loads take into consideration all live load reductions on the trusses and also include the weight of partitions. For additional information or information on the other buildings in the complex contact Mr. Suren Batra WTC Structural Engineer, at (212)435-2409

The tenant's loads must not overstress the existing structural system. If required, the floor system can be reinforced. Calculations to compare the proposed loading with the allowable, and any revision to the floor system shall be made in conformance with the latest edition of the NYC Building Code. Both, "Allowable Stress Design" and "Load Resistance Factor Design," are acceptable methods of design.

When applicable, in place of a detailed investigation of the stresses in the existing structure, the moments and shears due to the tenant's proposed live loads may be compared with the moments and shears produced by the original design live loads shown on drawing STR-01.

The corner sections of a typical floor, work as a two-way truss system. Portions of the corner areas can take greater loads than those shown on drawing STR-01. An analysis of the tenant's loads based on a two way truss grid may yield satisfactory results for higher loads placed in a non-critical area of the corners.

To cover an existing floor opening by a slab, all structural elements shall be designed for the strength of the adjacent existing areas, and not the theoretical design loads. This is particularly necessary for any slab which has an overload capacity to support local concentrated loads.

Show and locate on the construction drawings:

a. The weight of any equipment, or cluster of equipment, exceeding 500 lbs.

b. All files and shelves. Provide a legend showing each type of file or shelving unit, and indicate the size and number of tiers for files and the height for shelves.

The following minimum loads shall be used for calculations when applicable:

a. File cabinets: 33 psf per tier, includes the weight of the cabinet.

b. Open shelves for paper storage: 46 pcf of the net volume plus the weight of the shelves.

c. Mechanized file storage: Use the manufacturer's indicated fully loaded weight, or the net weight of the storage unit plus 46 pcf for contents.

d. Libraries:

   1) Aisle loading:

      -for aisle width equal to or less than 30", use 30 psf.
      -for aisle widths greater than 30", use 60 psf.

   2) Reading areas - 60 psf.

   3) Open shelves - 46 pcf of the net volume plus the weight of the shelves.

e. File rooms aisle loading:
   -for aisle widths equal to or less than 30", use 30 psf.
   -for aisle widths greater than 30", use 50 psf.

Bases (and heads) for rail posts, auxiliary columns, etc. shall be designed for the required loads. Plates and bolts are to be fully detailed on the drawings, including the location and number of anchor bolts, manufacturer, type, size, embedment length, etc.

Wherever proprietary devices are used to transfer loads, submit for review, the BS&A number, the manufacturer's name, and a catalog cut.

C. CORE HOLES AND OTHER SLAB PENETRATIONS

A survey of slab penetrations in the vicinity of the proposed cores shall be submitted as early as possible in the review process, so that the need for repairs to the existing cores may be determined. Repairs shall be made as per attached details STR-06 through STR-08

Proposed penetrations or cores in the slab shall be clearly identified on the construction drawings for the trade that is expected to do the coring.

The dimensioned location of all new penetrations or cores shall be shown on the "As Built" drawings.

Proposed penetrations or cores in tower slabs shall meet the criteria for location, spacing, etc. as specified in the attached drawings STR-02 through STR-08, and Sructuctural Design Specifications, page 12. New penetrations or cores are not allowed in "Prohibited" areas. Penetrations or cores may be located in "Restricted" areas. However, damaged steel must be repaired as per details shown on drawings STR-06 through STR-08. It is advisable to avoid "restricted" areas in the design. Each "restricted" area penetration or core shall be labelled as such on the drawing and reference made to STR-06 through STR-08, which shall then be included in the contract set.

Proposed cores in the vicinity of "Prohibited" or "Restricted" areas, shall be dimensioned on the drawings using the face of the glass as a reference.

D. HUNG CEILINGS

Where new ceilings are to be installed, unless otherwise noted, it will be assumed that the existing ceiling suspension system will be removed and replaced.

For ceilings in the double truss areas of the towers, the span between trusses requires that the size of the carrying channels and caddy clips be larger than that required by the NYC Building Code. Provide the details shown on Drawings STR-09 through STR-14 on the construction drawings.

The carrying channels must be perpendicular to the existing trusses. Concrete anchors into the slab shall only be used:

1. At the end of the trusses where the truss lower flange is at a higher than normal elevation (see Section S-1, on STR-10) **and,**

2. Where the the hung ceiling is not continuous at a partition and there is no truss within 10" of the partition (see STR-13, "Typical Section at Partition Wall."). In all other cases the ceiling rods shall be hung from the trusses.

In the rest of the facility (without double trusses), the ceiling shall comply with the NYC Building Code, Reference Standard 5-16, figures 3A, 3B and 3C. Concrete anchors shall be one of the preapproved anchors listed in the Structural Design Specifications, Section B. A complete detail with all the specified materials shall be shown on the drawings. The detail shall include the type and size of materials and the embedment length of anchors.

E. HVAC EQUIPMENT

For all HVAC equipment provide on the drawings the weight, dimensions, the proposed locations, and specify whether they are floor mounted or hung from above.

For hanging ducts, fans and AC units under 500 lbs., refer to the details shown on Drawings HVAC-21 through 28. The tenant's consultant is still responsible to verify the integrity of the existing structure from which the units are hung (information on the tenant loading from the floor above is available from WT Tenant Services). Where the weight of the unit exceeds the limits shown on the above drawings, calculations must be provided showing that the unit's proposed support system can carry the load.

For floor mounted equipment, provide calculations showing that the existing construction will not be overstressed due to the weight of the units and show all mounting details on the drawings.

F. WALLS

Where there is a wall over an opening such as a door or over a non-supportive material such as plastic, glass, etc., either a suitable lintel shall be designed or the wall may be suspended by studs from above. However, the top and bottom connections and diagonal braces attached to the slab above (where required for stability of the wall) shall be appropriately desinged and detailed on the drawings.

G. EXISTING STEEL

Holes shall not be made in existing steel for hanging purposes. Welds shall not be made to the trusses. BS&A or MEA approved clamps shall be used.

STRUCTURAL SPECIFICATIONS

1. CORING CRITERIA AT TOWER P/T CELLS AND UNDER INDUCTION UNITS

Scope and General Notes

1. This criteria applies only to those holes cored into the Power/Telephone cells and under induction units and only in the following typical tenant floors:

   1 WTC 10 to 40, 45 to 74, 78 to 105
   2 WTC 14 to 40, 45 to 74, 78 to 106

2. For modifications of criteria at stair and escalator openings at floors 45 to 48 and 78 to 82 in both towers see Drawing STR-04.

3. Existing cored holes being reused are to be included in this criteria.

4. Maximum core size is 4" diameter, where permitted. Minimum average center to center spacing along a Power/Telephone cell for any four (4) consecutive cored holes including abandoned and filled holes is 1'-4". For restricted and prohibited zone destinations, see notes 5 and 6. For spacing criteria along Power/Telephone cells adjacent to holes offset from cells , see Drawing STR-05.

5. Restricted Zone:

   Carefully locate cores to avoid cutting #4, #5 and #6 rebars, or repair cut and damaged rebars.

   Where the proposed location of a new hole can be changed in order to clear the existing rebars and avoid the need for repairs, use a bar locater or electric hammer the slab to locate the rebars.

   See Drawing STR-06 through STR-08 for rebar repair details.

6. Prohibited Zones:

   Coring is prohibited, except within the induction units at the Power/Telephone Cells only, which should be considered a restricted area and as noted in part plan detail at building perimeter. See Drawing STR-03.

   See Drawings STR-06 through STR-08 for rebar anchor repair details.

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7. Existing cored holes which are to be abandoned and which do not have damaged rebars or column straps are to be filled with non-shrink grout. See detailed requirements rider C, paragraph 15 of the Tenant Alteration Application. Abandoned core holes which require repairs to straps will be repaired by the Port Authority.

8. Where concrete or fill material is to be removed, exercise due care not to damage existing reinforcement. Under no circumstances should column strap anchors be damaged.

9. Extension dimension are measured from the glass face at the exterior wall.

10. Drawings of the proposed core locations are to be submitted by the tenant for review. World Trade Construction must be notified in advance when coring or other work is to start so that provisions can be made for inspection.

11. Remove rust, grease, cement and other contaminants from structural steel and rebar surfaces before welding.

12. Tenant shall submit certification that welders are qualified in accordance with the NYC Building Code and with applicable laws and requirements for each specific welding procedure and process which the welder will use in the work.

13. Where information in the drawing conflicts with information in Rider C of the Tenant Alteration Application, this drawing governs.

Codes and Material

1. All work shall conform to the requirements of the New York City Building Code, latest edition and revision.

2. Where more stringent, the latest edition, with supplements to date where applicable, of the following codes shall apply to the work:

   a. American Institute of Steel Construction, "Specification for the Design, Fabrication and Erection of Structural Steel for Buildings." Supplement 1 is specifically excluded.

   b. American Concrete Institute, "Standard Building Code Requirements for Reinforced Concrete" (ACI 318).

   c. American Welding Society, "Structural Welding Code - Structural Steel (AWS D1.1) and Reinforcing Steel" (AWS D1.4).

3. Added structural steel plates shall conform to ASTM A36.

4. Added rebar shall conform to ASTM A615, Grade 60.

5. Welding materials for structural steel shall be E7018 conforming to AWS A5.1 "Specifications for Covered Carbon Steel Arc Welding Electrodes." –

6. Welding materials for reinforcing steel shall be E7018.

7. Non-Shrink Grout shall be Crystex by L&M Construction Chemicals Company, or an equivalent material acceptable to the WTC.

2. LIGHT WEIGHT CEILING SUPPORT SYSTEM FOR FLOORS W/DOUBLE TRUSS

NOTES:

1. Materials

   Concrete Anchors - 3/8" diameter Liebig safety bolts (type LSN or LSH) with a minimum embedment length of 1-3/4", or Hilti HSL or HSLB anchors, size M8 with a minimum embedments length of 2-1/2" and a maximum embedment length of 3".

   Clip Angles - Hot rolled ASTM A36 steel.

   Hangers - 1/4" diameter A36 galvanized steel rod

1). Minimum weight

Carrying Channel - 2" cold rolled channels (Fy=33ksi minimum
590 lbs./1,000 linear feet (painted).

Hanger to truss connection - at cover plate only

a. Thickness of bottom flange of truss t < 0.75":

:rico Products Inc.

Caddy heavy duty flange clamps manufactured by E
BSA 1312-64-SM.

b. Thickness of bottom flange of truss t > 0.75":

ch as manufactured
ith set screw in top

Universal C-clamp Fig. 93 (wide throat) 0.41 pounds ea
by Grinnell Corp., or approved equal. Install C-clamp w
position.

, Model 4B2LS, as
l.
Monel metal.

Hanger to carrying channel - Caddy Gat channel clamp
manufactured by Erico Products Inc. BSA 131-68-SM
Wire ties - 16 Gauge stainless steel AISI - Type 304 I

be replaced by the

2. Removal of fireproffing shall be kept to a minimum and shall
contractor as directed by the Port Authority.

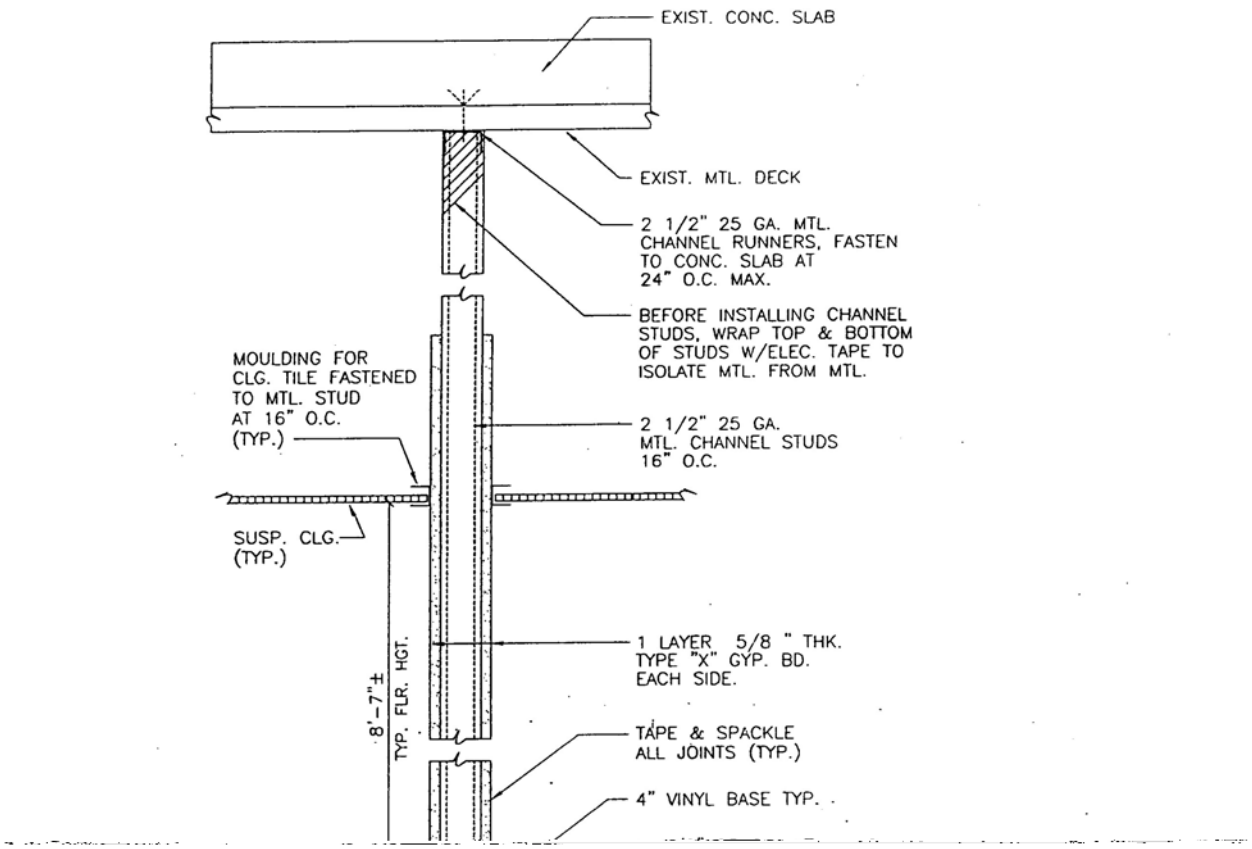
es, layout drawings
the Port Authority's
.

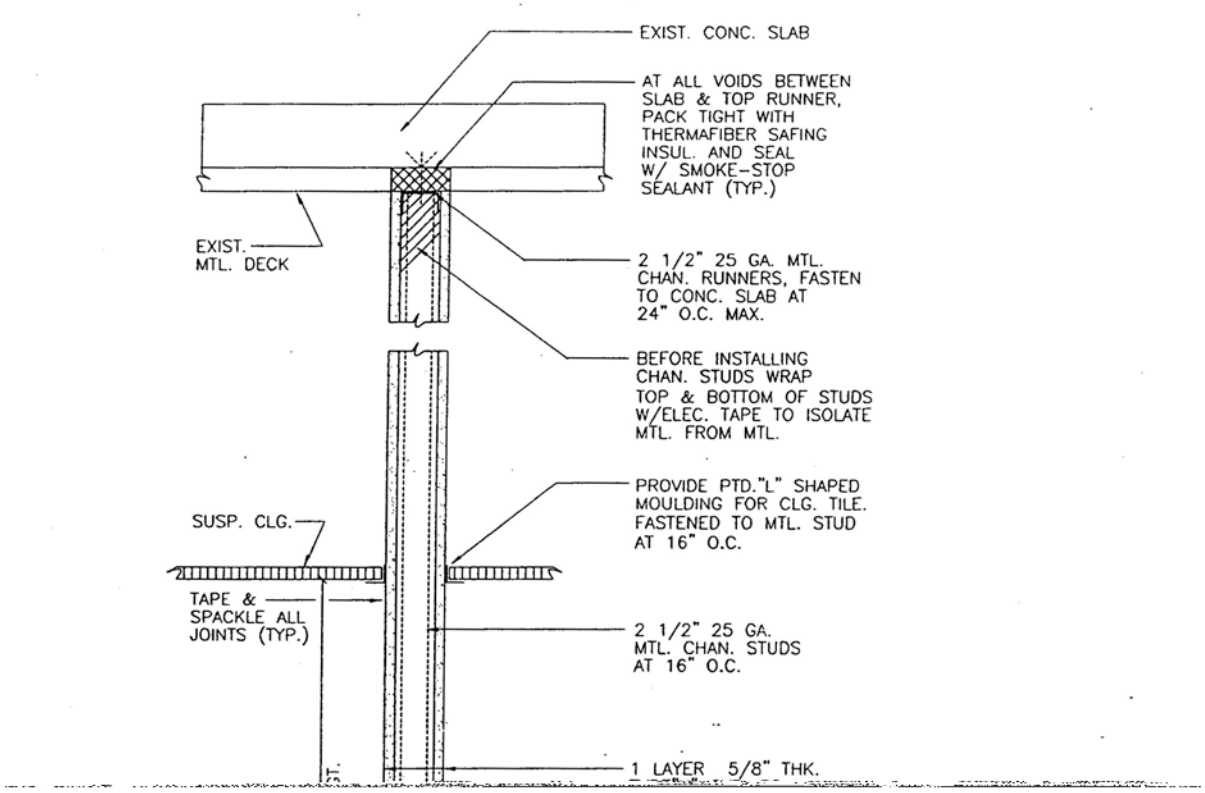
3. The contractor shall be required to submit catalog cuts, sampl
and details of all components of the ceiling support system for
review and approval prior to the start of any work in the field

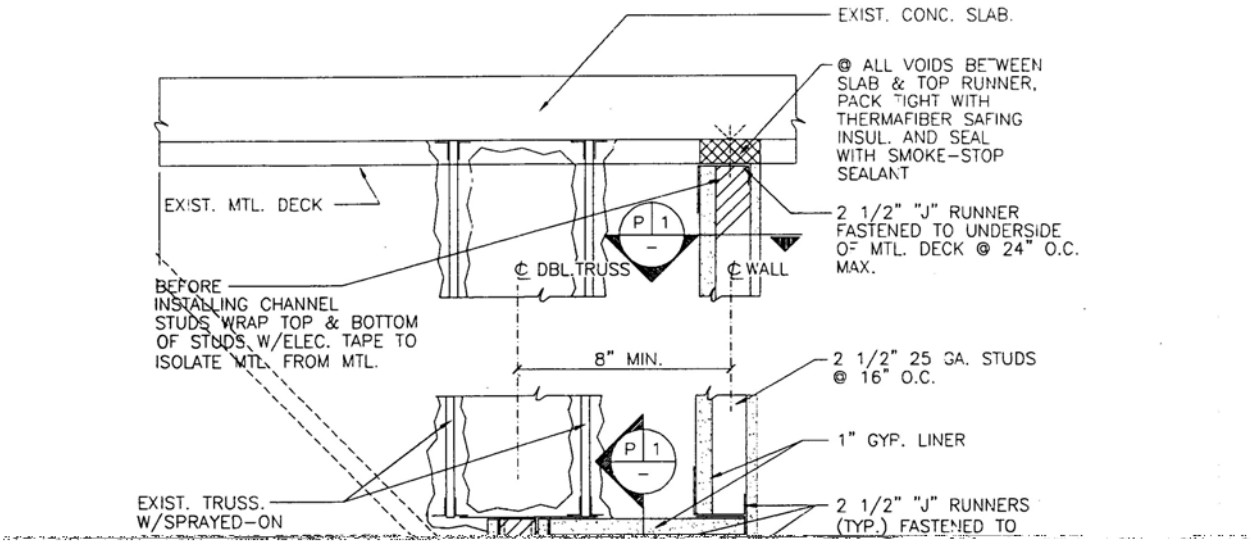
15

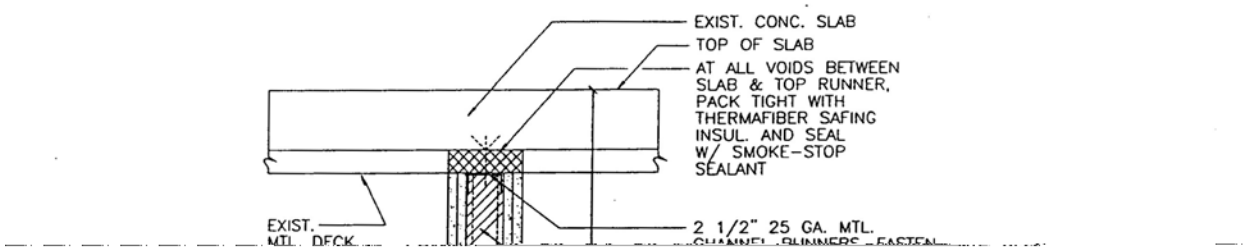
4. The Ramset fastening system with Ladd drive pin number 684 (1-1/2" long), power level "RED" for installation, and the Ladd ceiling clip number 651 is permitted to substitute the hanger top connection detail shown in Section S-1 on STR-10, anchored into 3000 psi light weight concrete slab over galvanized metal deck.

16

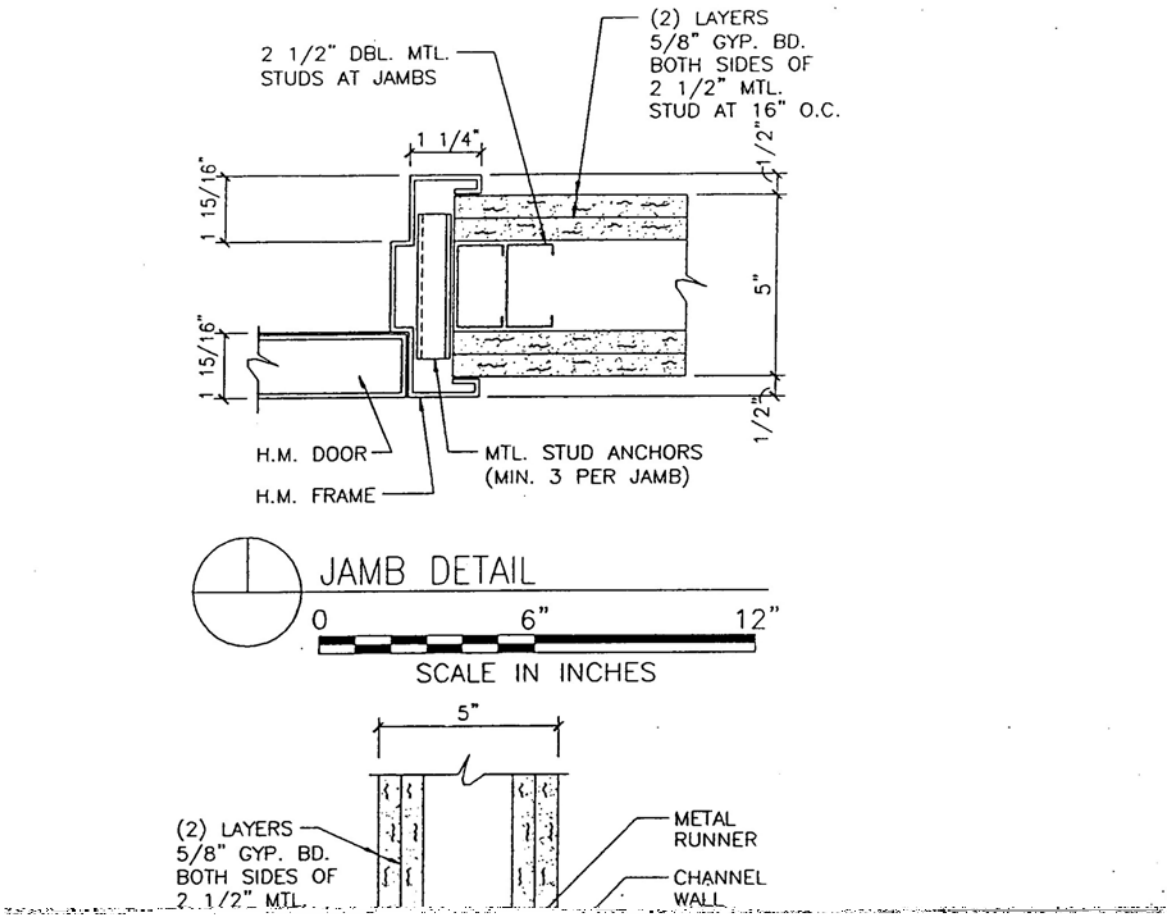

EXIST. CONC. SLAB
EXIST. MTL. DECK
2 1/2" 25 GA. MTL. CHANNEL RUNNERS, FASTEN TO CONC. SLAB AT 24" O.C. MAX.
BEFORE INSTALLING CHANNEL STUDS, WRAP TOP & BOTTOM OF STUDS W/ELEC. TAPE TO ISOLATE MTL. FROM MTL.
MOULDING FOR CLG. TILE FASTENED TO MTL. STUD AT 16" O.C. (TYP.)
2 1/2" 25 GA. MTL. CHANNEL STUDS 16" O.C.
SUSP. CLG. (TYP.)
1 LAYER 5/8 " THK. TYPE "X" GYP. BD. EACH SIDE.
8'-7"± TYP. FLR. HGT.
TAPE & SPACKLE ALL JOINTS (TYP.)
4" VINYL BASE TYP.

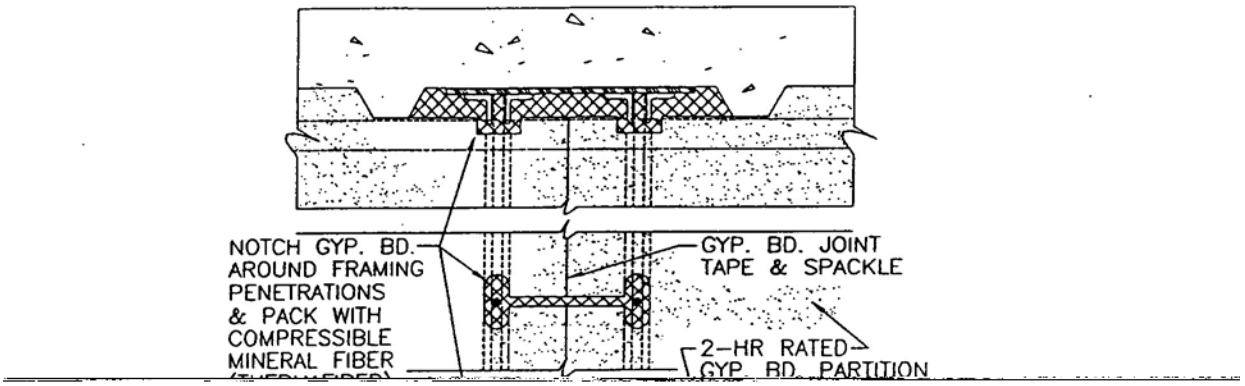

EXIST. CONC. SLAB
AT ALL VOIDS BETWEEN SLAB & TOP RUNNER, PACK TIGHT WITH THERMAFIBER SAFING INSUL. AND SEAL W/ SMOKE-STOP SEALANT (TYP.)
EXIST. MTL. DECK
2 1/2" 25 GA. MTL. CHAN. RUNNERS, FASTEN TO CONC. SLAB AT 24" O.C. MAX.
BEFORE INSTALLING CHAN. STUDS WRAP TOP & BOTTOM OF STUDS W/ELEC. TAPE TO ISOLATE MTL. FROM MTL.
PROVIDE PTD."L" SHAPED MOULDING FOR CLG. TILE. FASTENED TO MTL. STUD AT 16" O.C.
SUSP. CLG.
TAPE & SPACKLE ALL JOINTS (TYP.)
2 1/2" 25 GA. MTL. CHAN. STUDS AT 16" O.C.
1 LAYER 5/8" THK.


EXIST. CONC. SLAB.
@ ALL VOIDS BETWEEN SLAB & TOP RUNNER, PACK TIGHT WITH THERMAFIBER SAFING INSUL. AND SEAL WITH SMOKE-STOP SEALANT
EXIST. MTL. DECK
2 1/2" "J" RUNNER FASTENED TO UNDERSIDE OF MTL. DECK @ 24" O.C. MAX.
P 1
℄ DBL. TRUSS
℄ WALL
BEFORE INSTALLING CHANNEL STUDS WRAP TOP & BOTTOM OF STUDS W/ELEC. TAPE TO ISOLATE MTL. FROM MTL.
8" MIN.
2 1/2" 25 GA. STUDS @ 16" O.C.
1" GYP. LINER
EXIST. TRUSS. W/SPRAYED-ON
2 1/2" "J" RUNNERS (TYP.) FASTENED TO

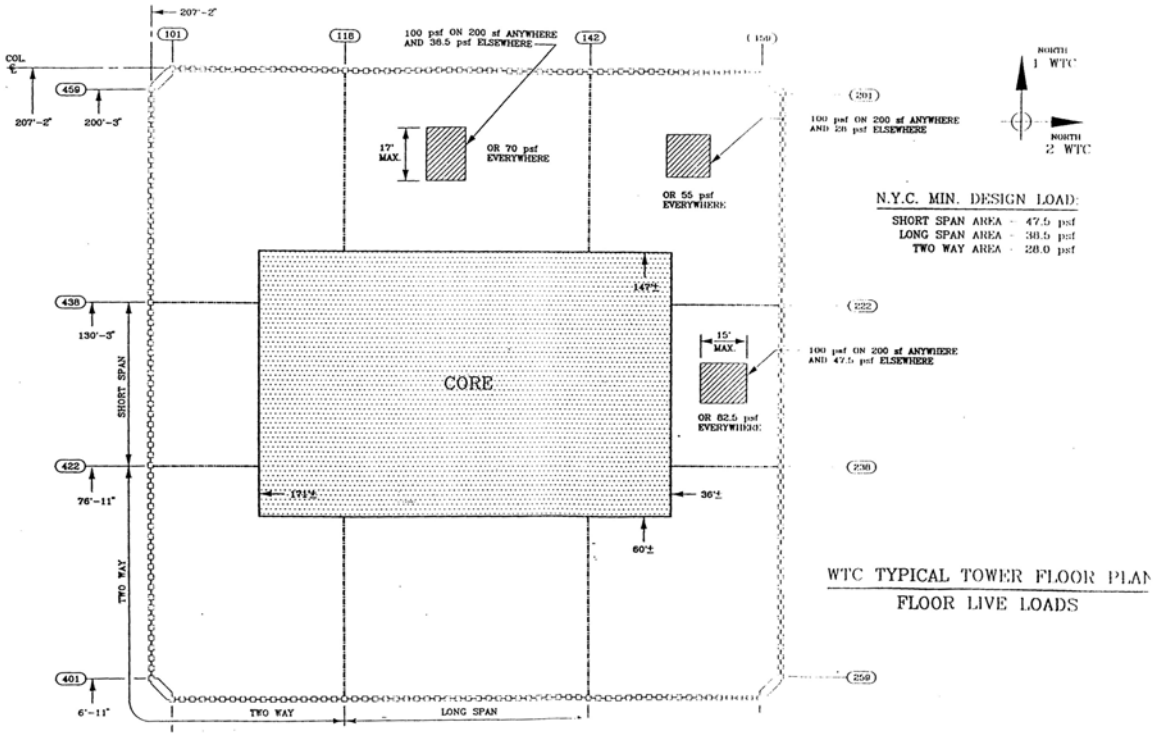

EXIST. CONC. SLAB
TOP OF SLAB
AT ALL VOIDS BETWEEN SLAB & TOP RUNNER, PACK TIGHT WITH THERMAFIBER SAFING INSUL. AND SEAL W/ SMOKE-STOP SEALANT
EXIST. MTL. DECK
2 1/2" 25 GA. MTL.

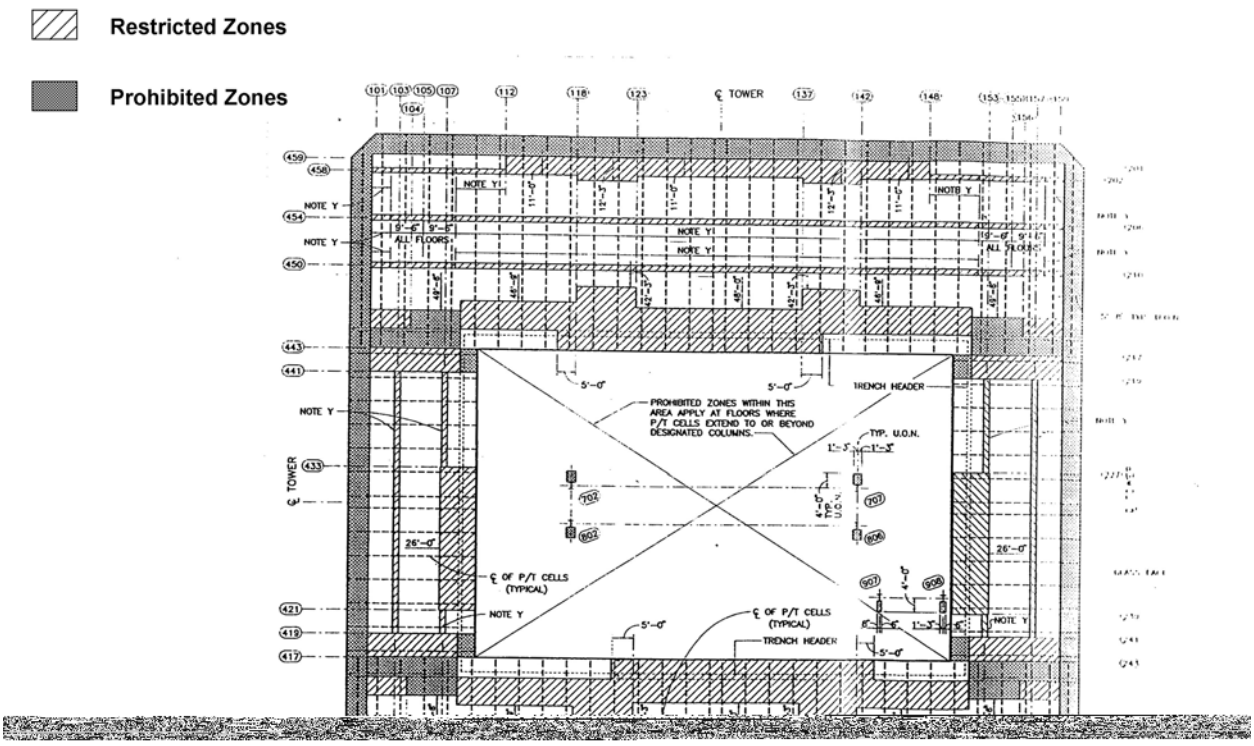

EXIST. CONC. SLAB.
ALL VOIDS BETWEEN

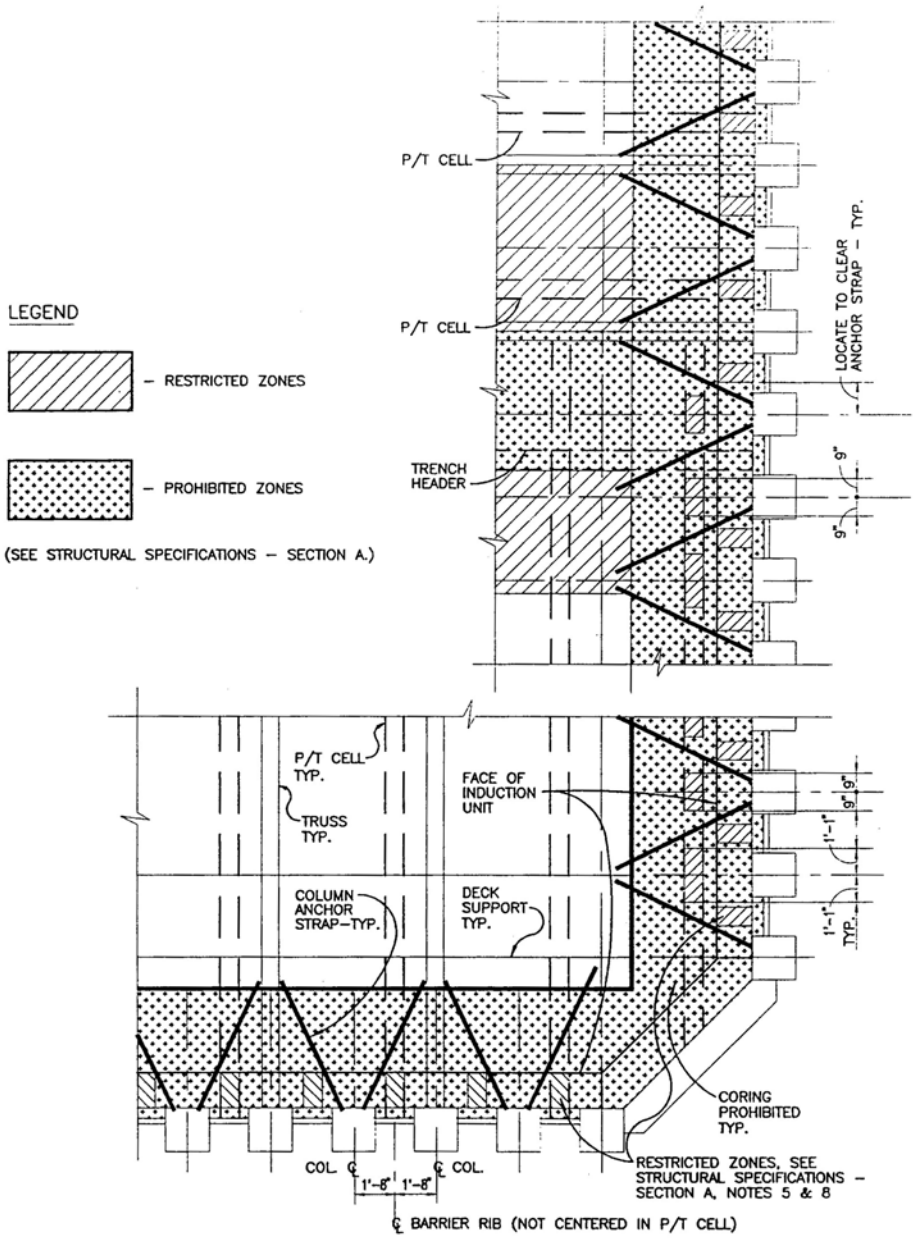

2 1/2" DBL. MTL. STUDS AT JAMBS
(2) LAYERS 5/8" GYP. BD. BOTH SIDES OF 2 1/2" MTL. STUD AT 16" O.C.
1 1/4"
1 15/16"
1 15/16"
1/2"
5"
1/2"
H.M. DOOR
H.M. FRAME
MTL. STUD ANCHORS (MIN. 3 PER JAMB)
JAMB DETAIL
0
6"
12"
SCALE IN INCHES
5"
(2) LAYERS 5/8" GYP. BD. BOTH SIDES OF 2 1/2" MTL.
METAL RUNNER
CHANNEL WALL


NOTCH GYP. BD.
AROUND FRAMING
PENETRATIONS
& PACK WITH
COMPRESSIBLE
MINERAL FIBER
GYP. BD. JOINT
TAPE & SPACKLE
2-HR RATED
GYP. BD. PARTITION


ALUMINUM
NOSING 1" X 1"


207'-2"
101
118
142
150
COL. ℄
459
207'-2"
200'-3"
100 psf ON 200 sf ANYWHERE
AND 38.5 psf ELSEWHERE
17' MAX.
OR 70 psf EVERYWHERE
OR 55 psf EVERYWHERE
201
100 psf ON 200 sf ANYWHERE
AND 28 psf ELSEWHERE
NORTH
1 WTC
NORTH
2 WTC
N.Y.C. MIN. DESIGN LOAD:
SHORT SPAN AREA - 47.5 psf
LONG SPAN AREA - 38.5 psf
TWO WAY AREA - 28.0 psf
438
130'-3"
SHORT SPAN
147'±
222
15' MAX.
100 psf ON 200 sf ANYWHERE
AND 47.5 psf ELSEWHERE
CORE
OR 82.5 psf EVERYWHERE
422
76'-11"
171'±
36'±
230
60'±
TWO WAY
401
6'-11"
TWO WAY
LONG SPAN
259
WTC TYPICAL TOWER FLOOR PLAN
FLOOR LIVE LOADS
STR-01


Restricted Zones
Prohibited Zones
℄ TOWER
NOTE Y
ALL FLOORS
PROHIBITED ZONES WITHIN THIS AREA APPLY AT FLOORS WHERE P/T CELLS EXTEND TO OR BEYOND DESIGNATED COLUMNS.
TRENCH HEADER
TYP. U.O.N.
℄ OF P/T CELLS (TYPICAL)
26'-0"
5'-0"



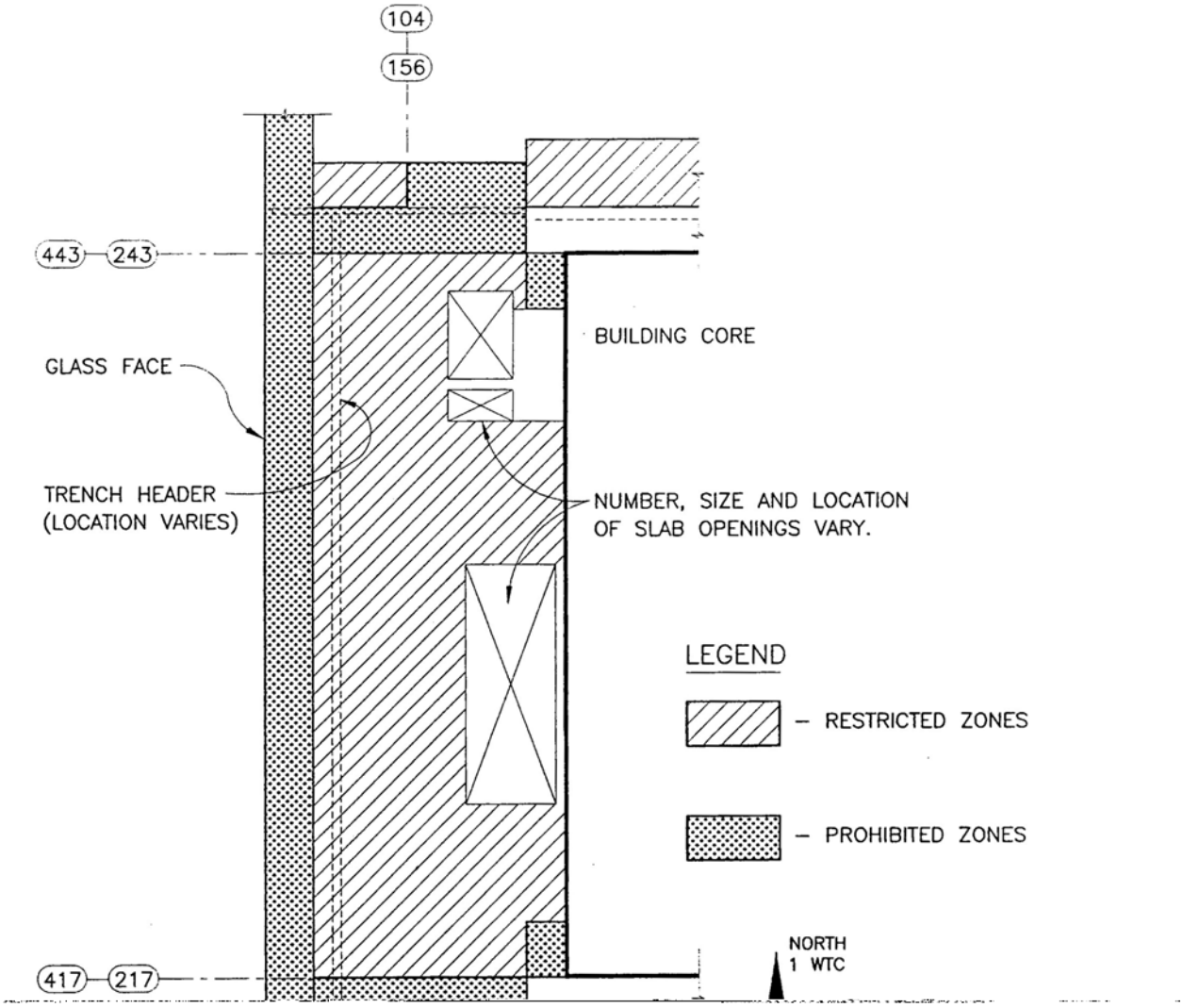
DETAIL AT BUILDING PERIMETER

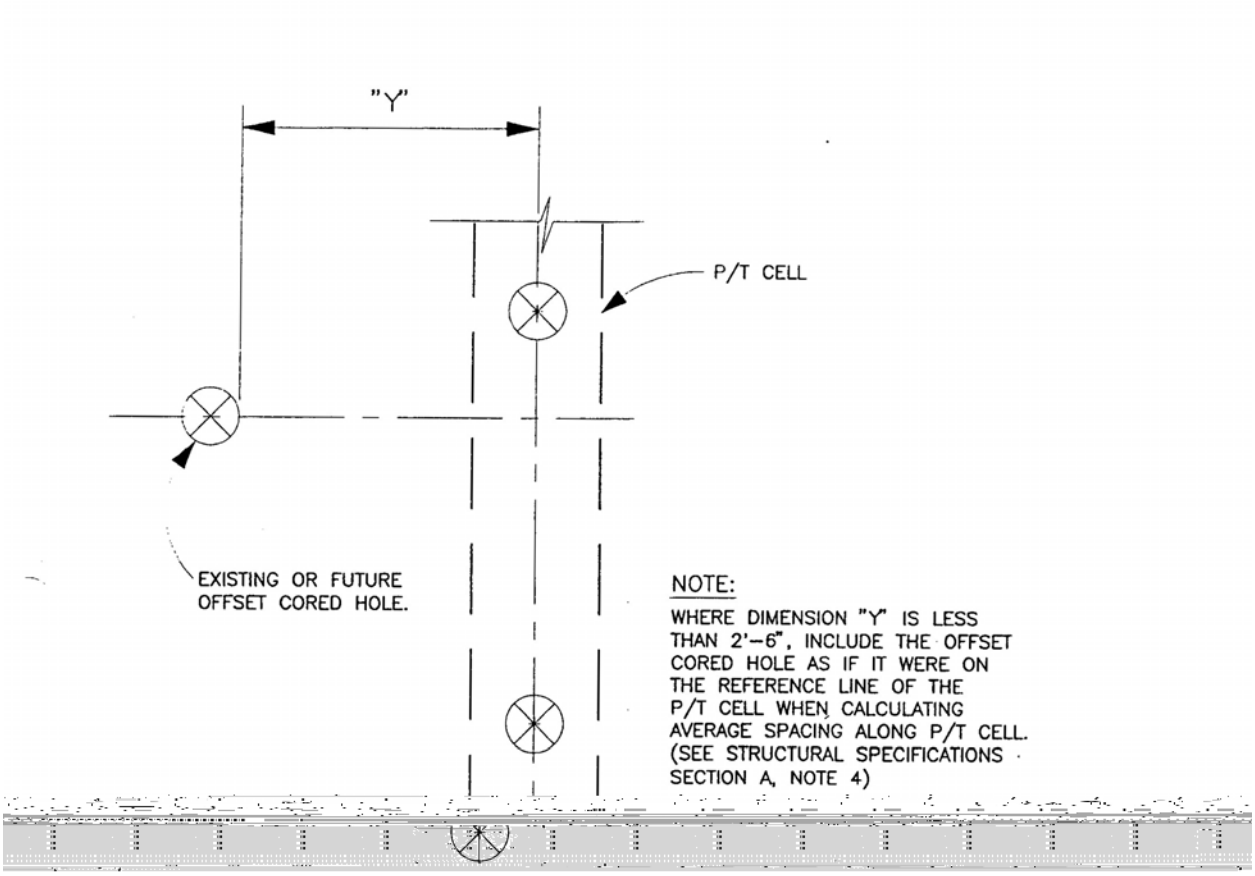
CORING CRITERIA

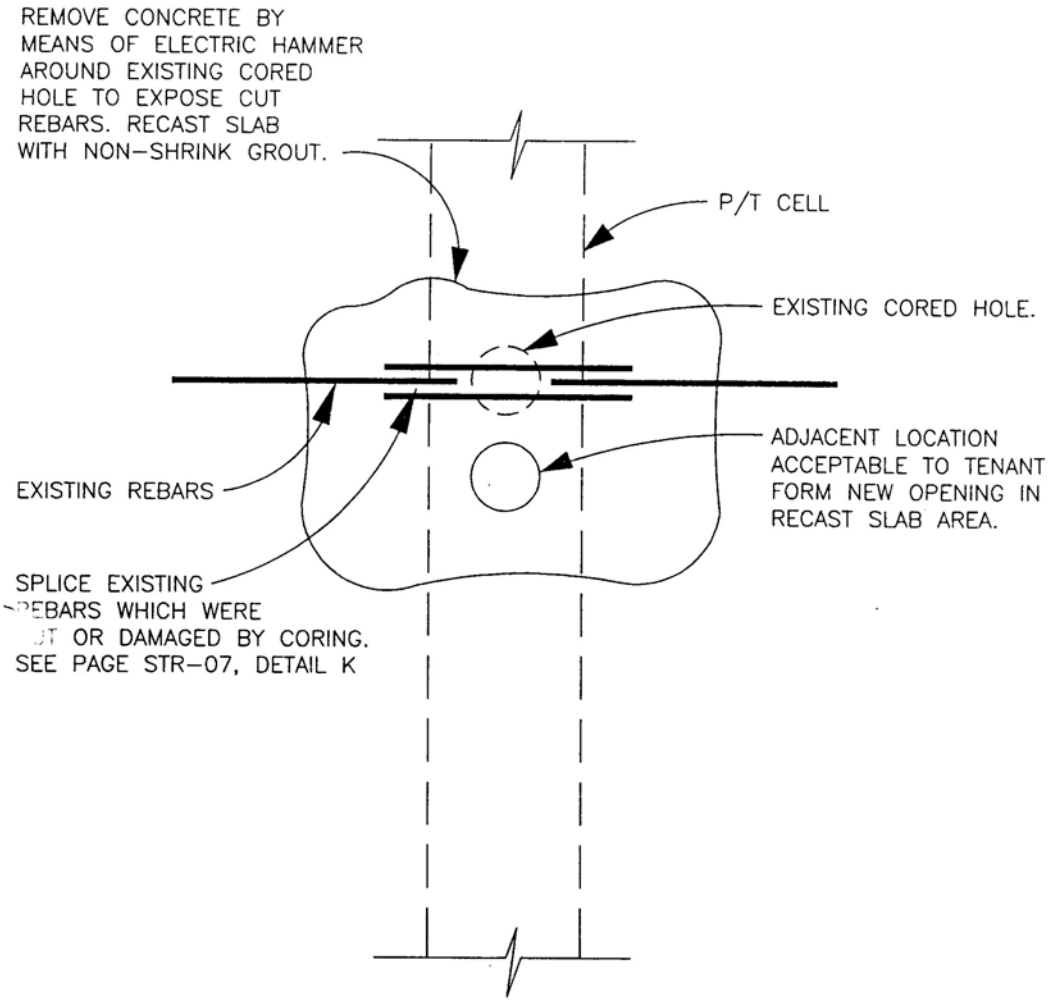
0 5' 10'

GRAPHIC SCALE

STR–03

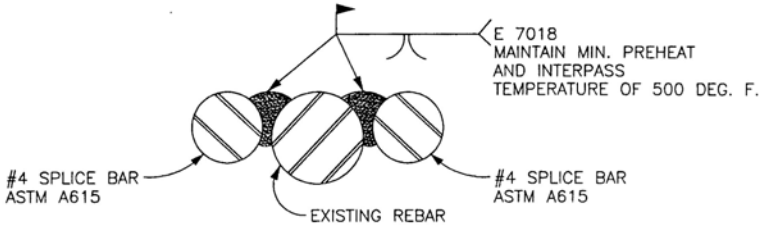

104
156
443
243
GLASS FACE
TRENCH HEADER
(LOCATION VARIES)
BUILDING CORE
NUMBER, SIZE AND LOCATION
OF SLAB OPENINGS VARY.
LEGEND
– RESTRICTED ZONES
– PROHIBITED ZONES
NORTH
1 WTC
417
217


"Y"
P/T CELL
EXISTING OR FUTURE
OFFSET CORED HOLE.
NOTE:
WHERE DIMENSION "Y" IS LESS
THAN 2'-6", INCLUDE THE OFFSET
CORED HOLE AS IF IT WERE ON
THE REFERENCE LINE OF THE
P/T CELL WHEN CALCULATING
AVERAGE SPACING ALONG P/T CELL.
(SEE STRUCTURAL SPECIFICATIONS
SECTION A, NOTE 4)

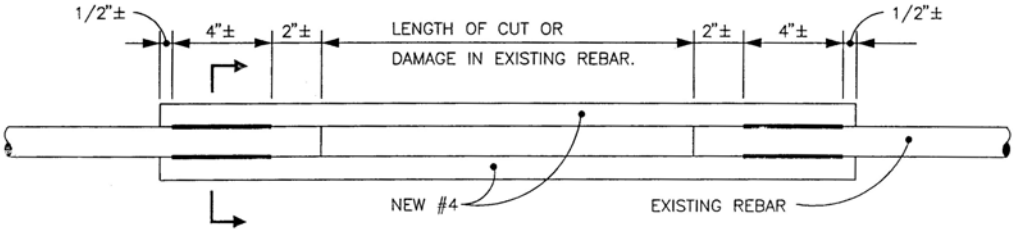


REBAR SPLICE

CORING CRITERIA



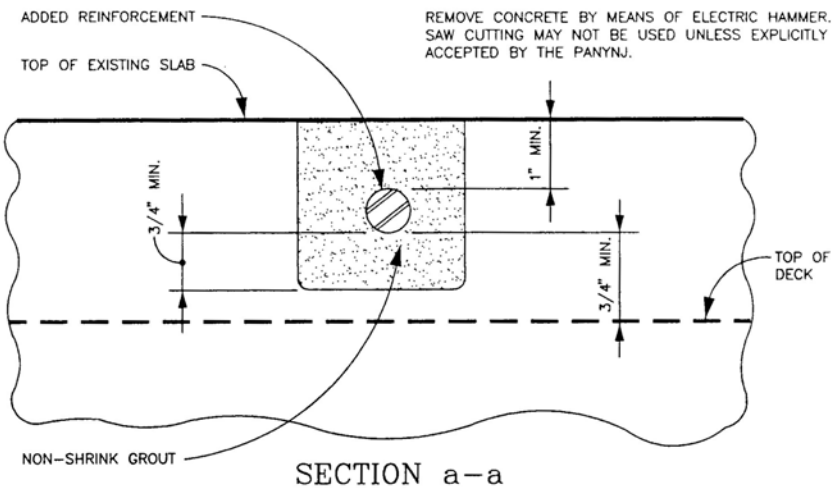
SECTION AT WELD



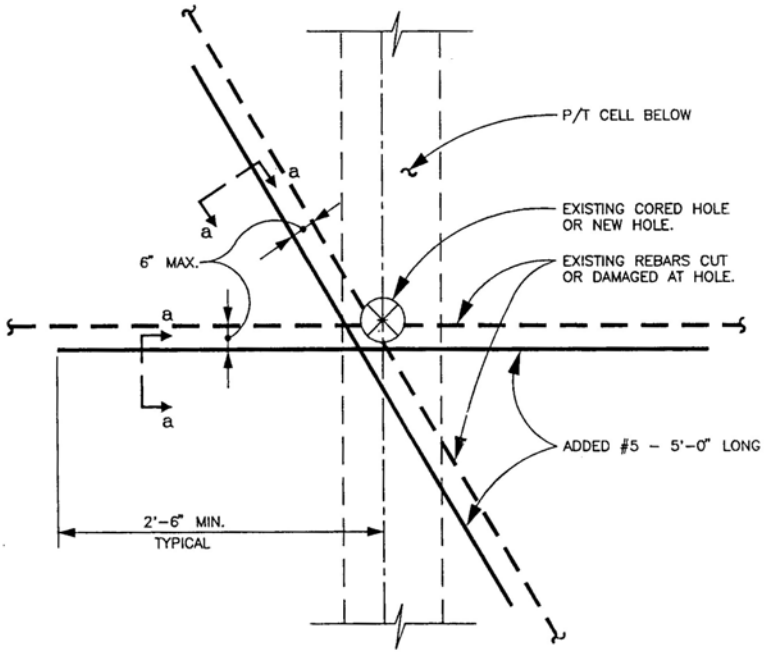
REBAR SPLICE

CORING CRITERIA

STR-07



SECTION a–a

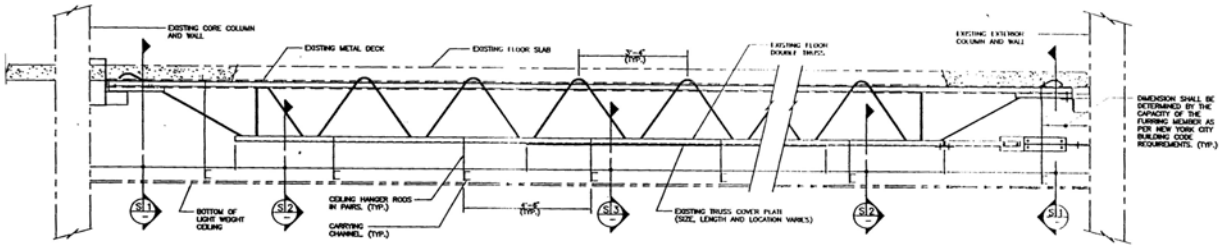


PLAN

REBAR REPAIR
CORING CRITERIA

SCHEMATIC REBAR REPAIR DETAIL WHERE HOLE CANNOT BE RELOCATED. THIS DETAIL TO BE USED ONLY WITH PRIOR APPROVAL OF PANYNJ.

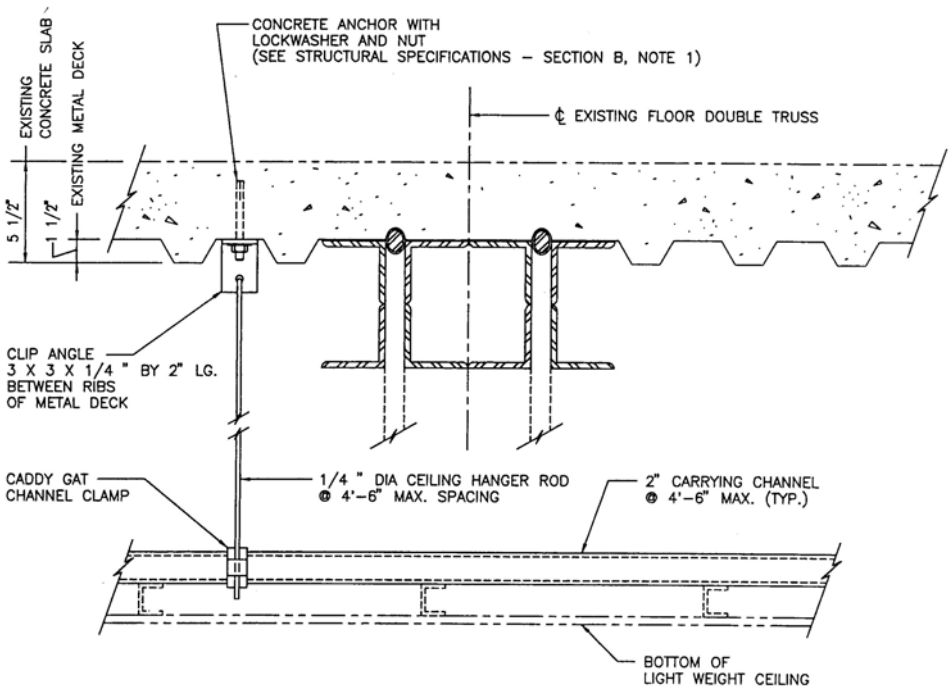
STR–08



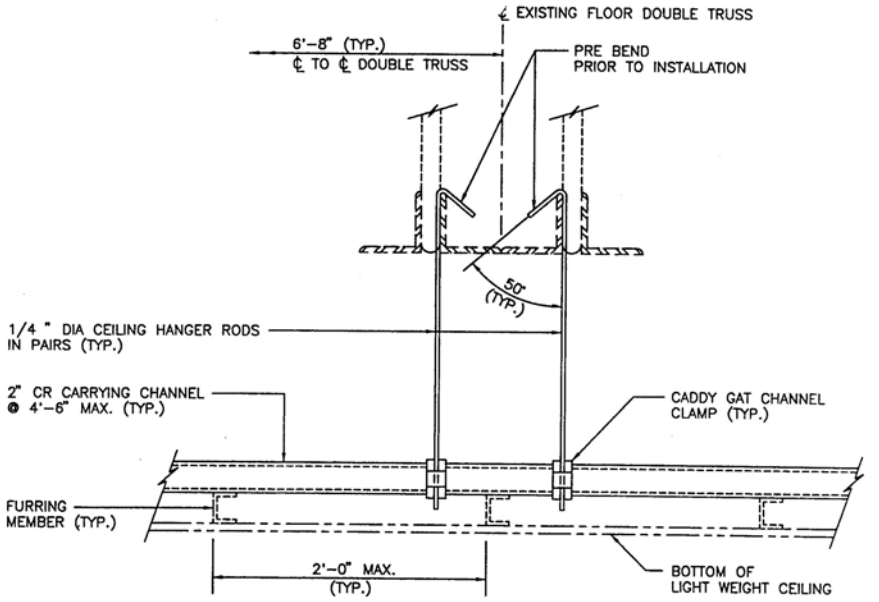
PART ELEVATION – TYPICAL FLOOR WITH DOUBLE TRUSS

LIGHT WEIGHT CEILING SUPPORT SYSTEM FOR FLOORS W/DOUBLE TRUSSES

STR–09


CONCRETE ANCHOR WITH
LOCKWASHER AND NUT
(SEE STRUCTURAL SPECIFICATIONS – SECTION B, NOTE 1)
℄ EXISTING FLOOR DOUBLE TRUSS
EXISTING CONCRETE SLAB
EXISTING METAL DECK
5 1/2"
1 1/2"
CLIP ANGLE
3 X 3 X 1/4 " BY 2" LG.
BETWEEN RIBS
OF METAL DECK
CADDY GAT
CHANNEL CLAMP
1/4 " DIA CEILING HANGER ROD
@ 4'–6" MAX. SPACING
2" CARRYING CHANNEL
@ 4'–6" MAX. (TYP.)
BOTTOM OF
LIGHT WEIGHT CEILING

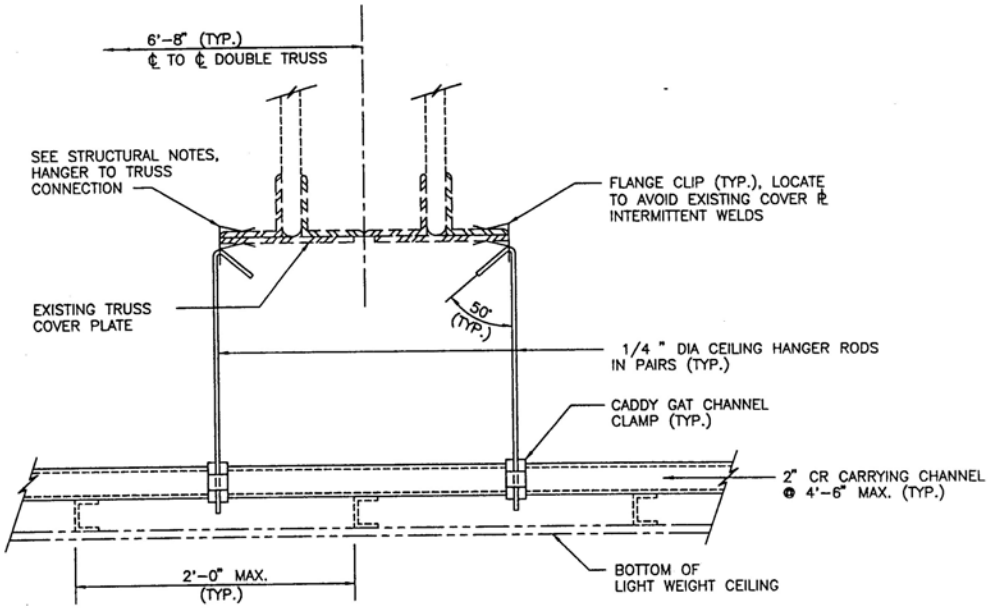
SECTION S–1



SECTION S-2

LIGHT WEIGHT CEILING SUPPORT SYSTEM FOR FLOORS W/DOUBLE TRUSSES

STR-11

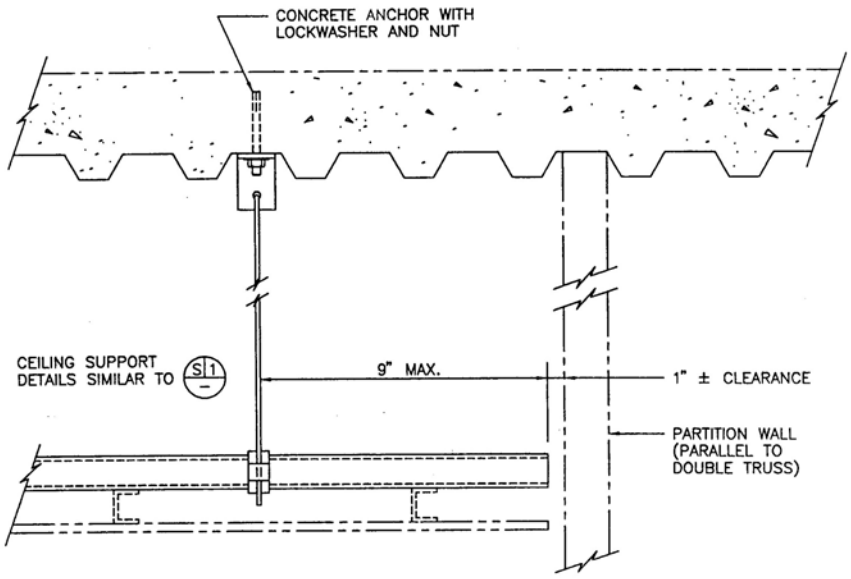


CEILING SUPPORT DETAIL
AT COVER PLATE ONLY

SECTION S-3

LIGHT WEIGHT CEILING SUPPORT SYSTEM FOR FLOORS W/DOUBLE TRUSSES

STR-12

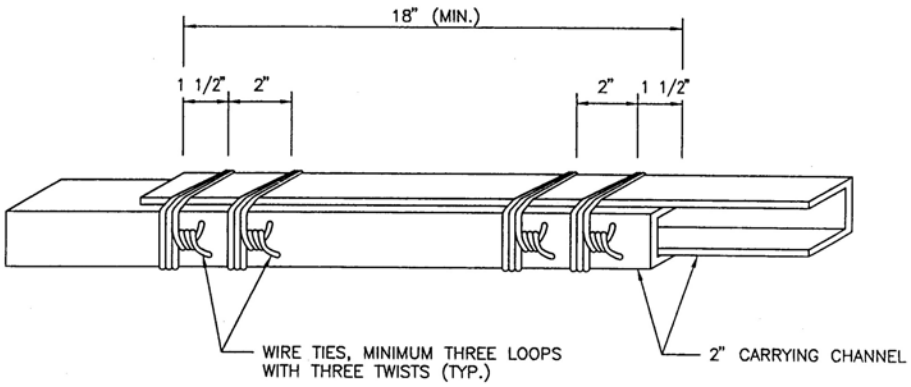


TYPICAL SECTION AT PARTITION WALL

TYPICAL SECTION AT PARTITION WALL

LIGHT WEIGHT CEILING SUPPORT SYSTEM FOR FLOORS W/DOUBLE TRUSSES

STR-13



TYPICAL "2" CHANNEL SPLICE DETAIL

TYPICAL "2" CHANNEL SPICE DETAIL

LIGHT WEIGHT CEILING SUPPORT SYSTEM FOR FLOORS W/DOUBLE TRUSSES

STR-14

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Appendix G
SUPPORTING DOCUMENTS

This appendix contains the supporting documents that are referenced in this report. All of the documents contained in this appendix are reproduced with permission of The Port Authority of New York and New Jersey. Table G–1 contains a summary of supporting documents and their location within this appendix.

Table G–1. Supporting documents for report.

Document Title		Page(s)
Section 2.1.4 – Tenant Construction Review Manual (1997 Edition)		
PANYNJ Memorandum dated August 8, 1995 from Oscar Suros, Manager of the Engineering Department Quality Assurance Division to Eugene J. Fasullo, Director and Chief Engineer		300
Section 3.2.1 – Structural Integrity Inspection Program (Overview)		
Letter dated January 12, 1990 from Saw-Teen See of Leslie E. Robertson Associates to Suren Batra of the Port Authority of New York and New Jersey (WTCI-123-P)		304
Section 3.2.2 – Summary of Structural Integrity Inspection Program Reports		
Locations of columns inspected in Accessible Columns Structural Integrity Inspection reports	1993 report	306
	1995 report	307
	1996 report	311
	1997 report	319
	1998 report	328
Historical Review of World Trade Center Damping Units (WTCI-230-L)		336

PANYNJ Memorandum dated August 8, 1995

THE PORT AUTHORITY OF NY & NJ

MEMORANDUM

TO: Eugene J. Fasullo, P.E., Director of Engineering & Chief Engineer
FROM: Oscar Suros
DATE: August 8, 1995
SUBJECT: **SEISMIC DESIGN - NEW YORK CITY BUILDING CODE**

COPY TO: A. Aronowitz, A. Brociner, J. Buchsbaum, R. Davidson, J. Englot, J. Kelly, T. Kelly, F. Lombardi, E. Ramabhushanam, EPMs

REF: Memo, Vanacore to Directors, October 4, 1988 and Memo, Suros to Fasullo, June 7, 1994

THE PORT AUTHORITY OF NY & NJ
QUALITY ASSURANCE DIV.
ENGINEERING DEPT.
AUG 1 0 1995
RECEIVED
NOTED: _____
ALTERED:

As established by the referenced memoranda, it has been our policy to design building structures and building components for seismic effects in both New Jersey and New York using the BOCA National Building Code. Recently the New York City Council and the Mayor enacted Local Law #17/95 providing requirements for seismic design of buildings and their components. This law adds provisions to the New York City Building Code that will be mandatory for all building or alteration applications filed on or after February 21, 1996.

Your approval is requested to start using the recently enacted changes to the New York City Building Code for all construction in New York City, including the revisions listed in Attachment A, effective immediately. The BOCA National Building Code will continue to be used for New Jersey and Yonkers construction.

The revisions in Attachment A are required in order to meet the stated intent of the seismic revisions to the New York City Building Code. This will insure that potential overhead hazards will not fall on building occupants as a result of a

COPY TO
ER
LD
RP
IB
SB
PD
BF
JH
IR
AT
MA
CK
FILE
POST

seismic event and that the building can be safely evacuated during and immediately following a seismic event. Similar provisions are included in the BOCA Code and are considered minimum requirements. No significant cost penalty is estimated due to the minor modifications included in Attachment A.

Oscar Suros, P.E.
Manager
E/A Design Division

APPROVED:

Director of Engineering &
Chief Engineer

Attachments

OS:cep

ATTACHMENT A

Revisions to the New York City Building Code

Revise Table No. 23-P of RS 9-6 by:

(a) Adding after II. 1. b.
"c. Overhead Signs . . . . . 2.00";

(b) Adding after II. 3.
"4. Anchorage for suspended ceilings weighing more than 4 psf without the weight of light fixtures . . . . 0.75";

(c) Adding after III. 1.
"2. Elevator and counterweight guardrails and supports . . . 1.25"
"3. Sprinkler piping[5] . . . . . 2.00"
"4. Gas and high hazard piping. . . . . 2.00"
"5. Other piping[6] . . . . . 0.67"
"6. HVAC ducts[6] . . . . . 0.67"

(d) Adding the following notes after note 4. at the bottom of the table:
"5. The design of seismic restraints for sprinkler piping in compliance with NFPA 13 using a design acceleration of 0.15 is acceptable in lieu of compliance with these provisions.
6. Seismic restraints are not required for any of the following conditions for other pipe systems or HVAC ducts:

1. Piping or ducts suspended by individual hangers 12 inches or less in length from the top of the pipe or duct to the supporting structure.
2. Piping in boiler and mechanical rooms which has less than 1 1/4 inches inside diameter.
3. Piping in other areas which has less than 2 1/2 inches inside diameter.
4. Ducts which have a cross-section area less than 6 square feet."

Table No. 23-P

HORIZONTAL FORCE FACTOR C_p[1]

ELEMENTS OF STRUCTURES, NONSTRUCTURAL COMPONENTS AND EQUIPMENT	VALUE OF C_p
I. Part of Portion of Structure	
1. Walls, including the following:	
a. Unbraced (cantilevered) parapets.	2.00
b. Other exterior walls above street grade [2].	0.75
c. All interior bearing walls.	0.75
d. All interior nonbearing walls and partitions around vertical exits, including offsets and exit passageways.	0.75
e. Nonbearing partitions and masonry walls in areas of public assembly > 300 people.	0.75
f. All interior nonbearing walls and partitions made of masonry in Occupancy I, II and III.	0.75
g. Masonry or concrete fences at grade over 10 feet high.	0.50
2. Penthouses (defined in article 2 of subchapter 2 of chapter 1 of title 27 of the building code) except where framed by an extension of the building frame	0.75
3. Connections for prefabricated structural floor and roof elements other than walls (see above) with force applied at center of gravity.	0.75
4. Diaphragms[3].	
II. Nonstructural Components	
1. a. Exterior ornamentation and appendages including cornices, ornamental statuaries or similar pieces of ornamentation.	2.00
b. Interior ornamentation and appendages in areas of public assembly including cornices, ornamental statuaries or similar pieces of ornamentation.	2.00
2. Chimneys, stacks, trussed towers and tanks on legs.	
a. Supported on or projecting as an unbraced cantilever above the roof more than one-half its total height.	2.00
b. All others, including those supported below the roof with unbraced projection above the roof less than one-half its height, or braced or guyed to the structural frame at or above its center of mass.	0.75
3. Exterior signs and billboards.	2.00
III. Equipment and Machinery[4]	
1. Tanks and vessels (including contents), including support systems and anchorage.	0.75

Notes:

1. See Section 2312(g)[2] for additional requirements for determining C_p for nonrigid equipment or for items supported at or below grade.

2. See Section 2312(h)2D(iii) and Section 2313(g)2.

3. See Section 2312(h)2I.

4. Equipment and machinery include such items as pumps for fire sprinklers, motors and switch gears for sprinkler pumps, transformers and other equipment related to life-safety including control panels, major conduit ducting and piping serving such equipment and machinery.

Letter dated January 12, 1990 from Saw-Teen See of Leslie E. Robertson Associates to Suren Batra of the Port Authority of New York and New Jersey (WTCI-123-P)

LESLIE E. ROBERTSON ASSOCIATES *Consulting Structural Engineers*
211 East 46th Street, New York, N.Y. 10017-2989
Phone: (212) 750-9000
Fax: (212) 750-9002

12 January 1990
File: B1003900

Mr. Suren Batra
The Port Authority of New York & New Jersey
WTC Planning & Design Department
One World Trade Center - 74 South
New York, NY 10048
Via messenger

Reference: The World Trade Center Facilities:
Structural Integrity Inspections

Gentlemen:

We are pleased to submit our proposal to monitor the structural integrity of the physical facilities of The World Trade Center complex.

Experience

Over the past 20 plus years, we at LERA have gained unparalleled insights into the structural behavior of the World Trade Center complex. We believe that the continuity of experience with the project which the engineers of our firm have provides us an extensive, accessible base of knowledge about these structures unmatched anywhere else.

In 1986, we provided to you an action plan of testing and inspection so as to assure the continued long term structural integrity of the complex.

Economy

Although we were not charged with carrying out this plan, our designs for building renovation have impacted the testing and inspection activities which have been undertaken. For example, we have recently recommended that planned renovation projects be used to access Plaza level tower columns for inspection rather than incurring the high cost of removing exterior column covers especially for inspection.

Many examples occur wherein economies can be attained through coordination of renovation, operations and inspection activities. Even tenant renovations, many of which we engineer, offer such opportunities. And because of the small number of people within our firm who would accomplish both the renovation and inspection work, coordination is an easy matter.

LESLIE E. ROBERTSON ASSOCIATES

Mr. Suren Batra -3- 12 January 1990

Other Facilities

This proposal addresses the monitoring of the structural integrity of the buildings that comprise The World Trade Center complex only. Monitoring of the structural integrity of the PANYNJ's Bathgate and Yonkers Industrial Parks, and Hoboken Piers, has not been included as part of this proposal. However, we would be pleased to prepare a similar detailed proposal for the inspection of these facilities.

We are most appreciative of this further opportunity to work with the PANYNJ and we hope for your favorable response.

Very truly yours,

LESLIE E. ROBERTSON ASSOCIATES

Saw Teen See

Saw-Teen See

WJF/blo
Enclosure

WJF, LER, RZ, DAS, EAC

Locations of Columns Inspected in Accessible Columns Structural Integrity Inspection Reports

- **1993 Accessible Columns SII Report (part of WTCI-66-L)**

LERA

WORLD TRADE CENTER
Structural Integrity Inspection
Accessible Columns @ 1,2,4 and 5 WTC

P1103904 & 3927
29 January 1993
Page 6 of 9

TABLE A

Tower	Elevator Shaft Number	Floors Inspected	Adjacent Column Number	Face of Column Inspected
A (1 WTC)	21	4-78	606	East
		4-78	607	West
	36	1-32	701	East, South
		1-32	801	East, North
	63	45-67	701	East, South
		45-67	801	East, North
	73	43-74	703	North, West
		43-74	803	North, West
	83	78-93	701	East, South
		78-93	801	East, North
B (2 WTC)	15	4-78	602	North
		4-78	603	South, West
	29	1-16	707	South, East
		1-16	806	South, West
	56	45-54	707	South, East
		45-54	806	South, West
	78	78-86	707	South, East
		78-86	806	South, West
Northeast Plaza (5 WTC)	E-7 28	1-9	E-7 28	W

See Appendix A for the plan locations of the above columns.

- **1995 Accessible Columns SII Report (part of WTCI-66-L)**

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LISTING OF INSPECTED COLUMNS AT 1 WTC

ELEVATOR SHAFT	COLUMN NUMBER	FLOORS INSPECTED	FACE OF COLUMN INSPECTED	LISTING OF PHOTOGRAPHS
1A	908	2-44 B2	WEST & SOUTH	1,2 3
2A	907	2-44 B2	EAST	4,5,6
3A	907	2-44 B2	WEST & SOUTH	7,8,9 10
4A	906	2-44 B2	EAST	- 11
8A	903	2-44 B2	WEST & SOUTH	12,13 -
9A	902	2-44 B2	EAST	14 15
12A	601	2-78 B2	EAST & NORTH	16,17 -
13A	602	2-78 B2	WEST & NORTH	- -
14A	602	B2	EAST	-
15A	603	B2	WEST & NORTH	30
18A	605	2-78 B2	EAST & NORTH	18,19 -
19A	606	2-78 B2	WEST	20 -
20A	606	B2	EAST & NORTH	31
21A	607	B2	WEST	-
22A	607	2-78 B2	EAST & NORTH	21 22

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LISTING OF INSPECTED COLUMNS AT 1 WTC

ELEVATOR SHAFT	COLUMN NUMBER	FLOORS INSPECTED	FACE OF COLUMN INSPECTED	LISTING OF PHOTOGRAPHS
23A	608	2-78 B2	WEST & NORTH	23,24,25 26
24A	807	B3	WEST & NORTH	-
29A	806	B3	EAST & NORTH	-
30A	806	B3	WEST & NORTH	-
35A	805	B3	EAST & NORTH	-
36A	801	B3	EAST & NORTH	-
41A	802	B3	WEST & NORTH	-
42A	802	B3	EAST & NORTH	34
47A	803	B3	WEST & NORTH	-
48A	905	B3	EAST & SOUTH	35
49A	704	B3	NORTH	32,33
50A	704 703 803	2-108 2-78 2-108	WEST & SOUTH EAST EAST	27,28 29 -

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File: 1113903
Page 3 of 4

LISTING OF INSPECTED COLUMNS AT 2 WTC

ELEVATOR SHAFT	COLUMN NUMBER	FLOORS INSPECTED	FACE OF COLUMN INSPECTED	LISTING OF PHOTOGRAPHS
1B	908	2-44 B2	EAST & SOUTH	36 -
2B	907	2-44 B2	NORTH	37 -
3B	907	B2	EAST & SOUTH	-
4B	906	B2	NORTH	-
5B	906	B2	EAST & SOUTH	66
6B	904	B2	EAST & SOUTH	-
7B	903	B2	NORTH	-
8B	903	B2	EAST & SOUTH	64,65
9B	902	B2	NORTH	-
10B	908	2-44 B2	EAST & SOUTH	38,39 40
11B	901	2-44 B2	EAST & NORTH	41,42 -
12B	601	2-44 B2	WEST & NORTH	43 -
13B	602	2-78 B2	WEST & SOUTH	44,45 -
14B	602	2-78 B2	NORTH	46,47
15B	603	2-78 B2	WEST & SOUTH	48,49 -
16B	603	B4	NORTH	-
17B	604	B4	WEST & SOUTH	50

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Page 4 of 4

LISTING OF INSPECTED COLUMNS AT 2 WTC

ELEVATOR SHAFT	COLUMN NUMBER	FLOORS INSPECTED	FACE OF COLUMN INSPECTED	LISTING OF PHOTOGRAPHS
18B	605	B2	WEST & NORTH	51
19B	606	B2	SOUTH	52
20B	606	B2	WEST & NORTH	53
21B	607	B2	SOUTH	-
22B	607	2-78 B2	WEST & NORTH	54 -
23B	608	2-78 B2	WEST & SOUTH	55,56,57
36B	801	B3	WEST & NORTH	-
41B	802	B3	WEST & SOUTH	-
42B	802	B3	WEST & NORTH	-
47B	803	B3	WEST & SOUTH	67
49B	704	B6	WEST & SOUTH	62,63
50B	704 703 803	2-108 2-78 2-108	EAST & SOUTH NORTH NORTH	58,59 60,61 -

- **1996 Accessible Columns SII Report (part of WTCI-66-L)**

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One and Two World Trade Center
Structural Integrity Inspection
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Page 4

4. LIST OF INSPECTED COLUMNS - 1 WTC

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
6A	904	B4/2-106	West & South
7A	903	B4/2-106	East
16A	603	B4/2-78	East
17A	604	B4/2-78	West & South
34A	706	B1/2-24	East & North
35A	805	2-24	East & North
42A	802	2-40	East & North
43A	702	B1/2-40	East & North
55A	707	43	East, North & South
56A	806	43	East, North & South
61A	706	43/44-61	East & North
62A	805	43/44-61	East & North
63A	801	43	East, North & South
64A	701	43	East, North & South
67A	702	42	West, North & South
68A	802	43	West, North & South
69A	802	43/44-74	East & North
70A	702	43/44-74	East & North
78A	707	76	East, North & South
79A	806	76	East, North & South

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4. LIST OF INSPECTED COLUMNS - 1 WTC (continued)

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
82A	801	77	East, North & South
83A	701	77	East, North & South
88A	802	77/78-100	East & North
89A	702	77/78-100	East, North & South
94A	805	77/78-107	East & North
95A	706	77/78-107	East, North & South
96A	707	77/78-106	West & South
97A	806	77/78-106	West, North & South
99A	703/803	105/106-110	West

Previously Inspected

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
1A	908	B2/2-44	West & South
2A	907	B2/2-44	East
3A	907	B2/2-44	West & South
4A	906	B2/2-44	East
8A	903	B2/2-44	West & South
9A	902	B2/2-44	East
12A	601	B2/2-78	East & North
13A	602	B2/2-78	West & North

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One and Two World Trade Center
Structural Integrity Inspection
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4. LIST OF INSPECTED COLUMNS - 1 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
14A	602	B2	East
15A	603	B2	West & North
18A	605	B2/2-78	East & North
19A	606	B2/2-78	West
20A	606	B2/4-78	East & North
21A	607	B2/4-78	East & West
22A	607	B2/2-78	East & North
23A	608	B2/2-78	West & North
24A	807	B3	West & North
29A	806	B3	East & North
30A	806	B3	West & North
35A	805	B3	East & North
36A	801	B3/1-32	East & North
37A	701	1-32	East & South
41A	802	B3	West & North
42A	802	B3	East & North
47A	803	B3	West & North

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4. LIST OF INSPECTED COLUMNS - 1 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
48A	905	B3	East & South
49A	704	B3	North
50A	704 703 803	2-108 2-78 2-108	West & South East East
63A	701	45-67	East & South
64A	801	45-67	East & South
73A	703	43-74	North & West
74A	803	43-74	North & West
82A	[illegible]	[illegible]	[illegible]

[redacted]

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5. LIST OF INSPECTED COLUMNS - 2 WTC

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
6B	904	2-106	East & South
7B	903	2-106	North
18B	605	2-78	West & North
19B	606	2-78	South
20B	606	2-78	West & North
21B	607	2-78	South
34B	706	B1/2-23	West & North
35B	805	B3/2-23	West & North
42B	802	2-40	West & North
43B	702	B1/2-40	West & North
48B	905	B3	East & North
55B	707	43	East, West & North
56B	806	43	East, West & North
61B	706	43/44-61	West & North
62B	805	43/44-61	West & North
63B	801	43	East, West & North
64B	701	43	East, West & North
67B	702	42	East, West & South
68B	802	43	East, West & South
69B	802	43/44-74	West & North

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5. LIST OF INSPECTED COLUMNS - 2 WTC (continued)

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
70B	702	43/44-74	West & North
78B	707	76	East, West & North
79B	806	76	East, West & North
82B	801	77	East, West & North
83B	701	77	East, West & North
88B	802	77/78-100	East, West & North

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5. LIST OF INSPECTED COLUMNS - 2 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pits/Floors Inspected	Face Of Column Inspected
7B	903	B2	North

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5. LIST OF PREVIOUSLY INSPECTED - 2 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
36B	801	B3	West & North
41B	802	B3	West & South
42B	802	B3	West & North
47B	803	B3	West & South
49B	704	B6	West & South
50B	704 703 803	2-108 2-78 2-108	East & South North North
55B	707	45-54	East & South
56B	806	45-54	East & West
78B	707	78-86	East & South
79B	806	78-86	East & West

- **1997 Accessible Columns SII Report (part of WTCI-66-L)**

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4. LIST OF INSPECTED COLUMNS - 1 WTC

Elevator Shaft/Pit*	Column Number	Pit/Floors Inspected	Face Of Column Inspected
10A	902	B1/2-44	West & South
11A	901	B1/2-44	East & South
24A(SO)	807	2-17	West & North
25A(SO)	708	2-17	West & South
40A	702	B1/2-33	West & North
41A(SO)	802	2-33	West & North
51A	807	43/44-54	West & North
52A	708	43/44-54	West & South
57A	806	43/44-61	West & North
58A	707	43/44-61	West & South
76A	807	77/78-86	West & South
77A	708	77/78-86	West & South
84A	702	77/78-93	West & South
85A	802	77/78-93	West & North
90A	703	77/78-100	West & South
91A	803	77/78-100	West & North

* (SO) Indicates the shaft only, not the pit, has been inspected

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4. LIST OF INSPECTED COLUMNS - 1 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
63A	801	45-67	East & South
64A	701	43/45-67	East, North & South
67A	702	42	West, North & South
68A	802	43	West, North & South
69A	802	43/44-74	East & North
70A	702	43/44-74	East & North
73A	703	43-74	North & West
74A	803	43-74	North & West
78A	707	76	East, North & South
79A	806	76	East, North & South

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5. LIST OF INSPECTED COLUMNS - 2 WTC

Elevator Shaft/Pit*	Column Number	Pit/Floors Inspected	Face Of Column Inspected
5B(SO)	906	B1-44	East & South
24B	807	B3/2-16	West & South
25B(SO)	708	2-16	East & South
30B	806	B3/2-24	West & South

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5. LIST OF INSPECTED COLUMNS - 2 WTC (continued)

Elevator Shaft/Pit*	Column Number	Pit/Floors Inspected	Face Of Column Inspected
88B(SO)	802	79-100	West & North
89B(SO)	702	79-100	East & North
90B	703	77-100	East & South
91B	803	77-100	West & South

*** (SO) Indicates the shaft only, not the pit, has been inspected**
*** (PO) Indicates the pit only, not the shaft, has been inspected**

Previously Inspected

Elevator Shaft/Pit	Column Number	Pits/Floors Inspected	Face Of Column Inspected
1B	908	B2/2-44	East & South
2B	907	B2/2-44	North
3B	907	B2	East & South
4B	906	B2	North
5B	906	B2	East & South
6B	904	B2/2-106	East & South
7B	903	B2/2-106	North
8B	903	B2	East & South
9B	902	B2	North
10B	908	B2/2-44	East & South
11B	901	B2/2-44	East & North

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5. LIST OF PREVIOUSLY INSPECTED - 2 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
12B	601	B2/2-44	West & North
13B	602	B2/2-78	West & South
14B	602	B2/2-78	North
15B	603	B2/2-78	West & South
16B	603	B4	North
17B	604	B4	West & South
18B	605	B2/2-78	West & North
19B	606	B2/2-78	South
20B	606	B2/2-78	West & North
21B	607	B2/2-78	South
22B	607	B2/2-78	West & North
23B	608	B22-78	West & South
28B	707	1-16	East & South
29B	806	1-16	West & South
34B	706	B1/2-23	West & North
35B	805	B3/2-23	West & North
36B	801	B3	West & North
41B	802	B3	West & South
42B	802	B3/2-40	West & North
43B	702	B1/2-40	West & North

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5. LIST OF PREVIOUSLY INSPECTED - 2 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
47B	803	B3	West & South
48B	905	B3	East & North
49B	704	B6	West & South
50B	704	2-108	East & South
50B	703	2-78	North
50B	803	2-108	North
55B	707	43	East, West & North
55B	707	45-54	East & South
56B	806	43	East, West & North
56B	806	45-54	East & West
61B	706	43/44-61	West & North
62B	805	43/44-61	West & North
63B	801	43	East, West & North
64B	701	43	East, West & North

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5. LIST OF PREVIOUSLY INSPECTED - 2 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
79B	806	78-86	East & West
82B	801	77	East, West & North
83B	701	77	East, West & North
88B	802	77/78-100	East, West & North
89B	702	77/78-100	East, West & North
95B	706	77	West & North
96B	707	77/78-106	East, West & South
97B	806	77/78-106	West & South
99B	703/803	105/106-110	South

- **1998 Accessible Columns SII Report (part of WTCI-66-L)**

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One and Two World Trade Center
Structural Integrity Inspection
Accessible Columns

4. LIST OF INSPECTED COLUMNS - 1 WTC

Elevator Shaft/Pit*	Column Number	Pit/Floors Inspected	Face Of Column Inspected
5A	906	2-44	South & West
14A(SO)	602	2-78	East
15A(SO)	603	2-78	North & West
25A(PO)	708	B1	South & West
28A	707	B1/2-16	North & East
29A(SO)	806	2-16	North & East
30A(SO)	806	2-24	North & West
31A	707	B1/2-24	North & West
37A(PO)	701	B1	North & East
46A	706	B1/2-40	North & West
47A(SO)	803	2-40	North & West
48A(SO)	905	2-40	East & West
55A(SO)	707	44-54	North & East
56A(SO)	806	44-54	North & East

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One and Two World Trade Center
Structural Integrity Inspection
Accessible Columns

4. LIST OF INSPECTED COLUMNS - 1 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
1A	908	B2/2-44	South & West
2A	907	B2/2-44	East
3A	907	B2/2-44	South & West
4A	906	B2/2-44	East
6A	904	B4/2-106	South & West
7A	903	B4/2-106	East
8A	903	B2/2-44	South & West
9A	902	B2/2-44	East
10A	902	B1/2-	[illegible]

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One and Two World Trade Center
Structural Integrity Inspection
Accessible Columns

4. LIST OF INSPECTED COLUMNS - 1 WTC (continued)

Previously Inspected (continued)

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
[redacted]			

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One and Two World Trade Center
Structural Integrity Inspection
Accessible Columns

4. LIST OF INSPECTED COLUMNS - 1 WTC (continued)

Previously Inspected (continued)

Elevator Shaft/Pit	Column Number	Pit/Floors Inspected	Face Of Column Inspected
69A	802	43/44-74	North & East
70A	702	43/44-74	North & East
73A(SO)	703	43-74	North & West
74A(SO)	803	43-74	North & West
76A	807	77/78-86	West & South
77A	708	77/78-86	West & South
78A(PO)	707	76	North, East & South
79A(PO)	806	76	North, East & South
82A(PO)	801	77	North, East & South
82A(SO)	801	78-93	East & South
83A(PO)	701	77	North, East & South
83A(SO)	701	78-93	North & East
84A	702	77/78-93	South & West
85A	802	77/78-93	North & West
88A	802	77/78-100	North & East
89A	702	77/78-100	North, East & South
90A	703	77/78-100	West & South
91A	803	77/78-100	North & West
94A	805	77/78-107	North & East
95A	706	77/78-107	East & South
96A	707	77/78-106	South & West
97A	806	77/78-106	North, South & West
99A	703/803	105/106-110	West

LERA

One and Two World Trade Center
Structural Integrity Inspection
Accessible Columns

5. **LIST OF INSPECTED COLUMNS - 2 WTC**

Elevator Shaft/Pit*	Column Number	Pit/Floors Inspected	Face Of Column Inspected
3B(SO)	907	2-44	East & South
4B(SO)	906	2-44	North
8B(SO)	903	2-44	South & West
9B(SO)	902	2-44	North
16B(SO)	603	2-78	North
17B(SO)	604	2-78	South & West
25B(PO)	708	B1	East & South
28B(PO)	707	B1	East & South
29B(PO)	806	B1	North & West
31B(PO)	707	B1	South & West
37B(PO)	701	B1	North & West
40B	702	B1/2-32	South & West
41B(SO)	802	2-32	South & West
46B	703	B1/2-32	South & West
47B(SO)	803	2-40	South & West
49B(SO)	703	2-74	North
73B(SO)	703	44-74	South & West
74B(SO)	803	44-74	South & West
76B(SO)	807	78-86	East & South
77B(SO)	708	78-86	East & South
82B(SO)	801	78-93	North, East & West
83B(SO)	701	78-93	North, East & West
84B	702	77/78-93	East & South
85B	802	77/78-93	East & South
94B	805	77/78-107	North & East
95B(SO)	706	78-107	North & East

*** (SO) Refers to the shaft only, not the pit**
*** (PO) Refers to the pit only, not the shaft**

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One and Two World Trade Center
Structural Integrity Inspection
Accessible Columns

5. LIST OF INSPECTED COLUMNS - 2 WTC (continued)

Previously Inspected

Elevator Shaft/Pit	Column Number	Pits/Floors Inspected	Face Of Column Inspected
1B	908	B2/2-44	East & South
2B	907	B2/2-44	North
3B(PO)	907	B2	East & South
4B(PO)	906	B2	North
5B	906	B2/B1-44	East & South
6B	904	B2/2-106	East & South
7B	903	B2/2-106	North
8B(PO)	903	B2	East & South
9B(PO)	902	B2	North
10B	908	B2/2-44	East & South
11B	901	B2/2-44	North &East
12B	601	B2/2-44	North &West
13B	602	B2/2-78	South &West
14B	602	B2/2-78	North
15B	603	B2/2-78	South & West
16B(PO)	603	B4	North
17B(PO)	604	B4	South & West
18B	605	B2/2-78	North & West
19B	606	B2/2-78	South
20B	606	B2/2-78	North & West
21B	607	B2/2-78	South
22B	607	B2/2-78	North & West
23B	608	B2/2-78	South & West
24B	807	B3/2-16	West & South
25B(SO)	708	2-16	East & South
28B(SO)	707	1-16	East & South
29B(SO)	806	1-16	North & West

LERA

One and Two World Trade Center
Structural Integrity Inspection
Accessible Columns

5. LIST OF INSPECTED COLUMNS - 2 WTC (continued)

Previously Inspected (continued)

30B	806	B1/2-24	South & West
31B(SO)	707	2-24	East & South
34B	706	B1/2-23	North & West
35B	805	B1/2-23	North & West
36B	801	B3/2-32	North & West
37B(SO)	701	2-32	North & East
41B(PO)	802	B3	South & West
42B	802	B3/2-40	North & West
43B	702	B1/2-40	North & West
47B(PO)	803	B3	South & West
48B	905	B3/B1-40	North & East
49B(PO)	704	B3	South & West
50B	704	B6/2-108	East & South
50B	803	B6/2-108	North
51B	807	43/44-54	South & West
52B	708	43/44-54	South & West
55B(PO)	707	43	North, East & West
55B(SO)	707	45-54	East & South
56B(PO)	806	43	North, East & West
56B(SO)	806	45-54	North & West
57B	806	43/44-61	South & West
58B	707	43/44-61	East & South
61B	706	43/44-61	North & West
62B	805	43/44-61	North & West
63B(PO)	801	43	North, East & West
63B(SO)	801	44-67	North & West
64B(PO)	701	43	North, East & West
64B(SO)	701	44-67	North & West

LERA

One and Two World Trade Center
Structural Integrity Inspection
Accessible Columns

5. LIST OF INSPECTED COLUMNS - 2 WTC (continued)

Previously Inspected (continued)

Elevator Shaft/Pit*	Column Number	Pit/Floors Inspected	Face Of Column Inspected
67B(PO)	702	42	East, South & West
67B(SO)	702	44-67	East & South
68B(PO)	802	43	East, South & West
68B(SO)	802	44-67	South & West
69B	802	43/44-74	North & West
70B	702	43/44-74	North & West
73B(PO)	801	43	East, South & West
74B	701	43	East, South & West
76B(PO)	702	77	East, South & West
77B(PO)	802	77	East, South & West
78B(PO)	707	76	North, East & West
78B(SO)	707	78-86	North & East
79B(PO)	806	76	North, East & West
79B(SO)	806	78-86	North & East
82B(PO)	801	77	North, East & West
83B(PO)	701	77	North, East & West
88B	802	77/78-100	East, South & West
89B	702	77/78-100	East, South & West
90B	703	77/78-100	East & South
91B	803	77/78-100	West & South
95B(PO)	706	77	West & North
96B	707	77/78-106	East, South & West
97B	806	77/78-106	East, South & West
99B	703/803	105/106-110	South

Historical Review of World Trade Center Damping Units (WTCI-230-L)

Historical Review of World Trade Center Damper

Ming-Lai Lai

Date	Event	Stiffness, kip/0.02", 75 °F
9/5/69	Specification defines stiffness and Warranty	6< F < 20
3/12/70 to 4/18/72	Made Lots 1-43 and 50 about 20,000 dampers. Each lot (230 to 475 dampers): Tested 5 dampers for stiffness, 5 dampers for strength, 5 dampers for five year storage in controlled temperature and relative humidity at 3M to form 4 guarantee lots (total 237 dampers).	Avg.=14.368 Lowest of 5 dampers = 10.178 Highest of 5 dampers = 17.157
9/24/71 to 10/20/76	3M retained extra dampers from guarantee Lots 1 (first 12 acceptance lots) and Lot 4 (last 10 acceptance lots) for internal testing besides the 5 year test required by Port Authority. Dampers were in temperature and humidity controlled room. 3M tested 8 dampers every 6 months for 5 years	dropped from 13.9 2 to 9.987
5/7/75	6 fires set by arsonist in WTC Towers. 3M tested 3 dampers from 12th floor of WTC Tower A.	
spring to end of 1976	Completed 5 year test for the four guarantee lots. Port authority accepted the results. Shipped 162 dampers to Port Authority 21 dampers held by 3M (3M paid)	10.7 accepted
5/8/81	10 year aging data on 3M retains. A report was generated by Caldwell.	9.5
7/6/82	Robertson submitted Port Authority the report by Caldwell on 3M in-house testing showing decrease in stiffness. Caldwell suggested test 6 dampers from each tower and 6 dampers from storage.	
1/10/83	Caldwell told A.D Nelson that gradual delamination of the 50 layers may be responsible for the decrease in stiffness. This delamination theory was shown in Caldwell's five and ten year aging report and was	

	shown to Port Authority by Lee Robertson 7/6/82	
12/17/32	6 dampers from each tower and 9 from storage (21 total) sent to 3M for testing. Data shown in the plot dated 1983. This was the first systematic test of dampers from the Towers.	
4/20/76 to 6/8/81 and 11/9/83	Damper #10 K per 0.02"=11.9 (4/20/76) 7.99 (6/8/81) 13.037 (6/8/81 after in 300 °F for two hours with a C-clamp on the damper) 5.278 (11/9/83)	
Sept. 1978 and Feb. 1984	16 out of 162 storage dampers by Port Authority were tested twice by D.K. Guha of Port Authority Engineering Department A linear regression of the averaged stiffness kips/in was shown as 759.55-57.562(temperature °F-75 °F.-0.059t where t is number of days between date of testing and manufacturing.	12.2 and 11.0
4/4/84	Wind storm hit WTC. Maximum acceleration 27 mg which is equivalent to 27" sway. Maximum acceleration recorded was 37 mg on 108th floor of Tower A on 3/21/81.	
July and October 1984	Under Dr. P. Mahmoodi: 3M put 4 LVDT on 4 Tower A dampers per floor on 74th and 104th floors to test dampers in-place. 3M tested 22 dampers from Tower A and 10 damper from WTC stored spares. Data plotted and not shown a significant difference compared to 1983 test.	8105 for 16 dampers from Tower A. 8698 for 10 stored dampers.
7/17/84	Wind anemometer and recorder installed on WTC.	
10/1/1984	Report by Robertson, Fowler & Ass. on "Investigation of Aging Effects: World Trade Center Dampers."	
10/25/93	3M Tested 36 WTC Dampers in Storage	6.7 Average Range: 7.6-10.1
11/11/88	3M tested 4 dampers from WTC Tower	7810
12/18/95	3M tested 4 dampers from WTC Tower. Damper displacement was measured by LVDT.	7292

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NIST NCSTAR 1-1D

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Fire Protection and Life Safety Provisions Applied to the Design and Construction of WTC 1, 2, and 7 and Post-Construction Provisions Applied after Occupancy

Raymond A. Grill
Duane A. Johnson

NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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Rolf Jensen & Associates, Inc.

September 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

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Disclaimer No. 3

Pursuant to section 7 of the National Construction Safety Team Act, the NIST Director has determined that certain evidence received by NIST in the course of this Investigation is "voluntarily provided safety-related information" that is "not directly related to the building failure being investigated" and that "disclosure of that information would inhibit the voluntary provision of that type of information" (15 USC 7306c).

In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

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National Institute of Standards and Technology National Construction Safety Team Act Report 1-1D
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ABSTRACT

This report was prepared to support the analysis of building and fire codes and standards of the National Institute of Standards and Technology World Trade Center (WTC) Investigation. To best analyze the performance of WTC 1, 2, and 7 in response to the September 11, 2001, attacks, the provisions of the design and construction of the buildings must first be understood. The purpose of this report is to summarize the fire protection (both passive and active) and life safety provisions that were used to design and construct WTC 1, 2, and 7 and to document the changes in building code regulations that occurred after their construction.

Determination of the applicable building provisions was a multi-step task. First, documentation (such as drawings, memoranda, and New York City building regulations) was analyzed to identify the initial construction provisions at the times of construction of the three buildings. Second, New York City building regulations, published since the time of construction, were analyzed to identify the new and amended building provisions. Third, the building provisions were analyzed to determine their applicability to the building characteristics of WTC 1, 2, and 7.

Keywords: Compartmentation, elevators, emergency power, fire alarm, fire protection, fire safety, fire sprinklers, high-rise buildings, inspections, interior finish, means of egress, pressurization, venting, voice communication, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

ASTM	ASTM International
BCNYC	Building Code of the City of New York (Local Law No. 76)
HVAC	heating, ventilating, and air conditioning
LL	Local Law to amend the New York City Administrative Code
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
PANYNJ	Port Authority of New York and New Jersey
RS	Reference Standard to the BCNYC
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

ºF	degrees Fahrenheit
cfm	cubic feet per minute
cm^2	square centimeters
ft	foot
ft^2	square feet
gal	gallon
gpm	gallons per minute
h	hour
in.	inch
$in.^2$	square inches
lb	pound
min	minute
V	volt
W	watt

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METRIC CONVERSION TABLE

To convert from	to	Multiply by
AREA AND SECOND MOMENT OF AREA		
square foot (ft^2)	square meter (m^2)	9.290 304 E-02
square inch ($in.^2$)	square meter (m^2)	6.4516 E-04
square inch ($in.^2$)	square centimeter (cm^2)	6.4516 E+00
square yard (yd^2)	square meter (m^2)	8.361 274 E-01
ENERGY (includes WORK)		
kilowatt hour (kW · h)	joule (J)	3.6 E+06
quad (1015 BtuIT)	joule (J)	1.055 056 E+18
therm (U.S.)	joule (J)	1.054 804 E+08
ton of TNT (energy equivalent)	joule (J)	4.184 E+09
watt hour (W · h)	joule (J)	3.6 E+03
watt second (W · s)	joule (J)	1.0 E+00
FORCE		
dyne (dyn)	newton (N)	1.0 E-05
kilogram-force (kgf)	newton (N)	9.806 65 E+00
kilopond (kilogram-force) (kp)	newton (N)	9.806 65 E+00
kip (1 kip=1,000 lbf)	newton (N)	4.448 222 E+03
kip (1 kip=1,000 lbf)	kilonewton (kN)	4.448 222 E+00
pound-force (lbf)	newton (N)	4.448 222 E+00
FORCE DIVIDED BY LENGTH		
pound-force per foot (lbf/ft)	newton per meter (N/m)	1.459 390 E+01
pound-force per inch (lbf/in.)	newton per meter (N/m)	1.751 268 E+02
HEAT FLOW RATE		
calorieth per minute (calth/min)	watt (W)	6.973 333 E-02
calorieth per second (calth/s)	watt (W)	4.184 E+00
kilocalorieth per minute (kcalth/min)	watt (W)	6.973 333 E+01
kilocalorieth per second (kcalth/s)	watt (W)	4.184 E+03

To convert from	to	Multiply by
LENGTH		
foot (ft)	meter (m)	3.048 E-01
inch (in)	meter (m)	2.54 E-02
inch (in.)	centimeter (cm)	2.54 E+00
micron (m)	meter (m)	1.0 E-06
yard (yd)	meter (m)	9.144 E-01
MASS and MOMENT OF INERTIA		
kilogram-force second squared per meter ($kgf \cdot s^2/m$)	kilogram (kg)	9.806 65 E+00
pound foot squared ($lb \cdot ft^2$)	kilogram meter squared ($kg \cdot m^2$)	4.214 011 E-02
pound inch squared ($lb \cdot in.^2$)	kilogram meter squared ($kg \cdot m^2$)	2.926 397 E-04
ton, metric (t)	kilogram (kg)	1.0 E+03
ton, short (2,000 lb)	kilogram (kg)	9.071 847 E+02
MASS DIVIDED BY AREA		
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428 E+00
pound per square inch (*not* pound force) ($lb/in.^2$)	kilogram per square meter (kg/m^2)	7.030 696 E+02
MASS DIVIDED BY LENGTH		
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164 E+00
pound per inch (lb/in.)	kilogram per meter (kg/m)	1.785 797 E+01
pound per yard (lb/yd)	kilogram per meter (kg/m)	4.960 546 E-01
PRESSURE or STRESS (FORCE DIVIDED BY AREA)		
kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	9.806 65 E+04
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	9.806 65 E+00
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	9.806 65 E+06
kip per square inch (ksi) ($kip/in.^2$)	pascal (Pa)	6.894 757 E+06
kip per square inch (ksi) ($kip/in.^2$)	kilopascal (kPa)	6.894 757 E+03
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026 E+01
pound-force per square inch (psi) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
pound-force per square inch (psi) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00
psi (pound-force per square inch) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
psi (pound-force per square inch) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00

To convert from	to	Multiply by
TEMPERATURE		
degree Celsius (°C)	kelvin (K)	T/K = t/°C + 273.15
degree centigrade	degree Celsius (°C)	t/°C ≈ t /deg. cent.
degree Fahrenheit (°F)	degree Celsius (°C)	t/°C = (t/°F - 32)/1.8
degree Fahrenheit (°F)	kelvin (K)	T/K = (t/°F + 459.67)/1.8
kelvin (K)	degree Celsius (°C)	t/°C = T/K 2 273.15
TEMPERATURE INTERVAL		
degree Celsius (°C)	kelvin (K)	1.0 E+00
degree centigrade	degree Celsius (°C)	1.0 E+00
degree Fahrenheit (°F)	degree Celsius (°C)	5.555 556 E-01
degree Fahrenheit (°F)	kelvin (K)	5.555 556 E-01
degree Rankine (°R)	kelvin (K)	5.555 556 E-01
VELOCITY (includes SPEED)		
foot per second (ft/s)	meter per second (m/s)	3.048 E-01
inch per second (in./s)	meter per second (m/s)	2.54 E-02
kilometer per hour (km/h)	meter per second (m/s)	2.777 778 E-01
mile per hour (mi/h)	kilometer per hour (km/h)	1.609 344 E+00
mile per minute (mi/min)	meter per second (m/s)	2.682 24 E+01
VOLUME (includes CAPACITY)		
cubic foot (ft^3)	cubic meter (m^3)	2.831 685 E-02
cubic inch ($in.^3$)	cubic meter (m^3)	1.638 706 E-05
cubic yard (yd^3)	cubic meter (m^3)	7.645 549 E-01
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412 E-03
gallon (U.S.) (gal)	liter (L)	3.785 412 E+00
liter (L)	cubic meter (m^3)	1.0 E-03
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353 E-05
ounce (U.S. fluid) (fl oz)	milliliter (mL)	2.957 353 E+01

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GLOSSARY

active fire protection – A means to help prevent the loss of life and property from fire by extinguishing, suppressing, or controlling a fire through functional systems. Sprinkler systems, fire alarm systems, and smoke control systems are examples of active fire protection.

area of refuge – A floor area to which egress is made through a horizontal exit or supplemental vertical exit.

combustible – A material that is not determined to be noncombustible.

damper – A device installed in heating, ventilating, and air conditioning ductwork used to prevent the spread of fire and/or smoke. Dampers are provided to maintain a fire resistance rating of the assembly being penetrated.

detector – An initiation device that automatically detects a change in state, such as presence of smoke, high temperature, or abnormal rate of temperature rise.

fire alarm system – A system, automatic or manual, arranged to give a signal indicating a fire emergency and initiate the appropriate response.

fire resistance rating – The time in hours that materials or their assemblies will withstand fire exposure as determined by a fire test.

fireproofing – Materials or assemblies used to provide a fire resistance rating to a building component.

firestop – A solid or compact, tight closure to retard the spread of flames or hot gases within concealed spaces.

initiation device – A system component that originates a change-in-state signal in the fire alarm system. An initiation device begins the life safety processes, such as evacuation; heating, ventilating, and air conditioning shut down; elevator recall; etc.

manual fire alarm box – A manually operated initiation device that originates a change-in-state signal in the fire alarm system.

means of egress – A continuous and unobstructed path of vertical and horizontal travel from any point in a building to a public way. The means of egress consists of the exit access, the exit, and the exit discharge.

noncombustible – A material that, in the form in which it is used in construction, will not ignite and burn when subjected to fire. However, any material which liberates flammable gas when heated to any temperature up to 1,380 °F for 5 min shall not be considered noncombustible.

notification appliance – A fire alarm system component such as a bell, horn, speaker, or strobe that provides audible, tactile, or visible outputs, or any combination thereof.

passive fire protection – Fire protection features that are incorporated into the building construction or building materials that do not rely on active fire protection methods to limit fire ignition, fire growth, or material failure. Fire separations and divisions, sprayed fire-resistive material, and enclosing structural members with noncombustible materials are examples of passive fire protection.

smoke and heat venting – A process used to move products of combustion to the outdoor air.

PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

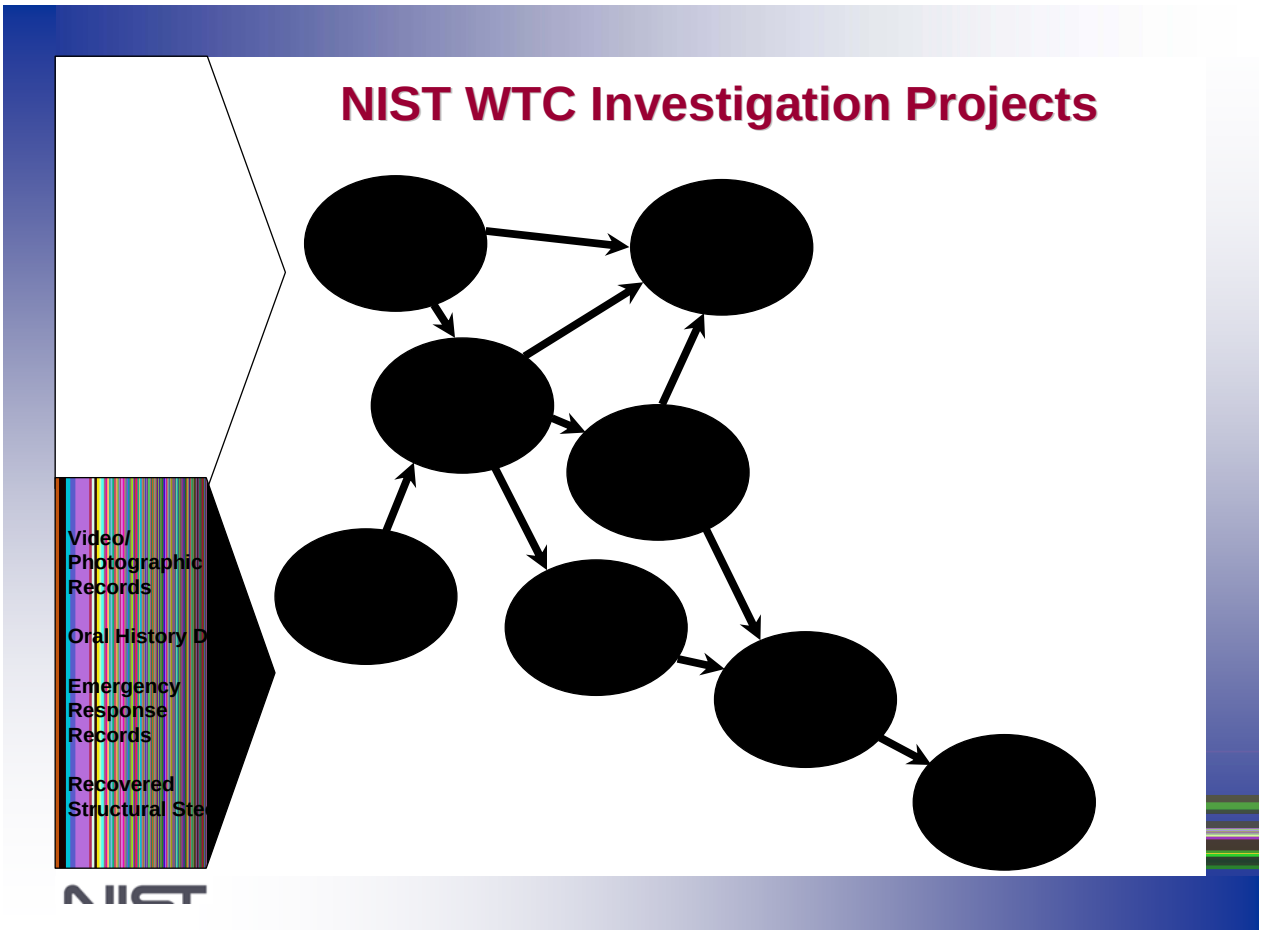

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

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SECTION I

FIRE PROTECTION SUMMARY FOR THE WORLD TRADE CENTER TOWERS

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EXECUTIVE SUMMARY

As part of the analysis of building and fire codes and standards of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation, this report supports the effort to determine the minimum construction requirements used in the design of WTC 1 and WTC 2. The purpose of this report is to summarize the fire protection (both passive and active) and life safety provisions used to design and construct WTC 1 and WTC 2.

Although the Port Authority of New York and New Jersey (PANYNJ) was not subject to the Building Code of the City of New York (BCNYC), WTC 1 and WTC 2 were to be designed in accordance with the BCNYC and all applicable Reference Standards (RS). The initial building concept, including an early conceptual design by Skidmore, Owings & Merrill, was based on the 1938 BCNYC. In 1965, PANYNJ instructed the designers to follow the latest (second and third) drafts of the revised (what would become the 1968) Code to take advantage of relaxations that could save on construction costs.

The BCNYC, building characteristics, and early design choices were used to determine the minimum construction requirements for the design of WTC 1 and WTC 2. Because the BCNYC contains requirements for various types of buildings, it was important to identify certain building requirements early in the design. By identifying specific building characteristics, the designer can determine which requirements must be complied with and which requirements are not applicable.

The information included in Table E–1 was used to classify the buildings and determine the minimum requirements within the BCNYC. Based on the height, area, primary occupancy classification, and no sprinkler protection, the minimum construction type (permitted by the 1968 BCNYC) was I-B (3 h protected) for both buildings. Fire resistance ratings for the structural components, fire divisions, and fire separations were based on this classification. Many of the means of egress, fire suppression, and fire alarm requirements were also based on the information in Table E–1. An abbreviated list of the fire protection provisions is as follows. A complete list of the requirements is identified in the main body of this report.

- A standpipe system was required.
- An automatic sprinkler system was only required in spaces below grade.
- A telephone and signaling system was required for fire department use in operating the standpipe system.
- Detectors were only required to sense smoke entering return grills of the heating, ventilating, and air conditioning system and to shut down fans.
- Manual fire alarm boxes were not required.
- Audible/visual devices were not required.

- Although a fire alarm and voice communication system was not required, a system was installed.
- Exit signs and emergency lighting were required in specified spaces.
- An emergency power system was not required.
- Smoke and heat venting was required in certain shafts, including elevators.
- Stair pressurization was not required.
- A smoke purge system was not required.

Table E–1. Building characteristics used to determine BCNYC requirements.

Building	Height	Number of Floors Above Grade	Footprint	Primary Occupancy Classification
WTC 1	1,368 ft	110	42,900 ft^2	Group E (Business)
WTC 2	1,362 ft	110	42,900 ft^2	Group E (Business)

Source: Merrit 2000a, 2000b; PANYNJ.

Chapter 1
INTRODUCTION

1.1 PURPOSE

The purpose of this report is to summarize the major fire protection (both passive and active) and life safety provisions used to design and construct the World Trade Center (WTC) towers.

1.2 INTRODUCTION

The regulation of building construction is a direct result of the recognition that life safety is served by the best available knowledge and practice. Codes and standards are created to establish minimum requirements. Model codes have been published throughout the United States since 1905 (Boring 1981). Through the use of technology advancements and serious incidents, such as fires, codes are developed and later revised to continually implement increased knowledge. Establishing reference standards is just as important to establishing codes. Referenced standards act as a technical basis of the code and provide further methods of testing, installation and maintenance. Municipalities can adopt model building codes and national standards or develop their own. Alternatively, many municipalities throughout the United States have adopted model building codes and national standards, and then amended portions as deemed necessary. New York City, however, developed their own building code and provide a technical basis with a mixture of nationally recognized standards (National Fire Protection Association, ASTM International, American National Standards Institute, etc.) and New York City developed reference standards (denoted by RS ##).

In accordance with the instructions issued by the Port Authority of New York and New Jersey (PANYNJ or Port Authority) at the start of the project, construction drawings for the WTC were to conform with the requirements of the Building Code of the City of New York (BCNYC), although as a so-called state compact under the U.S. Constitution, the Port Authority was exempt from state or local laws, including the BCNYC. Any variations from the Code were to be called to the attention of the Port Authority for final decision and authorization (Solomon 1975). Variances from the 1968 edition of the BCNYC, along with the applicable provisions of the Code, will be identified (to the best extent possible) in this report.[1] This report summarizes the major provisions of the BCNYC. Readers interested in the more detailed analysis should seek information directly from the BCNYC.

The design of the WTC towers took many years to develop. The initial design was to be in conformance with the 1938 BCNYC. However, in 1965, a decision was made to use the provisions of the newly proposed BCNYC (Kyle 1965). This decision included the rationale that (1) the new Code had been reviewed by technical groups and modified to meet the major objections; (2) the Code would probably be adopted before the WTC towers were constructed and (3) the Building Commissioner favored the approach of using advanced techniques in the design of the towers. Additionally, the PANYNJ repeatedly pointed out that it was not subject to the provisions of the BCNYC (e.g., Tozzoli 1966). Drafts

[1] The applicable provisions of the BCNYC, given throughout the report, are denoted by C26-###.

of the newly proposed code were used until December 1968 when the new BCNYC was adopted. The December 6, 1968, BCNYC was referred to as the applicable building code for the construction of WTC 1 and WTC 2 and is the base document for identifying the design and construction provisions in this report.

It was the policy of PANYNJ to follow the requirements of the BCNYC. Thus, since not all of the documentation used in the design and construction of the towers was identified, the assumption has been made that the construction followed the requirements of the BCNYC. Where documentation was identified, illustrating either conformance with or deviation from a BCNYC provision, a reference has been provided. This report does not evaluate whether or not the design provisions, indicated on drawings and in correspondence, were actually incorporated in the construction of the towers, but merely identifies the provisions established in the design. Since the buildings no longer exist, it is generally impossible to verify the inclusion of specific design features beyond their being discussed in other documents.

Chapter 2
GENERAL

2.1 APPLICABLE CODES AND STANDARDS

1. Building Code of the City of New York, 1968.[2]

2. USASI 17.1 (1965) including Supplement A17.1a (1967) – USA Standard Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks (as modified by Reference Standards [RS] 18-1).

3. National Fire Protection Association (NFPA) 13 – Standard for the Installation of Sprinkler Systems, 1966 (as modified by RS 17-2).

4. NFPA 22 – Standard for Water Tanks for Private Fire Protection, 1962 (as modified by RS 17).

5. NFPA 72 – Proprietary and Auxiliary Protective Signaling Systems, 1967 (as modified by RS 17-5).

6. NFPA 80 – Installation of Fire Doors and Windows, 1967 (as modified by RS 5-8).

7. NFPA 90A – Standard for the Installation of Air Conditioning and Ventilating Systems, 1967 (as modified by RS 13-1).

8. NFPA 204 – Guide for Smoke and Heat Venting, 1961 (RS 5-11).

9. ASTM International (ASTM) E 84 – Standard Method of Test for Surface Burning Characteristics of Building Materials, 1961 (as modified by RS 5-5).

10. ASTM E 119 – Standard Methods of Fire Tests of Building Construction and Materials, 1961 (as modified by RS 5-2).

11. RS 5-15 – Minimum Covering of Prestressing Steel for Various Fire Resistance Ratings.

12. RS 17-1 – Standpipe Construction.

13. RS 17-3 – Standards for the Installation of Fire, Sprinkler, Standpipe, Smoke Detection…and other Alarm and Extinguishing Systems.

[2] Including the BCNYC Reference Standards that modify national standards as deemed necessary.

2.2 BUILDING SUMMARIES

Table 2–1. Building characteristics used for design development.

Building[a]	Height	Number of Floors Above Grade[b]	Footprint	Construction Type (1968 BCNYC)	Primary Occupancy Classification
WTC 1[c]	1,368 ft	110	42,900 ft^2	I-B	Group E (Business)
WTC 2[d]	1,362 ft	110	42,900 ft^2	I-B	Group E (Business)

a. These buildings are located inside the Borough of Manhattan Fire District without additional restrictions imposed based on its use and occupancy (C26-402.1, C26-403.1).
b. Documentation indicates that the Concourse Level was treated as an underground street (Solomon 1975). Thus, the Plaza level is the first floor.
c. WTC 1 characteristics are from Merritt 2000a.
d. WTC 2 characteristics are from Merritt 2000b.

Source: Merrit 2000a, 2000b; PANYNJ.

Chapter 3
CONSTRUCTION

3.1 CONSTRUCTION CLASSIFICATION

The minimum construction type permitted for both World Trade Center (WTC) towers was Class I-B (3 h protected).[3]

3.2 BUILDING LIMITATIONS

In accordance with Table 4–2 of the Building Code of the City of New York (BCNYC) the height and area are not limited for an unsprinklered Class I-B construction building housing a Group E occupancy:

- Height – No Limit
- Area – No Limit

3.3 SECONDARY/ACCESSORY OCCUPANCIES

Occupancy	Fire Index
B-1, Storage (Moderate Hazard)	3
B-2, Storage (Low Hazard, Garage)	2
C, Mercantile	2
F-4, Assembly (Restaurant)	1

3.4 FIRE RESISTANCE RATINGS

The minimum required fire resistance ratings listed as follows are in accordance with Table 3–4 of the BCNYC, unless noted otherwise. According to Solomon 1969 and Bracco 1969, the fire resistance ratings of the buildings were designed in accordance with the BCNYC.

[3] Because there was considered to be "no economic advantage" to design WTC 1 and WTC 2 to a higher construction classification (i.e., Class I-A), the buildings were constructed to the minimum construction class required by the BCNYC (Feld 1987). Thus, all BCNYC requirements identified herein, which are dependent upon construction class, are given for Class I-B.

	Fire Resistance Rating (Hours)
1. Exterior Bearing Walls	3
2. Exterior Non-bearing Walls having an Exterior Separation of:[4]	
Three ft or less with 0 percent openings	2
Greater than 3 ft to less than 15 ft with 3½ percent protected openings	2
15 ft to less than 30 ft with 3½ percent openings[5]	1½
30 ft or greater with unlimited openings	NC[6]
3. Interior Walls:	
Interior bearing walls and bearing partitions	3
Exit access corridors (C26-604.2(h))	1[7]
4. Enclosure of vertical exits,[8] exit passageways, hoistways, and shafts	2
5. Columns, girders, trusses (other than roof trusses) and framing:	
Supporting one floor	2
Supporting more than one floor or a floor and roof	3

[4] When two or more buildings are constructed on the same lot and the combined floor area of the buildings does not exceed the limits established by BCNYC Tables 4–1 and 4–2 for any one of the buildings, no fire-resistance rating shall be required for non-bearing portions of the exterior walls of those buildings facing each other, and there shall be no limitation on the permitted amount of exterior openings.

[5] According to Solomon 1975, fire protected openings on exterior walls with a separation of less than 30 ft were omitted.

[6] Noncombustible.

[7] According to Solomon 1975, corridor partitions were designed to meet 2 h construction to minimize the limitations of dead end corridors.

[8] See sections C26-504.6 and C26-604.8(i) for exceptions to shaft and stair enclosures requirements.

	Fire Resistance Rating (Hours)
6. Structural members supporting a wall	Same as required fire resistance of wall supported, but not less than rating required for member by the class of construction
7. Floor construction including beams	2
8. Roof construction – including beams, trusses, framing, arches, domes, shells, cable supported roofs, and roof decks (based on height of lowest member above floor):	
15 ft or less	1½
Greater than 15 ft to 20 ft	1
20 ft or more	NC
9. Area of refuge separation (C26-604.5, C26-604.6)	2
10. Escalators not used as exits (C26-604.11)[9]	¾
11. Enclosures:	
Transformer vaults (greater than 35,000 V) (National Fire Protection Association [NFPA] 70)	3
Emergency generator and fire pump rooms	2
Storage rooms (B-1 occupancy) greater than 75 ft^2 (Table 5–1 note c)	1
Telephone closets	1[10]

[9] Escalators that connect two stories may be unenclosed.

[10] According to Solomon 1975, the original drawings indicated a 2 h rated shaft enclosure with louvers in a 1 ½ h rated door for the telephone closets. Additionally, a variance was granted permitting the omission of dampers. The requirements were changed in 1969 to permit 1 h rated construction with 1 ½ h rated doors. The shaft requirements were eliminated and all floor openings left for future installation of cables had to be firestopped.

The minimum covering of prestressing steel shall comply with the requirements of Reference Standard (RS) 5-15 (C26-502.2(d).

The design and installation provisions for fireproofing are not specifically contained in the BCNYC. The specific requirements for these provisions are derived from calculations, tests, and manufacturer's requirements. Although, C26-501 and C26-502 require that the fire resistance rating of construction assemblies and the protection of structural members shall comply with the requirements of the reference standards of RS-5. Furthermore, the materials or combinations of materials shall be in accordance with the specifications of materials used in the ASTM International (ASTM) E 119 test.

3.5 OPENING PROTECTION

	Fire Resistance Rating (Hours)
1. Openings in a 3 h rated Fire Division or Fire Separation wall (C26-504.4 and Table 5–3).	3 (Class A)
2. Openings in 2 h or 1½ h rated Fire Division or Fire Separation wall or vertical communication enclosure (C26-504.4, C26-604.4(a), C26-1800.6 and Table 5–3).	1½ (Class B)
3. Openings in 1 h rated Fire Division or Fire Separation walls, corridors or partitions (C26-504.4, C26-604.4(b) and Table 5–3).	¾ (Class B)
4. Openings in 1 h rated vertical communication enclosure.	1 (Class B)
5. Required protected openings in exterior walls (Class E or Class F) (C26-503.1(b)).	¾

Noncombustible mail slots not exceeding 40 in.^{2} may be provided in corridor doors (C26-604.4(b)).

Noncombustible louvers may be installed in corridor doors opening into toilets, service sink closets and electrical closets (C26-604.4(b)).[11]

Openings in Fire Divisions and Fire Separations shall not exceed the size limits in Section C26-504.4(a).

In shafts that contain only one opening below the roof, no opening protective is required (C26-504.6(c)).

Exterior street floor exit doors with a fire separation distance of more than 15 ft need not have a fire resistance rating (C26-604.4(a)(1)).

[11] BCNYC does not limit the size of the louver, however, the Board of Standards and Appeals permits louvers of 2 ft^2 in ¾ h rated doors (Solomon 1975).

Openings in elevator and dumbwaiter shafts shall comply with RS 18 (C26-504.6(c)).

3.6 SEPARATION OF OCCUPANCIES

	Fire Resistance Rating (Hours)
1. Fire Divisions	
Between Group B-1 and B-2, C, E, or F-4.	3
2. Fire Separations	
Between Groups E and B-2, C, or F-4.	NR[12,13]
Between tenant spaces (C26-504.3(a)).[14]	1[15]

Spaces classified in occupancy groups having a higher fire index than the occupancy group classification of the building shall be separated by "Fire Divisions" constructed in accordance with Section C26-504.1(a) and treated as separate buildings (C26-301.4(a)).

Spaces classified in occupancy groups having the same or lower fire index than the occupancy group classification of the building shall be separated by "Fire Separations" constructed in accordance with Section C26-504.1(b) (C26-301.4(b)).

When a building or space is used for multiple purposes at different times, the building/space shall be given a separate occupancy group classification for each of the activities. The design and construction shall be in accordance with the most restrictive provisions that apply to any of the classifications (C26-301.6).

A minor variation of occupancy or use of a space is acceptable without multiple classifications if the variation is normally associated with the occupancy classification and no specific danger or hazard is created (C26-301.6).

Fire divisions shall be constructed of noncombustible materials or assembly of noncombustible materials to provide the fire-resistance ratings (C26-504.2). The following requirements apply:

1. Vertical fire divisions shall be continuous between foundation, roof, or horizontal fire divisions, and through any concealed space in floor or roof construction.

[12] No Requirement.

[13] Separations are not required between accessory business and mercantile activities limited in area to 100 ft^2, and closets 75 ft^2 or less in area (Table 5–1 notes b and c).

[14] The rated partition was coordinated to terminate at a 1 h rated ceiling in lieu of extending the partition to the underside of the slab above (Solomon 1975).

[15] Solomon 1969 confirms the use of 1 h fire resistance rated demising walls between tenant spaces.

2. Horizontal fire divisions shall be continuous between exterior walls and/or vertical fire divisions.

3. Fire divisions shall be made smoketight at their junction with exterior walls.

4. Fire divisions may be offset if the construction between the offset divisions, including their supports, has the same fire-resistance rating as the fire division, with all hollow spaces within the construction firestopped with noncombustible material.

5. Where combustible members such as joists, beams, or girders bear on, or frame into, vertical fire divisions, such members shall not extend through the wall and shall have at least 4 in. of solid noncombustible material below, at the sides, and at the ends of each such member.

6. Chases or recesses shall not be cut into fire divisions so as to reduce their thickness below that required for the fire-resistance rating.

7. Vertical fire divisions that are hollow shall be firestopped with at least 4 in. of noncombustible material so as to prevent passage of flame, smoke, or hot gases through the hollow spaces to the story above or below, or to hollow spaces within connecting floor or roof construction.

3.7 FIRESTOPPING

All firestopping or fill materials shall consist of approved noncombustible materials that can be shaped, fitted, and permanently secured in place (C26-504.7(a)).

Concealed spaces within partitions, walls, floors, roofs, stairs, furring, pipe spaces, column enclosures, etc., that would permit passage of flame, smoke, fumes or hot gases from floor-to-floor shall be firestopped or filled with noncombustible material in the following locations (C26-504.7):

1. Hollow partitions and furred spaces.

2. Concealed spaces within stair construction.

3. Ceiling spaces.

4. Exterior cornices.

5. Duct and pipe spaces (C26-504.5 and RS 13-1 Sec. 313 and 314).

6. Hollow vertical Fire Division (C26-504.2(i)).

The concealed space above a fire resistance rated ceiling shall be firestopped into areas not exceeding 3,000 ft^2, except where (C26-502.5):

1. Structural members within the concealed space are individually protected, or

2. The concealed space is sprinklered.

3.8 THROUGH PENETRATION PROTECTION

Noncombustible pipes and conduits may pass through fire resistance rated construction provided the following (C26-504.5(b)):

1. Space between the pipe or conduit and its sleeve or opening does not exceed 2 in. and is packed with noncombustible material.

2. Close-fitting metal escutcheons are provided on both sides of the construction.

3. Aggregate net area of openings does not exceed 25 $in.^2$ in any 100 ft^2 of wall or floor area. Openings in excess of this limit are not permitted unless tested as part of a rated assembly and so protected.

Ceilings required to have a fire resistance rating may be pierced to accommodate noncombustible electric outlet boxes, recessed lighting fixtures, pipes and ducts as follows (C26-502.5(b)):

1. The aggregate area of outlet boxes and lighting fixtures does not exceed 16 $in.^2$ in each 90 ft^2 of ceiling area.

2. Outlet boxes and lighting fixtures are constructed of steel at least 0.022 in. thick and sealed tightly at the ceiling.

3. Additional or larger services are permitted only when tested as part of the assembly and protected as provided in the test.

The concealed space above fire resistance rated ceilings may be used as a return air plenum if listed (tested) for that purpose provided (RS 13-1 Sec. 316(a)):

1. All openings are tested as part of the assembly and protected in accordance with the test,

2. The integrity of firestopping is not destroyed,

3. No combustible materials are incorporated in the floor and ceiling construction, and

4. Electrical wiring is plenum rated (NFPA 70 Sec. 300-22).

3.9 FIRE AND SMOKE DAMPERS

Fire dampers shall be provided in accordance with RS 13-1 in each of the following locations (C26-504.5):

1. Duct penetrations of walls with a 2 h fire resistance rating or greater (RS 13-1 Sec. 902(a)).

2. Each opening in required vertical shaft enclosures (RS 13-1 Sec. 902(b)).

3. Each outlet or inlet opening in vertical shaft enclosure of duct systems serving two or more floors (RS 13-1 Sec. 902(c)). As an alternate, dampers may be provided at each point where the vertical duct pierces a floor it serves (RS 13-1 Sec. 902(c)).

4. Branch duct penetrations of vertical duct shaft enclosures (RS 13-1 Sec. 902(c)).

5. Fresh air intakes (RS 13-1 Sec. 902(e)).

6. Aluminum Class I duct penetrations of fire resistance rated floors (RS 13-1 Sec. 902(d)).

Fire dampers are not required at the following locations (RS 13-1 Sec. 903):

1. Non-aluminum or Class I vertical shaft branch duct penetrations with a cross-sectional area of less than 20 $in.^2$ which supply only air conditioning units discharging air at not over 4 ft above the floor (RS 13-1 Sec. 903(a)).

2. Non-aluminum or Class 1 duct penetrations of a floor (at one place only) with a cross-sectional area of less than 20 $in.^2$ which supply air conditioning units in one story only that discharge air at not over 4 ft above the floor (RS 13-1 Sec. 903(b)).

3. Duct penetrations in systems serving only one floor and used only for exhaust to the outside and not penetrating a fire wall or fire partition or passing entirely through the vertical shaft enclosure (RS 13-1 Sec. 903(d)).

4. Branch ducts connected to a return riser where subducts are extended at least 22 in. upward (RS 13-1 Sec. 903(e)).

5. Fire dampers shall be automatic closing 1½ h fire rated with a fusible link or other heat actuated device rated approximately 50 °F above the maximum system operating temperature (RS 13-1 Sec. 905(a)(g)).

Duct openings permitted in fire resistance rated ceilings are required to be protected with fire dampers (C26-502.5(b)).

Smoke dampers are required to be installed in the main supply duct and the main return duct in systems over 15,000 cfm capacity (RS 13-1 Sec. 1003).

Smoke dampers are required to be arranged to close automatically when the system is not in operation, by the operation of duct smoke detectors, and by the manual emergency fan stop (RS 13-1 Sec. 1003).

Chapter 4
INTERIOR FINISH

4.1 INTERIOR FINISH FLAME SPREAD RATINGS

The minimum interior finish flame spread ratings as defined in ASTM International (ASTM) E 84 and shown below are based on Table 5–4 of the Building Code of the City of New York (BCNYC) and other sections as noted.

	Classification
1. Exits and shafts (C26-504.10(c), C26-604.8(i)(3))	Class A (0-25)
2. Corridors (C26-504.10(c), C26-604.2(k)):[16,17]	
Group B-1	Class A (0-25)
Groups B-2, C, E, F-4	Class A or B (0-75)
3. Rooms greater than 1,500 ft^2 (C26-504.10(c)):	
Groups B-1, B-2, F-4	Class A or B (0-75)
Group E	Class A, B, or C (0-225)
4. Rooms less than 1,500 ft^2 (C26-504.10(c)):	
Groups B-1, B-2, E, F-4	Class A, B, or C (0-225)
5. Interior finish in kitchens, cooking spaces, pantries, repair and maintenance shops, boiler rooms, and incinerator combustion rooms (Table 5–4 note f).	Class A or B (0-75)

[16] When used in corridors, Class B finish material shall not extend more than 50 ft between separations of Class A finish material that are at least 2 ft wide (BCNYC Table 5–4 note b).

[17] Spaces through which it is necessary for occupants of an adjacent room to pass in order to reach the only exit are considered as corridors.

4.2 SMOKE DEVELOPED RATINGS

Interior finish materials shall be limited to smoke developed ratings as defined in ASTM E 84 in the locations specified:

1. Twenty-five or less in exits and corridors (C26-504.10(d)).

2. One hundred or less in rooms where the net floor area per occupant is 10 ft^2 or less (C26-504.10(d)).

No material shall be used in any interior location that upon exposure to fire will produce products that are more toxic in point of concentration than those given off by wood or paper (C26-504.10(e)).

4.3 INTERIOR TRIM

Up to 20 percent of the aggregate wall and ceiling area of any room or corridor may be finished with Class A, B, or C (0-225) materials and be exempt from the smoke developed rating requirements (C26-504.10(c)(4), C26-504.10(d)). This allowance shall include the area of doors, folding partitions, windows, glazing, skylights, luminous ceilings, trim, bases, chair rails, panels, moldings, etc.

4.4 FLOOR FINISH

Finish flooring in all exits shall be of noncombustible material (C26-504.13, C26-604.8(h)).

In all other areas, combustible finish flooring may be used when installed in accordance with Section C26-504.13(b).

Chapter 5
MEANS OF EGRESS

According to Feld (1987), the egress requirements were in accordance with the provisions of the Building Code of the City of New York (BCNYC).

5.1 GENERAL

Clear width measurement is the net, unobstructed width of a means of egress without projections in such width (C26-604.2(a), C26-604.3(b)):

1. In corridors, projections up to 18 in. wide to the extent of 2 in. per unit of egress width are permitted if the total area of such projections does not exceed 5 percent of the area of the wall on which they occur (C26-604.2(a)).

2. Handrails shall project not more than 3½ in. and stringers 2 in. (each side) into the required stair width (C26-604.8(b), C26-604.8(f)).

Headroom (C26-604.2(b), C26-604.3(c)):

1. Corridor and exit passageway minimum height of 7 ft 6 in. for 75 percent of the floor area with no point less than 7 ft.

2. Projections from the ceiling shall be at least 7 ft above the floor and located so as not to obstruct full view of exit signs (C26-604.2(b), C26-604.3(c)).

Changes in level requiring less than two risers in a corridor or exit passageway shall be by a ramp (C26-604.2(e), C26-604.8(d)(2)).

Obstructions to means of egress:

1. The required width of a means of egress shall not be obstructed or reduced in any manner (C26-604.2).

2. Corridors shall be kept free of combustible contents (C26-604.2).

3. All exterior means of egress elements, including exterior corridors and stairs, shall be maintained free of ice and snow accumulation (C26-604.2, C26-604.9).

Corridors may be used as supply or return air ducts or plenums if equipped with an approved smoke detector or thermostatic device to shut down fans (C26-604.2(j), RS 13-1 Sec. 316(d)).

Stairways connecting two or more stories shall not be used as plenums (RS 13-1 Sec. 316(e)).

5.2 EXITS

Every floor area shall be provided with at least two approved independent exits (C26-603.2).

Public garages shall be provided with at least two exits from each tier of parking (C26-709.8).

A minimum of two exits or exit access doors shall be provided from every room or space in which the occupant load exceeds the following limits (C26-603.1):

Occupancy	Occupant Load
B (Storage)	50
C (Mercantile)	75
E (Business)	75
F (Assembly)	75

All required exits shall be located such that they are clearly visible, accessible, and have unobstructed access at all times (C26-602.1).

In multi-tenant configurations, each tenant shall have access to the required numbers of exits without passing through other tenant spaces (C26-602.2).

Whenever more than one exit or exit access is required from any room, space, or floor of a building, they shall be located as remote from each other as practicable (C26-602.3).

Door openings to scissor stairs shall be at least 15 ft apart (C26-602.3).

All vertical exits shall extend in a continuous enclosure to discharge directly to an exterior space or at a yard, court, exit passageway, or street floor lobby of the required width and size to provide all occupants with a safe access to an open exterior space. Where vertical exits serving floors above grade continue in the same enclosure to serve floors below grade, the portion of such vertical exits above grade shall be separated from the portion below grade by construction having at least a 1 h fire resistance rating, with ¾ h self-closing doors opening in the direction of exit travel from the floors below grade (C26-602.4).

A maximum of 50 percent of the required number of vertical exits is permitted to discharge through a single exit passageway (C26-604.3).

One hundred percent of the number of vertical exits may discharge through a street floor lobby if egress is provided in two different directions from discharge points to open exterior spaces remote from each other (C26-604.3(h)(1)).

The clear width of an exit passageway serving two or more vertical exits shall be equal to 75 percent of the width of all vertical exits it serves (C26-604.3(b)).

The width of street floor lobbies serving as exit passageways shall be increased to accommodate the occupant load of all communicating spaces on the lobby floor that exit through them (C26-604.3(h)(2)).

No openings other than exit doors are permitted in exit passageways (C26-604.3(f)).

Openings between street floor lobbies serving as exit passageways and elevators or communicating spaces and show windows protected in accordance with Section C26-604.3(h)(3) are permitted.

Street floor lobbies serving as exit passageways may be occupied by newsstands, candy and tobacco stands, information booths, or similar occupancies if constructed of noncombustible materials, occupying not more than 5 percent of the net lobby floor area, and if not reducing the required clear width at any point (C26-604.3(h)(4)).

Horizontal and Supplemental Vertical Exits (C26-604.5 to C26-604.7):

1. The occupant load capacity for vertical exits may be reduced by 50 percent when one area of refuge is provided and by 66 percent when two or more areas of refuge are provided (C26-603.3).

2. At least 3 ft^2 per person of clear public space, or space occupied by the same tenant or owner, shall be provided within the area of refuge for the occupant load received in addition to its own occupant load (C26-604.5(b)).

3. Each area of refuge shall be provided with at least one vertical exit and when located above the 11th floor, the vertical exit shall be supplemented by at least one elevator (C26-604.5(c)).

4. Access to an area of refuge, on the same floor, through a horizontal exit, may consist of doors, balconies, bridges and tunnels (C26-604.6):

    a. Doors must swing in the direction of exit travel and be self-closing having a fire resistance rating of 1½ h. Where areas of refuge are provided on both sides of a horizontal exit, two door openings shall be provided, each swinging in opposite directions (C26-604.6(b)).

    b. Balconies, bridges and tunnels serving as horizontal exits shall comply with Section C26-604.6(c).

5. Access to an area of refuge on a floor nearer to the street, through a supplemental vertical exit, may consist of enclosed interior stairs, ramps, or escalators (C26-604.7):

    a. Supplemental vertical exits shall comply with the requirements for interior stairs, and serve no other purpose than to connect a floor area with an area of refuge with no openings in the enclosure other than exit doors (C26-604.7).

    b. Every supplemental vertical exit shall have a sign at the entrance stating EXIT TO AREA OF REFUGE ON _____ FLOOR (C26-604.7).

5.3 EXIT WIDTH AND CAPACITY

Occupant load shall be calculated based on the net floor areas in square feet divided by the occupant load factor (square foot per person) or the actual number of occupants from whom each occupied space is designed, whichever is greater (C26-601.2):

1. Non-simultaneous Occupancy – The occupant load of toilets, locker rooms, meeting rooms, storage rooms, employee cafeterias, and similar rooms or spaces that are not occupied at the same time as other rooms or spaces on the same floor may be omitted from the occupant load calculation of the floor on which they are located (C26-601.2(c)).

2. The occupant load of any space shall include the occupant load of all spaces that discharge through it in order to gain access to an exit (C26-601.2).

Occupancy	**Occupant Load Factor**
Business (offices)	100
Conference rooms (tables)	12
Conference rooms (chairs)	10
Dining spaces	12
Mercantile:	
1st floor/basement	25
All other floors	50
Assembly (fixed seats)	No. of seats
Waiting space (standing)	4
Garages/parking	250
Storage rooms	200
Mechanical rooms	200

Where vertical exits serve more than one floor, only the occupant load of each floor considered individually is used in computing the required capacity of exits at that floor, except where one floor is used by another as a means of egress (C26-601.1).

Exit capacity (width) shall not decrease in the direction of exit travel (C26-604.8).

The width of each means of egress component shall be that computed using the appropriate egress unit factor but not less than the minimum width prescribed for the component (C26-601.1, C26-601.3):

1. Where computations give fractional results, the next larger integral number of egress units or integral number plus ½ shall be used (C26-601.3).

2. A fraction less than ½ may be neglected when constituting less than 10 percent of the total required number of egress units.

When a floor area has access to areas of refuge that comply with the requirements of Section C26-604.5, the number of persons for whom vertical exits are to be provided may be reduced to 50 percent of the occupant load of the floor area when one area of refuge is provided, and may be reduce to 33 1/3 percent of the floor area when two areas of refuge are provided (C26-603.3).

Egress capacity factors – capacity per egress unit (C26-601.1, C26-601.3):

1. One unit of egress width is equal to 22 in.

2. Doors to outdoors at grade:

    a. Occupancy Group B (Storage) – 75 persons per unit.

    b. Occupancy Groups C (Mercantile), E (Business), and F (Assembly) – 100 persons per unit.

3. Other exit and corridor doors:

    a. Occupancy Group B (Storage) – 60 persons per unit.

    b. Occupancy Group C (Mercantile), E (Business), and F (Assembly) – 80 persons per unit.

4. Stairs and escalators:

    a. Occupancy Group B (Storage) – 45 persons per unit.

    b. Occupancy Groups C (Mercantile), E (Business), and F (Assembly) – 60 persons per unit.

5. Ramps, corridors, exit passageways, horizontal exits:

    a. Occupancy Group B (Storage) – 75 persons per unit.

    b. Occupancy Groups C (Mercantile), E (Business), and F (Assembly) – 100 persons per unit.

    c. When ramp slope exceeds 1 in 10, the capacity shall be reduced by 25 percent (Table 6–1 note b).

Where a door is divided by mullions into two or more door openings, each opening shall be measured separately in computing the number of egress units (Table 6–1 note m).

5.4 DOORS

Minimum nominal width shall be 32 in. except for corridor and exit door openings, which shall be 36 in. (C26-604.4(e)):

1. Door jambs or stops and the door thickness when open shall not reduce the required width by more than 3 in. for each 22 in. of width (C26-604.4(e)).

2. In all cases where a door opening is divided by mullions into two or more door openings, the minimum nominal width of each such opening shall be 32 in. (C26-604.4(c)).

Maximum width of leaf (C26-604.4(e)) is 48 in.

Minimum height (C26-604.4(f)) is 6 ft 8 in.

Door jambs, stops, sills, and closers shall not reduce the clear opening to less than 6 ft 6 in. (C26-604.4(f)).

The floor on both sides of all exit and corridor doors shall be substantially level and have the same elevation for a distance at least equal to the width of the leaf (C26-604.4(h)).

Where doors lead out of a building, the floor level inside may be 7½ in. higher than the level outside (C26-604.4(h)).

Exit doors, corridor doors serving high hazard occupancy Group A spaces, and corridor doors from rooms required to have more than one door shall swing in the direction of egress (C26-604.4(g)).

Vertically sliding doors, rolling shutters, and folding doors shall not be used as exit doors or as corridor doors (C26-604.4(d)).

Revolving doors designed and constructed in accordance with Section C26-604.4(m) are permitted to be used as exits except that revolving doors shall not be used as interior exit access doors, at the foot of stairs, or at the head of basement stairs (C26-604.4(d)).

Turnstiles designed and constructed in accordance with Section C26-604.4(n) may also be permitted.

Power operated or power assisted manually operated doors may be used as exit or corridor doors provided they remain closed in case of power failure and are manually operable. To be credited as a required exit, power operated doors must swing in the direction of exit travel (C26-604.4(l)).

Exit doors and corridor doors shall normally be kept in the closed position (C26-604.4(i)).

Latch bolts shall be provided on all exit doors and corridor doors to hold them in a closed position against the pressure of expanding gases (C26-604.4(j)(1)(c)).

Obstruction of means of egress during door opening:

1. Doors providing access to stairways or ramps shall not block stairs/ramps or stair landings or reduce the width of landings/stairs/ramps to less than 75 percent of the required width or to less than the width of the door opening on them (C26-604.8(g), C26-604.10(c)(4)).

2. No door shall swing over the sloping portion of a ramp (C26-604.8(c)(4)).

Exit and corridor doors and doors providing access to areas of refuge shall be readily openable at all times from the side from which egress is made without the use of a key (C26-604.4(j)(1)(a), C26-604.5(d)):

1. Locks may be used in places where extra safeguards are required (banks, museums, etc.), subject to approval of the commissioner, provided the locks are equipped with electrical release devices for remote control in case of emergency (C26-604.4(j)(1)(a)(2)).

2. Doors opening into interior enclosed stairs shall not be locked from either side except that doors may be locked to prevent access to the stair from the outside at the street floor (C26-604.4(j)(1)(b).

5.5 EXIT ACCESS

Minimum clear width of corridors shall be:

1. Occupancy Groups B (Storage), C (Mercantile) - 36 in.

2. Occupancy Groups E (Business), F (Assembly) - 44 in.

The maximum travel distance shall not exceed the following limits. Travel distance shall be measured along the natural and unobstructed path of travel. Where the path of travel is over an access stair, it shall be measured along an inclined straight line through the center of the outer edge of each tread (C26-601.4(a)(c), Table 6–1).

Occupancy	Distance (Feet)[18]
B-1 (Storage)	100
B-2 (Storage)	125
B-2 (Parking garage)	100
C (Mercantile)	150
E (Business)	200
F (Assembly < 75 persons)	150

[18] Distances given are for unsprinklered conditions (BCNYC Table 6–1).

The maximum dead-end distance shall not exceed the following limits (C26-604.2(d), Table 6–1):

Occupancy	Distance (Feet)[19]
B-1 (Storage)	50
B-2 (Storage)	NR
C (Mercantile)	50
E (Business)	50
F (Assembly)	30

5.6 STAIRWAYS

Minimum clear width shall be at least 44 in. (C26-604.8(b)):

1. The width of stairs shall be the clear width between walls, grilles, guard, or newel posts. Stair stringer projections which do not exceed 2 in. on each side and handrail projections of 3½ in. are permitted.

2. Vertical exits in public garages may be 36 in. wide.

3. The minimum width of landings and platforms shall be at least the required width of the stairway. On a straight run stair, landing and platform widths need not be more than 44 in.

Minimum headroom shall be at least 7 ft (C26-604.8(c)).

Maximum height between landings shall be 12 ft (C26-604.8(d)).

Treads and risers (C26-604.8(e), Table 6–4):

1. Maximum riser height:

   a. Occupancy Group F (Assembly) – 7½ in.

   b. All others – 7¾ in.

2. Minimum tread depth – 9½ in. plus nosing

3. The sum of two risers plus one tread exclusive of the nosing shall not be less than 24 nor more than 25½ in.

4. Stair riser and tread dimensions shall be constant in any flight of stairs from story to story.

Curving or skewed stairs that conform to Section C26-604.8(e)(4) are permitted to be used as exits.

[19] Distances given are for unsprinklered conditions. When a corridor is completely enclosed in 2 h fire resistance rated construction with 1/2 h fire rated doors, the permissible length of dead end may be increased by 100 percent (C26-604.2(d)).

Where exit stairways serving floors above grade continue in the same enclosure to serve floors below grade, the above and below grade portions shall be separated by 1 h fire resistance rated construction.

Stair identification signs shall be posted on the occupancy side of the stair door indicating the letter designation of the stair.

In buildings or in building sections more than three stories or 40 ft high with roofs having a slope of less than 20 degrees, access to the roof shall be provided by at least one interior stair. Access to set back roof areas may be through a door or window opening to the roof.

No openings of any kind are permitted into stair enclosures other than windows, fire department access panels, and exit door.

Exterior stairs designed and constructed in accordance with Section C26-604.9 may be used as exits in lieu of interior stairs.

No exterior stair shall exceed 75 ft or six stories in height.

Escalators designed and constructed in accordance with Section C26-604.11 may be used as exits in lieu of interior stair.

5.7 RAMPS

The minimum clear width of exit ramps is 44 in. (C26-604.10, C26-604.8(b)).

Level platforms or landings at least as wide as the ramp shall be provided at the top and bottom of all ramps and at intermediate levels as necessary:

1. Level platforms shall be provided on each side of door openings into or from ramps.

2. Platforms shall be at least 3 ft wide; 5 ft when a door swings onto the platform.

Minimum headroom is 6 ft 8 in.

Changes in direction of travel shall be made only at landings (or platforms) (C26-604.10(c)).

Ramps with a slope not greater than 1 in 12 at any place may be curved.

Ramps shall not have a slope steeper than 1 in 8 and sloping portions shall be at least 3 ft but not more than 30 ft long between platforms or landings.

Level and ramped moving walkways designed and constructed in accordance with Section C26-604.12 may be used as exits (C26-604.12).

5.8 HANDRAILS AND GUARDRAILS

Continuous handrails are required on both sides of all stairs, and all ramps with a slope exceeding 1 in 12:

1. Stairs less than 44 in. wide may have a handrail on one side only.

2. Intermediate handrails shall be provided to divide stairs more than 88 in. wide into widths that maintain nominal multiples of 22 in. and widths not greater than 88 in. nor less than 44 in.

3. Handrail height shall be 30 to 34 in. measured vertically above the nosing of treads.

4. Handrail ends shall be returned to walls and posts when terminated.

5. Handrails shall provide a finger clearance of 1½ in. and shall project not more than 3½ in. into the required stair width.

Stair landings and platforms shall be enclosed on sides by walls, grilles, or guards at least 3 ft height.

5.9 EXIT SIGNS

In all buildings, the location of every exit on every floor shall be clearly indicated by approved EXIT signs (C26-606.1).

EXIT signs shall be placed at an angle with the exit opening if such placement is required for the signs to serve their purpose.

In areas where the location of the exit may not be readily visible or understood (including long corridors and open floor areas), directional signs shall be provided to serve as guides from all portions of the corridor or floor.

The size, color and illumination of EXIT signs shall conform to Section C26-606.3. Directional signs shall conform to Section C26-606.4.

All EXIT signs shall be illuminated at all times when the building is occupied.

Where a total of more than four signs (exit and/or directional) are required, all EXIT signs shall be connected to circuits that are separate from the general lighting and power circuits. These circuits shall be taken off ahead of the main switch or connected to an emergency lighting power source when such source is provided.

Any door, passageway, stair, or other means of communication that is not an exit shall be so identified with a NOT AN EXIT sign and a sign indicating its use or purpose or a directional exit sign shall be provided.

5.10 MEANS OF EGRESS LIGHTING

Corridors and exits shall be equipped with artificial lighting facilities to provide at least 5 ft candle intensity floor lighting continuously during the time that conditions of occupancy of the building require that the exits be available (C26-605.1).

Lighting shall be provided to illuminate changes in direction in and intersections of corridors, balconies, exit passageways, stairs, ramps, escalators, bridges, tunnels, landings, and platforms.

Illumination shall be arranged so that failure of any one light does not leave any area in darkness.

Where a total of more than four lights are required, exit lighting shall be connected to circuits that are separate from the general lighting and power circuits. The circuits shall be taken off ahead of the main switch or connected to an emergency lighting power source when such source is provided.

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Chapter 6
FIRE SUPPRESSION

6.1 AUTOMATIC SPRINKLER PROTECTION

Automatic sprinkler protection shall be designed and installed in accordance with Section C26-1703.1 and Reference Standard (RS) 17-2 in the following areas:

1. Spaces in group B-1 > 500 ft^2.

2. Spaces in group B-1 < 500 ft^2 when required by the commissioner.

3. Spaces in group B-2 > 5,000 ft^2 or 75 ft in height.

4. Spaces in high-rise buildings classified as mercantile occupancy group C > 7,500 ft^2 in floor area or with an unenclosed stair or escalator between any two or more floors.

5. Regardless of occupancy, any story above grade and the first story below grade without required ventilation.

    a. All other stories below grade.

    b. Sprinklers may be omitted in toilets, shower rooms, stair, and mechanical and electrical rooms.

A wet-pipe sprinkler system shall be provided throughout all areas requiring automatic sprinkler protection. In areas subject to freezing, the sprinkler system shall be protected (insulation, heat trace, antifreeze solution) from freezing or a dry-pipe system shall be provided (C26-1703.13).

A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or section (C26-1703.4).

6.2 STANDPIPES

Wet standpipes designed and installed in accordance with Section C26-1702.1 and RS 17-1 shall be provided (C26-1702.1(a)(1)):

The number and location of standpipes shall be such that every point of every floor can be reached by a 20 ft stream from a nozzle attached to not more than 125 ft of hose connected to a riser outlet valve (C26-1702.4):

1. Standpipe risers and 2½ in. hose valves shall be located within stairway enclosures (C26-1702.5(a)).

2. When stairway enclosures are not available within the 125 plus 20 ft distance (145 ft total), risers and valves shall be located as near to the enclosure as practicable (C26-1702.5(a)).

The highest riser shall be extended above the roof with a 3-way manifold with 2½ in. hose valves (C26-1702.11(a)(2)).

A 2½ in. hose outlet shall be provided at each standpipe riser on each floor served, and on the entrance floor above the riser control valve, located between five and six ft above the landing or floor (C26-1702.11(a)(1)).

Hose stations shall be located at the standpipe risers, either inside or adjacent to the entrance of stairway enclosures (C26-1702.11(b)):

1. Hose stations shall be located to satisfy the 125 plus 20 ft (145 total) requirement (C26-1702.11(b)(1)).

2. Hose shall be (C26-1702.11(c)):

   a. 1½ in. unlined (flax-line) linen hose in Groups C, E, and F.

   b. 2½ in. (unlined) in Group B.

3. Auxiliary hose stations equipped with 1½ in. (unlined) hose are permitted in Groups C, E, and F (C26-1702.11(c)(4), C26-1702.11(d)).

Standpipe systems that include more than one riser shall have all risers cross-connected at, or below, the street entrance floor level (C26-1702.10(a)).

Standpipe systems having more than one zone shall be arranged such that the risers supplied from each zone are cross-connected below, or in, the story of the lowest hose outlets from the water source in each zone (C26-1702.10(b)).

Standpipe risers shall be at least 4 in. in diameter where the riser height is 150 ft or less from the highest hose outlet to the level of the entrance floor, 6 in. in diameter where greater than 150 ft (C26-1702.7, Table 17–1).

6.3 WATER SUPPLY

Standpipe systems shall have a primary water supply available at all times to every hose outlet or made available automatically when the hose valve at any outlet is opened (C26-1702.14).

Combinations of two or more of the following sources shall serve as the primary water supply (C26-1702.14(b)):

1. Direct connection to city water system.

2. Direct connection to a private yard main.

3. Pressure tank(s).

4. Automatic fire pump (C26-1702.14(b)(5)).

    a. In buildings higher than 300 ft, the automatic fire pump shall be used only for the lower 300 ft.

    b. Zones above 300 ft shall be supplied by either a gravity or pressure tank.

5. An additional standpipe system water supply shall be provided for standpipes in buildings over 300 ft high (C26-1702.15(a)). The primary water supply to the standpipe system shall be supplemented by one or more manually operated fire pumps (C26-1702.15(a)).

At least one of the following automatic source of water supply shall be provided for sprinklers (C26-1703.8(a)):

1. Gravity tank(s).

2. Pressure tank(s).

3. Automatic fire pump.

4. Direct connection to public water system.

Domestic water supply may be used to supply cooling tower sprinklers and sprinklers installed in buildings classified in Occupancy Group E (Business) in accordance with Section C26-1703.9(e) (C26-1703.9 (c) and (d)).

Auxiliary sources of water supply for sprinkler systems may include a manually actuated fire pump or siamese connection (C26-1703.8(b)).

Combined Water Supplies:

1. Fire pumps may simultaneously serve as the required auxiliary water supply for standpipe and sprinkler systems in accordance with Section C26-1702.15(d).

2. Tanks used to provide the required primary water supply to a standpipe system may also be used as a supply for an automatic sprinkler system (C26-1703.8(c)).

One standpipe system and one sprinkler system siamese connection shall be provided for each 300 ft of exterior building wall or fraction thereof facing each street or public space (C26-1702.9(a), C26-1703.6(a)(1)). In addition:

1. Modifications based on street frontage are permitted by Sections C26-1702.9(b)-(f).

2. Each siamese connection shall be connected to a riser or to a cross connection connecting other siamese connections or risers (C26-1702.10(f)).

3. In below grade sprinkler systems for garage occupancies, a sprinkler siamese connection shall be provided within 50 ft of every exit or entrance used by motor vehicles (C26-1703.6(a)(2)).

4. Siamese connections for partial sprinkler systems shall be in accordance with Section C26-1703.6(a)(3).

Chapter 7
FIRE DETECTION AND ALARM

7.1 FIRE ALARM SYSTEM

A fire alarm system was not required by the Building Code of the City of New York (BCNYC) at the time of design and construction of World Trade Center (WTC) 1 and WTC 2, but smoke detectors were required to be provided to prevent the recirculation of smoke through certain heating, ventilating, and air conditioning (HVAC) systems (C26-1300.7(a)). A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or Section (C26 1703.4). (Note that the underground spaces and parking garage were originally sprinklered.)

A local water flow alarm unit shall be provided (outdoor water motor or electric alarm gongs) where there is no watchman with watch service (Reference Standard [RS] 17-2 Sec. 3721).

Central station water flow alarm service is desirable but does not waive the local alarm requirement (RS 17-2 Sec. 3721).

7.2 SMOKE AND HEAT DETECTOR LOCATIONS

HVAC Systems (C26-1300.7(a), RS 13-1):[20]

1. In systems over 5,000 cfm capacity, thermostatic devices shall be provided for automatic fan shut-down as follows (RS 13-1 Sec. 1002):

    a. 125 °F (max) devices located in the return air stream prior to exhaust or dilution by outside air (RS 13-1 Sec. 1002(a)).

    b. 50 °F (max) above maximum operating temperature devices located in the main supply duct down stream of the filters (RS 13-1 Sec. 1002(b)).

    c. Where thermostatic devices are installed in systems utilizing recirculated air on floors protected by sprinkler or fire alarm systems, fans shall automatically shut down on alarm (RS 13-1 Sec. 1005).

2. In systems over 15,000 cfm capacity smoke detectors shall be provided for automatic fan shutdown as follows (RS 13-1 Sec. 1003).

    a. Smoke detectors shall be located in the main supply duct downstream of the filters (RS 13-1 Sec. 1003(b)).

[20] A Port Authority fire safety report contained in Appendix A of NIST NCSTAR 1-1H indicates that smoke detectors were installed on each floor at return air ducts. The NIST NCSTAR 1-1H report is one of the companion documents from this Investigation. A list of these documents appears in the Preface.

b. Smoke detectors shall be arranged to provide audible and visual annunciation at a local supervisory control board in the building in accordance with RS 13-1 Sec. 1003(c).

3. In systems utilizing recirculated air, smoke detectors shall be provided for automatic fan shut-down when any of the following conditions exists (RS 13-1 Sec. 1003(a)):

   a. System supplies an exit passageway, or a space leading from elevators to a street or to the exterior.

   b. System supplies spaces on more than one story or spaces in different fire areas in the same story.

   c. Where the area of a building or space served is over 20,000 ft^2 in mercantile or indoor assembly occupancies.

   d. Where there is a duct opening in a required 2 h fire resistance rated interior Fire Division.

   e. Where a duct passes through a firewall.

   f. Where a corridor is used as a plenum.

4. Systems incorporating automatic exhaust in lieu of automatic fan shutdown are acceptable provided they are equipped with smoke detectors (RS 13-1 Sec. 1004).

5. Each installation shall be equipped with a manual emergency stop for quick shut down of the fan(s) in case of fire (RS 13-1 Sec. 1001).

7.3 MANUAL FIRE ALARM BOXES

No requirement per BCNYC.

7.4 AUDIBLE/VISUAL ALARM NOTIFICATION APPLIANCES

No requirement per BCNYC.

7.5 COMMUNICATION SYSTEM

In every building more than 300 ft high, a telephone and signaling system shall be provided for fire department use in operating the standpipe system (C26-1702.21, C26-1704.7(a)).

The standpipe telephone system shall be as follows:

1. System shall permit communication by permanent telephones in the following locations (C26-1704.7(b)):

   a. Pump rooms.

   b. Entrance floor.

c. Gravity tank rooms.

d. Each floor near main standpipe riser.

2. The system shall be a selective ringing, common talking system supplied by a 24 V direct current power source (C26-1704.7(b)).

3. Permanent wall telephones shall be provided with 6 in. gongs except in the pump room where a loud speaking receiver shall be provided (C26-1704.7(c)).

4. Where portable phones are used, jacks protected by break-glass boxes shall be provided (C26-1704.7(c)).

   a. At least three portable phones shall be provided for each standpipe installation, kept in a dedicated, locked cabinet located in the main hall of the entrance floor (C26-1704.7(d)).

   b. A pilot light shall be provided over the cabinet to indicate if the system is in use or a receiver is off the hook (C26-1704.7(e)).

5. Manual, individually coded sending stations shall be located in the main corridor of the building arranged to transmit a signal to alarm sounding devices (C26-1704.7(f)(1)). The system shall be installed in accordance with RS 17-3 (C26-1704.7(f), C26-1704.8).

6. An 8 in. gong shall be provided in the pump rooms and in elevator shafts at intervals not exceeding 10 floors (C26-1704.7(f)(1)).

7. Adjacent to each telephone station and near the main standpipe riser, a closed circuit strap key connected in series with the box circuit of the signal sending station shall be provided (C26-1704.7(f)(2)).

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Chapter 8
ELEVATORS AND HOISTWAYS

8.1 GENERAL

Elevators or escalators shall be provided in accordance with Section C26-1800.1 and Reference Standard (RS) 18-1 in all new buildings exceeding four stories in height (C26-604.1(a), C26-1800.6(d)).

1. When areas of refuge are provided above the 11th floor of a building, they shall be served by at least one elevator (C26-604.5(c)).

2. Escalators may be used as exits in lieu of interior stairs (C26-604.11, C26-1800.6(g).

In every building exceeding 100 ft in height, at least one elevator shall be kept available for immediate use by the fire department during all hours (C26-1702.22, C26-1800.8).[21]

In buildings exceeding 150 ft in height, there shall be an operator available at all times (C26-1800.8).

Automatic passenger elevators shall be equipped with emergency controls for fire department use (RS 18-1 Rule 210.13).

1. A two-position keyed switch shall be provided at a main floor of each elevator or group of elevators for recall to the main floor in accordance with RS 18-1 Rule 210.13(a).

2. A keyed switch shall be provided in or adjacent to an operating panel of each elevator to initiate emergency service in accordance with RS 18-1 Rule 210.13(b).

Fire drills shall be conducted in accordance with the fire safety plan at least once every 3 months for existing buildings during the first 2 years. Thereafter, fire drills shall be conducted at least once every 6 months. The occupants of the building, other than building service employees, shall not be required to leave the floor or use the exits during the drill.

[21] According to Bracco 1969, all passenger elevators were capable of being recalled to their respective lobbies using manual controls. The control over-rides all individual floor hall calls, preventing manual or heat activation from calling a car to a "fire floor" and makes the car available for manual operation by the Fire Department. This arrangement is similar to requirements for emergency operation added by LL 5/1973, to which the elevators were retrofit later.

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Chapter 9
SPECIAL FEATURES

9.1 EMERGENCY POWER SYSTEMS

No requirement per Building Code of the City of New York (BCNYC).

9.2 PUBLIC GARAGES

A public garage used exclusively for parking of vehicles having fuel storage tanks of 26 gal capacity or less is classified in storage Occupancy Group B-2 (C26-709.2(b)).

All floors shall be concrete or equivalent noncombustible material and columns shall be protected from vehicle impact or designed to resist lateral forces in accordance with Section C26-902.4 (C26-709.3).

Public garages shall be ventilated in accordance with Section C26-709.7.

Ramps serving as required exits shall be enclosed in 2 h fire resistance rated construction with vehicle openings at each parking tier protected by a 3 gpm per linear foot deluge type sprinkler water curtain (C26-709.9).

9.3 SMOKE AND HEAT VENTING[22]

Elevator and dumbwaiter shafts shall be in accordance with RS 18-1.

Other closed shafts shall be as follows:[23]

1. All closed shafts having an area exceeding 4 ft^2 shall be provided with a smoke vent having an area of at least 3½ percent of the maximum shaft area at any floor but not less than ½ ft^2 (C26-504.6(d)).

2. Smoke vents may be windows, louvers, skylights, vent ducts or similar devices (C26-504.6(d)).

3. Vent ducts shall be enclosed by construction having the same fire resistance rating as required for the shaft and extend vertically, diagonally, or horizontally in accordance with Sec. C26-504.6(d)(1)(2).

[22] A Port Authority fire safety report contained in Appendix A of NIST NCSTAR 1-1H indicates that a smoke purge configuration (not yet required by BCNYC) for the heating, ventilating, and air conditioning system was installed. Requirements for smoke purge systems were adopted in LL 16-1984.

[23] The original design omitted vents from closed shafts (Solomon 1975).

4. Of the total required vent area for shafts at least 1/3 shall be clear to the outdoors either in the form of fixed louvers, ridge vents, or hooded or goose-necked openings (C26-504.6(e)).

5. As an alternate, skylights or trap doors may be arranged to open automatically by fusible link or other mechanical device when subjected to 160 °F fixed temperature or 15-20 °F per min temperature rise (C26-504.6(e)).

6. The remaining portion of the required vent area may be a window or skylight glazed with plain glass not more than 1/8 in. thick or slow burning plastic (C26-504.6(e)).

Machine Rooms.

1. Any compartment containing machinery that communicates with a shaft enclosure shall comply with all requirements for shafts (C26-504.6(f)).

2. The required louver or glazing shall not be located in any door leading into such compartment (C26-504.6(f).

Chapter 10
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Section II
Fire Protection Summary for World Trade Center 7

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EXECUTIVE SUMMARY

As part of the analysis of building and fire codes and standards of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation, this report supports the effort to determine the minimum construction requirements used in the design of WTC 7. The purpose of this report is to summarize the fire protection (both passive and active) and life safety provisions used to design and construct WTC 7.

Although the Port Authority of New York and New Jersey (PANYNJ or Port Authority) was not subject to the Building Code of the City of New York (BCNYC), WTC 7 was intended to be designed in accordance with the BCNYC and all applicable reference standards. Based on citations in the construction documents, the 1968 BCNYC, including amendments to January 1, 1985, appears to have been used for the design and construction provisions of WTC 7.

The BCNYC, building characteristics, and early design choices were used to determine the minimum construction requirements for the design of WTC 7. Because the BCNYC contains requirements for various types of buildings, it is crucial to identify applicable building requirements early in the design. By identifying specific building characteristics, a designer is able to determine which requirements must be complied with and which requirements are not applicable.

The building summaries in Table E–1 were used to classify the building and determine the minimum requirements of the BCNYC. Based on the height, area, primary occupancy classification, and installation of a fire sprinkler and standpipe system, the minimum construction type (permitted by the BCNYC) was type I-C (2 h protected). However, some documentation, including some building drawings and specifications for bidders on the contract for fireproofing the structural steel, indicate a type 1-B (3 h) classification. No documents were found containing measured thicknesses of fireproofing which might settle this difference. Fire resistance ratings for the structural components, fire divisions, and fire separations were based on this classification. In this report, type 1-C is assumed, but the possibility exists that the actual classification might have been 1-B. Many of the means of egress, fire suppression, and fire alarm requirements were also based on the building summaries of Table E–1. An abbreviated list of the fire protection requirements is as follows. A complete list of the requirements is identified in the main body text of this report.

- Standpipes were required.
- A complete automatic sprinkler system was required.
- A Class E fire alarm and communication system was required.
- A telephone and signaling system was required for fire department use in operating the standpipe system.
- Detectors were required in certain locations of the building and the heating, ventilating, and air conditioning system.

- Manual fire alarm boxes were required.
- Audible/visual devices were required.
- Exit signs and emergency lighting were required in selected spaces.
- An emergency power system was required.
- Smoke and heat venting was required in selected spaces.
- A smoke purge system was required.
- Stair pressurization was not directly required but could be used as an alternative to eliminate smoke and heat venting requirements.

Table E–1. Building characteristics used to determine BCNYC requirements.

Building	Height	Number of Floors Above Grade	Footprint	Primary Occupancy Classification
WTC 7	618 ft	47	48,000 ft^2	Group E (Business)

Source: PANYNJ.

Chapter 11
INTRODUCTION

11.1 PURPOSE

The purpose of this report is to summarize the fire protection (passive and active) and life safety provisions used to design and construct World Trade Center (WTC) 7.

11.2 INTRODUCTION

The regulation of building construction is a direct result of the recognition that life safety is served by the best available knowledge and practice. Codes and standards are created to establish minimum requirements. Model codes have been published throughout the United States since 1905 (Boring 1981). Through the use of technology improvements and as a result of serious incidents, such as fires, codes are developed and later revised to continually implement increased knowledge. Establishing reference standards is just as important as establishing codes. Reference standards act as a technical basis of the code and provide methods of testing, installation and maintenance. Municipalities can adopt model building codes and national standards or develop their own. Alternatively, many municipalities throughout the United States have adopted model building codes and national standards, and then amend portions as deemed necessary. New York City, however, developed their own building code and provided a technical basis with a mixture of nationally recognized standards (National Fire Protection Association, ASTM International, American National Standards Institute, etc.) and New York City developed reference standards (denoted by RS ##).

In accordance with the instructions issued by the Port Authority of New York and New Jersey (PANYNJ or Port Authority) at the start of the project, construction drawings for the WTC were to conform with the requirements of the Building Code of the City of New York (BCNYC), although as a so-called state compact under the U.S. Constitution, it was exempt from state or local laws, including the BCNYC. Based on citations in the construction documents, the 1968 edition of BCNYC, including amendments to January 1, 1985,[24] has been used for citing the design and construction requirements for WTC 7. The applicable provisions of the BCNYC given throughout this report are denoted by C26-###.

As stated previously, it was the policy of the Port Authority to follow the requirements of the BCNYC. Where documentation was identified, illustrating either conformance or deviation from the BCNYC provision, a reference has been provided. This report does not evaluate whether or not the design provisions were actually incorporated in the design of WTC 7, but merely identifies the provisions used in the design.

[24] The year is an assumption based on the years of building construction and a reference to the 1983 edition of NFPA 13 located on sprinkler drawing PFP-1 of the construction documents.

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Chapter 12
GENERAL

12.1 APPLICABLE CODES AND STANDARDS

1. Building Code of the City of New York, 1968 including amendments to January 1, 1985.[25, 26]
2. Local Law No. 5, Fire Safety Requirements and Controls, January 18, 1973.[27]
3. Local Law No. 16, March 27, 1984.[28]
4. American National Standards Institute A17.1 – Safety Code for Elevators and Escalators and Supplement A17.1-85a, 1984 (as modified by Reference Standards (RS) 18).
5. National Fire Protection Association (NFPA) 13 – Standard for the Installation of Sprinkler System, 1983 (as modified by RS 17-2).
6. NFPA 22 – Standard for Water Tanks for Private Fire Protection, 1981.
7. NFPA 72A – Standard for the Installation, Maintenance and Use of Local Protective Signaling Systems for Guard's Tour, Fire Alarm and Supervisory Service, 1979 (as modified by RS 17).
8. NFPA 72B – Standard for the Installation, Maintenance and Use of Auxiliary, Protective Signaling Systems for Fire Alarm Service, 1982 (as modified by RS 17).
9. NFPA 72C – Standard for the Installation, Maintenance and Use of Remote Station Protective Signaling Systems for Fire Alarm and Supervisory Service, 1982 (as modified by RS 17).
10. NFPA 72D – Standard for the Installation, Maintenance and Use of Proprietary Protective Signaling Systems, 1979 (as modified by RS 17).
11. NFPA 72E – Standard on Automatic Fire Detectors, 1978 (as modified by RS 17).
12. NFPA 80 – Installation of Fire Doors and Windows, 1979 (RS 5-8).

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[25] Including the Building Code Reference Standards that modify national standards as deemed necessary. This edition of the BCNYC includes Local Laws No. 5 and No. 16.

[26] See footnote 1.

[27] According to Syska 1984d, the building was completely sprinklered and provided with a standpipe system, Class E fire alarm system (with voice communication), manual pull stations and smoke detection systems to comply with Local Law No. 5.

[28] According to Syska 1984a, the building was designed in compliance with Local Law No. 16.

13. NFPA 90A – Standard for the Installation of Air Conditioning and Ventilating Systems, 1981 (as modified by RS 13-1).

14. NFPA 204 – Guide for Smoke and Heat Venting, 1968 (RS 5-11).

15. ASTM International (ASTM) E 84 – Standard Method of Test for Surface Burning Characteristics of Building Materials, 1961 (as modified by RS 3-2).

16. ASTM E 119 – Standard Methods of Fire Tests of Building Construction and Materials, 1961 (as modified by RS 3-1).

17. RS 5-15 – Minimum Covering of Pre-stressing Steel for Various Fire Resistance Ratings.

18. RS 5-17 – Standards for the Installation of Smoke Shafts.

19. RS 5-18 – Standard for the Pressurization of Stairs.

20. RS 17-1 – Standpipe System Construction.

21. RS 17-3 – Standards for the Installation of Fire, Sprinklers, Standpipe Smoke Detection…and other Alarm and Extinguishing Systems.

22. RS 17-3A – Standards for the Installation of Class E Fire Alarm Signal Systems.

23. RS 17-3B – Standards for the Installation of Modified Class E Fire Alarm Signal Systems.

12.2 BUILDING SUMMARY

Table 12–1. Building characteristics used for design development.

Building[29]	Height	Number of Floors Above Grade	Footprint	Construction Type (1968 BCNYC)	Primary Occupancy Classification
WTC 7	618 ft	47	48,000 ft^2	I-C (but some documents cite 1-B)	Group E (Business)

Source: PANYNJ.

[29] This building is located inside the Borough of Manhattan Fire District without additional restrictions imposed based on its use and occupancy (C26-402.1, C26-403.1).

Chapter 13
CONSTRUCTION

13.1 CONSTRUCTION CLASSIFICATION

The minimum construction type permitted for the building was I-C (2 h protected).[30]

13.2 BUILDING LIMITATIONS

In accordance with Table 4–2 of the Building Code of the City of New York (BCNYC) the height and area are not limited for a sprinklered Class I-C construction building housing a Group E occupancy.

- Height – No Limit
- Area – No Limit

13.3 SECONDARY/ACCESSORY OCCUPANCIES

Occupancy	Fire Index
B-1, Storage (moderate hazard)	3
B-2, Storage (low hazard, garage)	2
C, Mercantile	2
F-4, Assembly (restaurant)	1

13.4 FIRE RESISTANCE RATINGS

The minimum required fire resistance ratings listed as follows are in accordance with Table 3–4 of the BCNYC, unless noted otherwise. The fire resistance ratings are based on the test procedures of reference standard RS 3-1.

[30] All BCNYC requirements identified herein, which are dependent upon construction class, are given for Class I-C.

	Fire Resistance Rating (Hours)
1. Exterior bearing walls	2
2. Exterior non-bearing walls having an exterior separation of:[31]	
3 ft or less with 0 percent openings	2
Greater than 3 ft to less than 15 ft with ½ percent protected openings	2
15 ft to less than 30 ft with 3½ percent openings	1
30 ft or greater with unlimited openings	NC[32]
3. Interior walls:	
Walls and partitions (structurally bearing)	2
Corridors (C26-604.2(h))	1
4. Enclosure of vertical exits[33], exit passageways, hoistways and shafts	2
5. Columns, girders, trusses (other than roof trusses) and framing:	
Supporting one floor	1½
Supporting more than one floor or a floor and roof	2

[31] When two or more buildings are constructed on the same lot and the combined floor area of the buildings does not exceed the limits established by Tables 4–1 and 4–2 for any one of the buildings, no fire resistance rating shall be required for non-bearing portions of the exterior walls of those buildings facing each other, and there shall be no limitation on the permitted amount of exterior openings.

[32] Noncombustible.

[33] See Sections C26-504.6 and 26-604.8(i) for exceptions to shaft and stair enclosures requirements.

	Fire Resistance Rating (Hours)
6. Structural members supporting a wall	Same as required fire resistance of wall supported, but not less than rating required for member by the class of construction.
7. Floor construction including beams	1½
8. Roof construction - Including beams, trusses, framing, arches, domes, cable supported roofs and roof decks – above floor to lowest member:	
15 ft or less	1[34]
15 ft to 20 ft	1[34]
20 ft or more	1[35] or 0[36]

The minimum covering of prestressing steel shall comply with the requirements of RS 5-15 (C26-502.2(d).

[34] Materials which are not noncombustible, as defined in article 2 of the BCNYC, may be used in non-bearing construction elements if they fall into one of the following categories:

a. Materials having a structural base of noncombustible material as defined in article 2, and having a surface not over 1/8 in. thick which when tested in accordance with the provisions of reference standard RS 3-2 have a flame spread rating not higher than 50.

b. Materials which when tested in accordance with the provisions of reference standard RS 3-2 have a surface flame spread rating not higher than 25 without evidence of continued progressive combustion, and which are of such composition that surfaces which would be exposed by cutting through the material in any way would not have a flame spread rating higher than 25 without evidence of continued progressive combustion.

[35] Applies to occupancy groups: A, B-1, B-2, and D-1. See also footnote 34.

[36] Applies to all occupancy groups other than those indicated in footnote 35. Fire retardant treated wood complying with the requirements of Section C26-502.6 may be used. See also footnote 34.

13.5 OPENING PROTECTION

	Fire Resistance Rating (Hours)
1. Openings in a 3 h rated Fire Division or Fire Separation wall (C26-504.4 and Table 5–3).	3 (Class A)
2. Openings in 2 h or 1½ h rated Fire Division or Fire Separation wall or vertical communication enclosure (C26-504.4, C26-604.4(a), C26-1800.6 and Table 5–3).	1½ (Class B)
3. Openings in 1 h rated Fire Division or Fire Separation walls, corridors or partitions (C26-504.4, C26-604.4(b) and Table 5–3).	¾ (Class B)
4. Openings in 1 h rated vertical communication enclosure.	1 (Class B)
5. Required protected openings in exterior walls (Class E or Class F) (C26-503.1(b)).	¾

Noncombustible mail slots not exceeding 40 $in.^2$ may be provided in corridor doors (C26-604.4(b)).

Noncombustible louvers may be installed in corridor doors opening into toilets, service sink closets, and electrical closets (C26-604.4(b)).

Openings in Fire Divisions and Fire Separations should not exceed the size limits as follows (C26-504.4(a)):

1. In buildings that are not sprinklered no opening through a fire division or a fire separation shall exceed 120 ft^2 in area, with no dimension greater than 12 ft, and the aggregate width of all openings at any level shall not exceed 25 percent of the length of the wall.

2. Where the areas on both sides of a fire division or fire separation are sprinklered in accordance with the construction provisions of article 17, the size of the opening may be 150 ft^2 in area, with no dimension greater than 15 ft.

3. In buildings fully sprinkled in compliance with the provisions of article 17, the size and aggregate width of openings through the fire divisions or fire separations shall be unlimited.

4. When a fire division or fire separation serves as a horizontal exit also, it shall have no opening other than door openings not exceeding 56 ft^2 in area, the aggregate width of all openings at any level shall not exceed 25 percent of the length of the wall.

In shafts that contain only one opening below the roof, no opening protective is required (C26-504.6(c)).

Exterior street floor exit doors with a fire separation distance of more than 15 ft need not have a fire resistance rating (C26-604.4(a)(1)).

Openings in elevator and dumbwaiter shafts shall comply with RS 18 (C26-504.6(c)).

13.6 SEPARATION OF OCCUPANCIES

	Fire Resistance Rating (Hours)
1. Fire Divisions	
Between Group B-1 and B-2, C, E or F-4.	3
2. Fire Separations	
Between Groups E and B-2, C or F-4.	NR[37, 38]
Between tenant spaces (C26-504.3(a)).	1

Separate Building (Building Section) – Spaces classified in occupancy groups having a higher fire index than the occupancy group classification of the building shall be separated by "Fire Divisions" constructed in accordance with Section C26-504.1(a) and treated as separate buildings (C26-301.4(a)).

Separate Spaces – Spaces classified in occupancy groups having the same or lower fire index than the occupancy group classification of the building shall be separated by "Fire Separations" constructed in accordance with Section C26-504.1(b) (C26-301.4(b)).

Multiple occupancy or use – When a building or space is used for multiple purposes at different times, the building/space shall be given a separate occupancy group classification for each of the activities. The design and construction shall be in accordance with the most restrictive provisions that apply to any of the classifications (C26-301.6).

A minor variation of occupancy or use of a space is acceptable without multiple classifications if the variation is normally associated with the occupancy classification and no specific danger or hazard is created (C26-301.6).

Fire divisions shall be constructed of noncombustible materials or assembly of noncombustible materials to provide the fire-resistance ratings (C26-504.2). The following requirements apply:

1. Vertical fire divisions shall be continuous between foundation, roof, or horizontal fire divisions, and through any concealed space in floor or roof construction.

[37] No requirement.

[38] Separations are not required between accessory business and mercantile activities limited in area to 100 ft^2, and closets 75 ft^2 or less in area (Table 5–1 notes b and c).

2. Horizontal fire divisions shall be continuous between exterior walls and/or vertical fire divisions.

3. Fire divisions shall be made smoketight at their junction with exterior walls.

4. Fire divisions may be offset if the construction between the offset divisions, including their supports, has the same fire-resistance rating as the fire division, with all hollow spaces within the construction firestopped with noncombustible material.

5. Where combustible members such as joists, beams, or girders bear on, or frame into, vertical fire divisions, such members shall not extend through the wall and shall have at least 4 in. of solid noncombustible material below, at the sides, and at the ends of each such member.

6. Chases or recesses shall not be cut into fire divisions so as to reduce their thickness below that required for the fire-resistance rating.

7. Vertical fire divisions that are hollow shall be firestopped with at least 4 in. of noncombustible material so as to prevent passage of flame, smoke, or hot gases through the hollow spaces to the story above or below, or to hollow spaces within connecting floor or roof construction.

13.7 COMPARTMENTATION

All new buildings classified in occupancy group E (Business) having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located, and unsprinklered floor areas[39] more than 40 ft above curb level, shall be subdivided by fire separations into spaces or compartments as indicated below (C26-504.1):

1. All unsprinklered floor areas shall be segregated by 1 h fire separations into spaces or compartments not to exceed 7,500 ft^2.

2. Where the floor area exceeds 10,000 ft^2, at least one of the subdividing fire separations shall be of 2 h construction, creating areas of refuge, complying with section C26-604.5 except that the requirement for an elevator in each area shall not apply.

3. The floor area or any subdivided area may be increased to not more than 15,000 ft^2 if complete area protection by approved devices for the detection of products of combustion other than heat is provided within such increased area and provided further that at least one of the subdividing fire separations shall be of 2 h construction where the floor area exceeds 15,000 ft^2, creating areas of refuge complying with C26-604.5 as noted in 2 above. The activation of the detectors shall have the same effect as section C26-1704.5(f).

4. Compartmentation is not required when complete sprinkler protection is provided.

[39] The floor area shall be defined as the area within exterior walls and excluding any areas enclosing stairs, corridors, elevators, and shafts. (C26-504.1)

13.8 FIRESTOPPING

All firestopping or fill materials shall consist of approved noncombustible materials that can be shaped, fitted and permanently secured in place (C26-504.7(a)).

Concealed spaces within partitions, walls, floors, roofs, stairs, furring, pipe spaces, column enclosures, etc. that would permit passage of flame, smoke, fumes or hot gases from floor to floor shall be firestopped or filled with noncombustible material in the following locations (C26-504.7):

1. Hollow partitions and furred spaces.
2. Concealed spaces within stair construction.
3. Ceiling spaces.
4. Exterior cornices.
5. Duct and pipe spaces (C26-504.5 and RS 13-1 Sec. 313 and 314).
6. Hollow spaces where combustible trim and finish is permitted.
7. Hollow vertical Fire Division (C26-504.2(i)).

The concealed space above a fire resistance rated ceiling shall be firestopped into areas not exceeding 3,000 ft^2, except where (C26-502.5):

1. Structural members within the concealed space are individually protected, or
2. The concealed space is sprinklered.

Firestopping shall not be required where (C26-502.5(a)(1)):

1. The structural members within the concealed space are individually protected with materials having the required fire resistance rating.
2. The ceiling is not an essential part of the fire resistive assembly
3. A concealed space is sprinklered in accordance with the construction requirements of article 17.

13.9 THROUGH PENETRATION PROTECTION

Noncombustible pipes and conduits may pass through fire rated construction provided the following (C26-504.5(b)):

1. Space between the pipe or conduit and its sleeve or opening does not exceed 2 in. and is packed with noncombustible material.

2. Close-fitting metal escutcheons are provided on both sides of the construction.

3. Aggregate net area of openings does not exceed 25 $in.^2$ in any 100 ft^2 of wall or floor area. Openings in excess of this limit are not permitted unless tested as part of a rated assembly and so protected.

Ceilings required to have a fire resistance rating may be pierced to accommodate noncombustible electric outlet boxes, recessed lighting fixtures, pipes and ducts as follows (C26-502.5(b)):

1. The aggregate area of outlet boxes and lighting fixtures does not exceed 16 $in.^2$ in each 90 ft^2 of ceiling area.

2. Outlet boxes and lighting fixtures are constructed of steel at least 0.022 in. thick and sealed tightly at the ceiling.

3. Additional or larger services are permitted only when tested as part of the assembly and protected as provided in the test.

The concealed space above fire rated ceilings may be used as a return air plenum if listed (tested) for that purpose provided (RS 13-1 Sec. 316):

1. All openings are tested as part of the assembly and protected in the test,

2. The integrity of firestopping is not destroyed,

3. No combustible materials are incorporated in the floor and ceiling construction, and

4. Electrical wiring is plenum rated (NFPA 70 Sec. 300-22).

13.10 FIRE AND SMOKE DAMPERS

Fire dampers shall be provided in accordance with RS 13-1 in the following locations (C26-504.5(a)):

1. Duct penetrations of walls with a 2 h fire resistance rating or greater (RS 13-1 Sec. 902(a)).

2. Each opening in required vertical shaft enclosures (RS 13-1 Sec. 902(b)).

3. Each outlet or inlet opening in vertical shaft enclosure of duct systems serving two or more floors (RS 13-1 Sec. 902(c)).

4. As an alternate, dampers may be provided at each point where the vertical duct pierces a floor it serves (RS 13-1 Sec. 902(c)).

5. Branch duct penetrations of vertical duct shaft enclosures (RS 13-1 Sec. 902(c)).

6. Fresh air intakes (RS 13-1 Sec. 902(e)).

7. Aluminum Class I duct penetrations of fire resistance rated floors (RS 13-1 Sec. 902(d)).

Fire dampers are not required at the following locations (RS 13-1 Sec. 903):

1. Non-aluminum or Class I vertical shaft branch duct penetrations with a cross-sectional area of less than 20 in.^{2} which supply only air conditioning units discharging air at not over 4 ft above the floor (RS 13-1 Sec. 903(a)).

2. Non-aluminum or Class 1 duct penetrations of a floor (at one place only) with a cross-sectional area of less than 20 in.^{2} which supply air conditioning units in one story only that discharge air at not over 4 ft above the floor (RS 13-1 Sec. 903(b)).

3. Duct penetrations in systems serving only one floor and used only for exhaust to the outside and not penetrating a fire wall or fire partition or passing entirely through the vertical shaft enclosure (RS 13-1 Sec. 903(d)).

4. Branch ducts connected to a return riser where subducts are extended at least 22 in. upward (RS 13-1 Sec. 903(e)).

Fire dampers should be automatic closing 1½ h fire rated with a fusible link or other heat actuated device rated approximately 50 °F above the maximum system operating temperature (RS 13-1 Sec. 905(a)(g)).

Duct openings permitted in fire resistance rated ceilings shall be protected with fire dampers (C26-502.5(b)).

Smoke dampers shall be installed in the main supply duct and the main return duct in systems over 15,000 cfm capacity (RS 13-1 Sec. 1003).

Smoke dampers shall be arranged to close automatically when the system is not in operation, by the operation of duct smoke detectors, and by the manual emergency fan stop (RS 13-1 Sec. 1003).

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Chapter 14
INTERIOR FINISH

14.1 INTERIOR FINISH FLAME SPREAD RATINGS

The minimum interior finish flame spread ratings below are based on Table 5–4 of the Building Code of the City of New York (BCNYC) and other sections as noted.

	Classification
1. Exits and shafts (C26-504.10(c), C26-604.8(i)(3))	Class A (0-25)
2. Corridors (C26-504.10(c), C26-604.2(k)): [40, 41]	
Group B-1	Class A (0-25)
Groups B-2, C, E, F-4	Class A or B (0-75)
3. Rooms greater than 1,500 ft^2 (C26-504.10(c)):	
Groups B-1, B-2, F-4	Class A or B (0-75)
Group E	Class A, B or C (0-225)
4. Rooms less than 1,500 ft^2 (C26-504.10(c)):	
Groups B-1, B-2, E, F-4	Class A, B or C (0-225)
5. Interior finish in kitchens, cooking spaces, pantries, repair and maintenance shops, boiler rooms and incinerator combustion rooms (Table 5–4 note f).	Class A or B (0-75)

[40] When used in corridors, Class B finish material should not extend more than 50 ft between separations of Class A finish material that are at least 2 ft wide (Table 5–4 note b).

[41] Spaces through which it is necessary for occupants of an adjacent room to pass in order to reach the only exit are considered as corridors.

14.2 SMOKE DEVELOPED RATINGS

Twenty-five or less in exits and corridors (C26-504.10(d)).

One hundred or less in rooms where the net floor area per occupant is 10 ft^2 or less (C26-504.10(d)).

No material shall be used in any interior location that upon exposure to fire will produce products that are more toxic in point of concentration than those given off by wood or paper (C26-504.10(e)).

14.3 INTERIOR TRIM

Up to 20 percent of the aggregate wall and ceiling area of any room or corridor may be finished with Class A, B, or C (0-225) materials and be exempt from the smoke developed rating requirements (C26-504.10(c)(4), C26-504.10(d)). This allowance shall include the area of doors, folding partitions, windows, glazing, skylights, luminous ceilings, trim, bases, chair rails, panels, moldings, etc.

14.4 FLOOR FINISH

Finish flooring in all exits shall be of noncombustible material (C26-504.13, C26-604.8(h)).

In all other areas, combustible finish flooring may be used when installed in accordance with Section C26-504.13(b).

Chapter 15
MEANS OF EGRESS

15.1 GENERAL

Clear width measurement is the net, unobstructed width of a means of egress without projections in such width (C26-604.2(a), C26-604.3(b)):

1. In corridors, projections up to 18 in. wide to the extent of 2 in. per unit of egress width are permitted if the total area of such projections does not exceed 5 percent of the area of the wall on which they occur (C26-604.2(a)).

2. Handrails shall project not more than 3½ in. and stringers 2 in. (each side) into the required stair width (C26-604.8(b), C26-604.8(f)).

Headroom (C26-604.2(b), 604.3(c)):

1. Corridor and exit passageway minimum height of 7 ft 6 in. for 75 percent of the floor area with no point less than 7 ft.

2. Projections from the ceiling shall be at least 7 ft above the floor and located so as not to obstruct full view of exit signs (C26-604.2(b), 604.3(c)).

Changes in level requiring less than two risers in a corridor or exit passageway shall be by a ramp (C26-604.2(e), C26-604.8(d)(2)).

Obstructions to means of egress:

1. The required width of a means of egress shall not be obstructed or reduced in any manner (C26-604.2).

2. Corridors shall be kept free of combustible contents (C26-604.2).

3. All exterior means of egress elements, including exterior corridors and stairs, shall be maintained free of ice and snow accumulation (C26-604.2, C26-604.9).

Corridors may be used as supply or return air ducts or plenums if equipped with an approved smoke detector or thermostatic device to shutdown fans (C26-604.2(j), Reference Standard [RS] 13-1 Sec. 316(d)).

Stairways connecting two or more stories shall not be used as plenums (RS 13-1 Sec. 316(e)).

15.2 EXITS

Every floor area shall be provided with at least two approved independent exits (C26-603.2).

A minimum of two exits or exit access doors shall be provided from every room or space in which the occupant load exceeds the following limits (C26-603.1):

Occupancy	Load
B (Storage)	50
C (Mercantile)	75
E (Business)	75
F (Assembly)	75

All required exits shall be located such that they are clearly visible, accessible and have unobstructed access at all times (C26-602.1).

In multi-tenant configurations, each tenant shall have access to the required numbers of exits without passing through other tenant spaces (C26-602.2).

Whenever more than one exit or exit access is required from any room, space or floor of a building, they shall be located as remote from each other as practicable (C26-602.3). The minimum distance between such doors shall be the greater of 30 ft or be one-third the maximum travel distance of the floor, provided, however, that where such distance will result in travel distances exceeding those authorized in section C26-601.1, additional vertical exits shall be provided (C26-602.3).

All vertical exits shall extend in a continuous enclosure to discharge directly to an exterior space or at a yard, court, exit passageway or street floor lobby of the required width and size to provide all occupants with a safe access to an open exterior space. Where vertical exits serving floors above grade continue in the same enclosure to serve floors below grade, the portion of such vertical exits above grade shall be separated from the portion below grade by construction having at least a 1 h fire resistance rating, with ¾ h self-closing doors opening in the direction of exit travel from the floors below grade (C26-602.4).

A maximum of 50 percent of the required number of vertical exits is permitted to discharge through a single exit passageway (C26-604.3).

One hundred percent of the number of vertical exits may discharge through a street floor lobby if egress is provided in two different directions from discharge points to open exterior spaces remote from each other (C26-604.3(h)(1)).

The clear width of an exit passageway serving two or more vertical exits shall be equal to 75 percent of the width of all vertical exits it serves (C26-604.3(b)).

The width of street floor lobbies serving as exit passageways shall be increased to accommodate the occupant load of all communicating spaces on the lobby floor that exit through them (C26-604.3(h)(2)).

No openings other than exit doors are permitted in exit passageways (C26-604.3(f)).

Openings between street floor lobbies serving as exit passageways and elevators or communicating spaces and show windows protected in accordance with Section C26-604.3(h)(3) are permitted.

Street floor lobbies serving as exit passageways may be occupied by newsstands, candy and tobacco stands, information booths or similar occupancies if constructed of noncombustible materials, occupying not more than 5 percent of the net lobby floor area, and if not reducing the required clear width at any point (C26-604.3(h)(4)).

Horizontal and Supplemental Vertical Exits (C26-604.5 to C26-604.7):

1. The occupant load capacity for vertical exits may be reduced by 50 percent when one area of refuge is provided and by 66 percent when two or more areas of refuge are provided (C26-603.3).

2. At least 3 ft^2 per person of clear public space, or space occupied by the same tenant or owner, shall be provided within the area of refuge for the occupant load received in addition to its own occupant load (C26-604.5(b)).

3. Each area of refuge shall be provided with at least one vertical exit and when located above the 11th floor, the vertical exit should be supplemented by at least one elevator (C26-604.5(c)).

4. Access to an area of refuge, on the same floor, through a horizontal exit, may consist of doors, balconies, bridges, and tunnels (C26-604.6):

    a. Doors must swing in the direction of exit travel and be self-closing having a fire resistance rating of 1½ h. Where areas of refuge are provided on both sides of a horizontal exit, two door openings shall be provided, each swinging in opposite directions (C26-604.6(b)).

    b. Balconies, bridges and tunnels serving as horizontal exits shall comply with Section C26-604.6(c).

5. Access to an area of refuge on a floor nearer to the street, through a supplemental vertical exit, may consist of enclosed interior stairs, ramps, or escalators (C26-604.7):

    a. Supplemental vertical exits shall comply with the requirements for interior stairs, and serve no other purpose than to connect a floor area with an area of refuge with no openings in the enclosure other than exit doors (C26-604.7).

    b. Every supplemental vertical exit shall have a sign at the entrance stating EXIT TO AREA OF REFUGE ON _____ FLOOR (C26-604.7).

15.3 EXIT WIDTH AND CAPACITY

Occupant load – Calculated based on the net floor area in square feet divided by the occupant load factor (square foot per person) or the actual number of occupants for whom each occupied space is designed, whichever is greater (C26-601.2):

1. Non-simultaneous Occupancy – The occupant load of toilets, locker rooms, meeting rooms, storage rooms, employee cafeterias, and similar rooms or spaces that are not occupied at the same time as other rooms or spaces on the same floor may be omitted from the occupant load calculation of the floor on which they are located (C26-601.2(c)).

2. The occupant load of any space shall include the occupant load of all spaces that discharge through it in order to gain access to an exit (C26-601.2).

Occupancy	**Occupant Load Factor**
Business (offices)	100
Conference rooms (tables)	12
Conference rooms (chairs)	10
Dining spaces	12
Mercantile:	
1st floor/basement	25
All other floors	50
Assembly (fixed seats)	No. of seats
Waiting space (standing)	4
Garages/parking	250
Storage rooms	200
Mechanical rooms	200

Where vertical exits serve more than one floor, only the occupant load of each floor considered individually is used in computing the required capacity of exits at that floor, except where one floor is used by another as a means of egress (C26-601.1).

Exit capacity (width) shall not decrease in the direction of exit travel (C26-604.8).

The width of each means of egress component shall be that computed using the appropriate egress unit factor but not less than the minimum width prescribed for the component (C26-601.1, C26-601.3):

1. Where computations give fractional results, the next larger integral number of egress units or integral number plus ½ shall be used (C26-601.3).

2. A fraction less than ½ may be neglected when constituting less than 10 percent of the total required number of egress units.

When a floor area has access to areas of refuge that comply with the requirements of section C26-604.5, the number of persons for whom vertical exits are to be provided may be reduced to 50 percent of the occupant load of the floor area when one area of refuge is provided, and may be reduce to 33 1/3 percent of the floor area when two areas of refuge are provided (C26-603.3).

Egress capacity factors – capacity per egress unit (C26-601.1, C26-601.3):

1. One unit of egress width is equal to 22 in.

2. Doors to outdoors at grade:

    a. Occupancy Group B (Storage) – 75 persons per unit

    b. Occupancy Groups C (Mercantile), E (Business), and F (Assembly) – 100 persons per unit

3. Other exit and corridor doors:

    a. Occupancy Group B (Storage) – 60 persons per unit

    b. Occupancy Group C (Mercantile), E (Business), and F (Assembly) – 80 persons per unit

4. Stairs and escalators:

    a. Occupancy Group B (Storage) – 45 persons per unit

    b. Occupancy Groups C (Mercantile), E (Business), and F (Assembly) – 60 persons per unit

5. Ramps, corridors, exit passageways, horizontal exits:

    a. Occupancy Group B (Storage) – 75 persons per unit

    b. Occupancy Groups C (Mercantile), E (Business), and F (Assembly) – 100 persons per unit

    c. When ramp slope exceeds 1 in 10, the capacity shall be reduced by 25 percent (Table 6–1 note b).

Where a door is divided by mullions into two or more door openings, each opening should be measured separately in computing the number of egress units (Table 6–1 note m).

15.4 DOORS

Minimum nominal width shall be 32 in. except for corridor and exit door openings which shall be 36 in. (C26-604.4(e)):

1. Door jambs or stops and the door thickness when open shall not reduce the required width by more than 3 in. for each 22 in. of width (C26-604.4(e)).

2. In all cases where a door opening is divided by mullions into two or more door openings, the minimum nominal width of each such opening shall be 32 in. (C26-604.4(c)).

Maximum width of leaf (C26-604.4(e)) shall be 48 in.

Minimum height (C26-604.4(f)) shall be 6 ft 8 in.

Door jambs, stops, sills, and closers should not reduce the clear opening to less than 6 ft 6 in. (C26-604.4(f)).

The floor on both sides of all exit and corridor doors shall be substantially level and have the same elevation for a distance at least equal to the width of the leaf (C26-604.4(h)).

Where doors lead out of a building, the floor level inside may be 7½ in. higher than the level outside (C26-604.4(h)).

Exit doors, corridor doors serving high hazard occupancy Group A spaces, and corridor doors from rooms required to have more than one door shall swing in the direction of egress (C26-604.4(g)).

Vertically sliding doors, rolling shutters, and folding doors shall not be used as exit doors or as corridor doors (C26-604.4(d)).

Revolving doors designed and constructed in accordance with Section C26-604.4(m) are permitted to be used as exits except that revolving doors shall not be used as interior exit access doors, at the foot of stairs, or at the head of basement stairs (C26-604.4(d)).

Turnstiles designed and constructed in accordance with Section C26-604.4(n) may also be permitted.

Power operated or power assisted manually operated doors may be used as exit or corridor doors provided they remain closed in case of power failure and are manually operable. To be credited as a required exit, power operated doors must swing in the direction of exit travel (C26-604.4(l)).

Exit doors and corridor doors shall normally be kept in the closed position (C26-604.4(i)).

Latch bolts shall be provided on all exit doors and corridor doors to hold them in a closed position against the pressure of expanding gases (C26-604.4(j)(1)(c)).

Obstruction of means of egress during door opening:

1. Doors providing access to stairways or ramps shall not block stairs/ramps or stair landings or reduce the width of landings/stairs/ramps to less than 75 percent of the required width or to less than the width of the door opening on them (C26-604.8(g), C26-604.10(c)(4)).

2. No door shall swing over the sloping portion of a ramp (C26-604.8(c)(4)).

Exit and corridor doors and doors providing access to areas of refuge shall be readily openable at all times from the side from which egress is made without the use of a key (C26-604.4(j)(1)(a), C26-604.5(d)):

1. Locks may be used in places where extra safeguards are required (banks, museums, etc.), subject to approval of the commissioner, provided the locks are equipped with electrical release devices for remote control in case of emergency (C26-604.4(j)(1)(a)(2)).

2. Doors opening into interior enclosed stairs shall not be locked from either side except that doors may be locked to prevent access to the stair from the outside at the street floor (C26-604.4(j)(1)(b).

15.5 EXIT ACCESS

Minimum clear width of corridors:

1. Occupancy Groups B (Storage), C (Mercantile) – 36 in.

2. Occupancy Groups E (Business), F (Assembly) – 44 in.

The maximum length of exit access travel shall not exceed the following limits, measured from the most remote point in an area, to the center of an exit door. Travel distance shall be measured along the natural and unobstructed path of travel. Where the path of travel is over an access stair, it shall be measured along an inclined straight line through the center of the outer edge of each tread.

Occupancy	Distance (Feet)[42]
B-1 (Storage)	150
B-2 (Storage)	175
B-2 (Parking Garage)	150
C (Mercantile)	200
E (Business)	300
F (Assembly < 75 persons)	200

[42] Distances given are for sprinklered conditions (Table 6–1).

The maximum dead-end distance shall not exceed the following limits:

Occupancy	Distance (Feet)[43]
B-1 (Storage)	50
B-2 (Storage)	NR
C (Mercantile)	50
E (Business)	50
F (Assembly)	30

Exterior corridors designed and constructed in accordance with Section C26-604.2(f) may be used as a means of egress.

15.6 STAIRWAYS

Minimum clear width shall be at least 44 in. (C26-604.8(b)):

1. The width of stairs shall be the clear width between walls, grilles, guard, or newel posts. Stair stringer projections which do not exceed two in. on each side and handrail projections of 3½ in. are permitted.

2. Vertical exits in public garages may be 36 in. wide.

3. The minimum width of landings and platforms should be at least the required width of the stairway. On a straight run stair, landing and platform widths need not be more than 44 in.

Minimum headroom shall be at least 7 ft (C26-604.8(c)).

Maximum height between landings shall be 12 ft (C26-604.8(d)).

Treads and risers (C26-604.8(e), Table 6-4):

1. Maximum riser height – 7¾ in.

   a. Occupancy Group F (Assembly) – 7½ in.

   b. All others – 7¾ in.

2. Minimum tread depth – 9½ in. plus nosing

[43] Distances given are for unsprinklered conditions. When a corridor is completely enclosed in 2 h fire resistance rated construction with ½ h fire rated doors, the permissible length of dead ends may be increased by 100 percent (C26-604.2(d)).

3. The sum of two risers plus one tread exclusive of the nosing shall not be less than 24 nor more than 25½ in.

4. Stair riser and tread dimensions shall be constant in any flight of stairs from story to story.

Curving or skewed stairs that conform to Section C26-604.8(e)(4) are permitted to be used as exits.

Where exit stairways serving floors above grade continue in the same enclosure to serve floors below grade, the above and below grade portions shall be separated by 1 h fire resistance rated construction.

Stair identification signs shall be posted on the occupancy side of the stair door indicating the letter designation of the stair.

In buildings or in building sections more than three stories or 40 ft high with roofs having a slope of less than 20 degrees, access to the roof shall be provided by at least one interior stair. Access to set back roof areas may be through a door or window opening to the roof.

No openings of any kind are permitted into stair enclosures other than windows, fire department access panels and exit doors.

Exterior stairs designed and constructed in accordance with Section C26-604.9 may be used as exits in lieu of interior stairs.

No exterior stair shall exceed 75 ft or six stories in height.

Escalators designed and constructed in accordance with Section C26-604.11 may be used as exits in lieu of interior stairs.

15.7 RAMPS

The minimum clear width of exit ramps is 44 in. (C26-604.10, C26-604.8(b)).

Level platforms or landings at least as wide as the ramp shall be provided at the top and bottom of all ramps and at intermediate levels as necessary:

1. Level platforms shall be provided on each side of door openings into or from ramps.

2. Platforms shall be at least 3 ft wide, 5 ft when a door swings onto the platform.

Minimum headroom shall be 6 ft 8 in.

Changes in direction of travel shall be made only at landings (or platforms) (C26-604.10(c)).

Ramps with a slope not greater than 1 in 12 at any place may be curved.

Ramps shall not have a slope steeper than 1 in 8 and sloping portions shall be at least 3 ft but not more than 30 ft long between platforms or landings.

Level and ramped moving walkways designed and constructed in accordance with Section C26-604.12 may be used as exits.

15.8 HANDRAILS AND GUARDRAILS

Continuous handrails are required on both sides of all stairs, and all ramps with a slope exceeding 1 in 12:

1. Stairs less than 44 in. wide may have a handrail on one side only.
2. Intermediate handrails shall be provided to divide stairs more than 88 in. wide into widths that maintain nominal multiples of 22 in. and widths not greater than 88 in. nor less than 44 in.
3. Handrail height shall be 30 to 34 in. measured vertically above the nosing of treads.
4. Handrail ends shall be returned to walls and posts when terminated.
5. Handrails shall provide a finger clearance of 1½ in. and shall project not more than 3½ in. into the required stair width.

Stair landings and platforms shall be enclosed on sides by walls, grilles, or guards at least 3 ft height.

15.9 EXIT SIGNS

In all buildings, the location of every exit on every floor shall be clearly indicated by approved EXIT signs (C26-606.1).

EXIT signs shall be placed at an angle with the exit opening if such placement is required for the signs to serve their purpose.

In areas where the location of the exit may not be readily visible or understood (including long corridors and open floor areas), directional signs shall be provided to serve as guides from all portions of the corridor or floor.

The size, color and illumination of EXIT signs shall conform to Section C26-606.3. Directional signs shall conform to Section C26-606.4.

All EXIT signs shall be illuminated at all times when the building is occupied.

Where a total of more than four signs (exit and/or directional) are required, all EXIT signs shall be connected to circuits that are separate from the general lighting and power circuits. These circuits shall be taken off ahead of the main switch or connected to an emergency lighting power source when such source is provided.

Any door, passageway, stair, or other means of communication that is not an exit shall be so identified with a NOT AN EXIT sign and a sign indicating its use or purpose or a directional exit sign shall be provided.

15.10 MEANS OF EGRESS LIGHTING

Corridors and exits shall be equipped with artificial lighting facilities to provide at least 2 ft candle intensity floor lighting continuously during the time that conditions of occupancy of the building require that the exits be available (C26-605.1(a)).

Lighting shall be provided to illuminate changes in direction in and intersections of corridors, balconies, exit passageways, stairs, ramps, escalators, bridges, tunnels, landings, and platforms.

Illumination shall be arranged so that failure of any one light does not leave any area in darkness.

Where a total of more than four lights are required, exit lighting shall be connected to an emergency power source or to approved storage battery equipment (C26-605.2(a)).

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Chapter 16
FIRE SUPPRESSION

16.1 AUTOMATIC SPRINKLER PROTECTION

Automatic sprinkler protection shall be designed and installed in accordance with Section C26-1703.1 and Reference Standard (RS) 17-2 in the following areas:

1. Spaces in group B-1 > 500 ft^2.
2. Spaces in group B-1 < 500 ft^2 when required by the commissioner.
3. Spaces in group B-2 > 5,000 ft^2 or 75 ft in height.
4. Spaces in high-rise buildings classified as mercantile occupancy group C > 7,500 ft^2 in floor area or with an unenclosed stair or escalator between any two or more floors.
5. Showroom spaces exceeding 7,500 ft^2 in area located more than 40 ft above curb level in new and existing buildings classified in occupancy group E, 100 ft or more in height having air-conditioning and/or mechanical ventilation systems that serve more than the floor in which the equipment is located.
6. Regardless of occupancy, any story above grade and the 1st story below grade without required ventilation:
    a. All other stories below grade.
    b. Sprinklers may be omitted in toilets, shower rooms, stair, and mechanical and electrical rooms.
7. Catering establishments and banquet halls with an occupancy load of 300 or more persons.
8. Spaces in occupancy group F-4 located more than 75 ft above curb level.
9. Notwithstanding the requirement of other sections, new high rise buildings in occupancy group E (Business).

A wet-pipe sprinkler system should be provided throughout all areas requiring automatic sprinkler protection (C26-1703.13). In areas subject to freezing the sprinkler system shall be protected (insulation, heat trace, antifreeze) or a dry-pipe system shall be provided (C26-1703.13).

A sprinkler alarm system shall be provided in accordance with RS 17-2 and RS 17-3 or in accordance with RS 17-3A or RS 17-3B if a class E or modified class E fire alarm system is provided (C26-1703.4).

A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or section.

16.2 STANDPIPES

Wet standpipes designed and installed in accordance with Section C26-1702.1 and RS 17-1 shall be provided (C26-1702.1(a)(1)).

The number and location of standpipes shall be such that every point of every floor can be reached by a 20 ft stream from a nozzle attached to not more than 125 ft of hose connected to a riser outlet valve (C26-1702.4):

1. Standpipe risers and 2½ in. hose valves shall be located within stairway enclosures (C26-1702.5(a)).

2. When stairway enclosures are not available within the 125 plus 20 ft distance (145 ft total), risers and valves shall be located as near to the enclosure as practicable (C26-1702.5(a)).

The highest riser shall be extended above the roof with a 3-way manifold with 2½ in. hose valves (C26-1702.11(a)(2)).

A 2½ in. hose outlet shall be provided at each standpipe riser on each floor served, and on the entrance floor above the riser control valve, located between 5 and 6 ft above the landing or floor (C26-1702.11(a)(1)).

Hose stations shall be located at the standpipe risers, either inside or adjacent to the entrance of stairway enclosures (C26-1702.11(b)):

1. Hose stations shall be located to satisfy the 125 plus 20 ft (145 ft total) requirement (C26-1702.11(b)(1)).

2. Hose shall be (C26-1702.11(c)):

   a. 1½ in. unlined (flax-line) linen hose in Groups C, E, and F.

   b. 2½ in. (unlined) in Group B.

3. Auxiliary hose stations equipped with 1½ inch (unlined) hose are permitted in Groups C, E, and F (C26-1702.11(c)(4), C26-1702.11(d)).

Standpipe systems that include more than one riser shall have all risers cross-connected at, or below, the street entrance floor level (C26-1702.10(a)).

Standpipe systems having more than one zone shall be arranged such that the risers supplied from each zone are cross-connected below, or in the story of the lowest hose outlets from the water source in each zone (C26-1702.10(b)).

Standpipe risers shall be at least 4 in. in diameter where the riser height is 150 ft or less from the highest hose outlet to the level of the entrance floor, 6 in. in diameter where greater than 150 ft (C26-1702.7, Table 17–1).

16.3 WATER SUPPLY

Standpipe systems shall have a primary water supply available at all times to every hose outlet or made available automatically when the hose valve at any outlet is opened (C26-1702.14).

Combinations of two or more of the following sources shall serve as the primary water supply (C26-1702.14(b)):

1. Direct connection to city water system.
2. Direct connection to a private yard main.
3. Gravity tank(s).
4. Pressure tank(s).
5. Automatic fire pump (C26-1702.14(b)(5)):
    a. In buildings higher than 300 ft, the automatic fire pump shall be used only for the lower 300 ft.
    b. Zones above 300 ft shall be supplied by either a gravity or pressure tank.
6. An additional standpipe system water supply shall be provided for standpipes in buildings over 300 ft high (C26-1702.15(a)). The primary water supply to the standpipe system should be supplemented by one or more manually operated fire pumps (C26-1702.15(a)).

At least one of the following automatic sources of water supply shall be provided for sprinklers (C26-1703.8(a):

1. Gravity tank(s).
2. Pressure tank(s).
3. Automatic fire pump.
4. Direct connection to public water system.

Domestic water supply may be used to supply cooling tower sprinklers and sprinklers installed in buildings classified in Occupancy Group E (Business) in accordance with Section C26-1703.9(e) (C26-1703.9 (c) and (d)).

Auxiliary sources of water supply for sprinkler systems may include a manually actuated fire pump or siamese connection (C26-1703.8(b)).

Combined Water Supplies:

1. Fire pumps may simultaneously serve as the required auxiliary water supply for standpipe and sprinkler systems in accordance with Section C26-1702.15(d).

2. Tanks used to provide the required primary water supply to a standpipe system may also be used as a supply for an automatic sprinkler system (C26-1703.8(c)).

One standpipe system and one sprinkler system siamese connection shall be provided for each 300 ft of exterior building wall or fraction thereof facing each street or public space (C26-1702.9(a), C26-1703.6(a)(1)):

1. Modifications based on street frontage as permitted by Sections C26-1702.9(b)-(f).

2. Each siamese connection shall be connected to a riser or to a cross connection connecting other siamese connections or risers (C26-1702.10(f)).

3. In below grade sprinkler systems for garage occupancies, a sprinkler siamese connection shall be provided within 50 ft of every exit or entrance used by motor vehicles (C26-1703.6(a)(2)).

4. Siamese connections for partial sprinkler systems shall be in accordance with Section C26-1703.6(a)(3).

Chapter 17
FIRE DETECTION AND ALARM

17.1 FIRE ALARM SYSTEM

New buildings classified in occupancy group E 75 ft or more in height and existing buildings in occupancy group E 100 or more ft in height are required to be provided with a Class E (or modified Class E) fire alarm and communication system including loud speakers, two-way voice, and a fire command station. (C26-1704.1(a)(9), C26-1704.4(g)(h), C26-1704.5(f)(g), C26-1704.8)

A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or section (C26-1703.4).

A local water flow alarm unit shall be provided (outdoor water motor or electric alarm gongs) where there is no watchman with watch service (Reference Standard [RS] 17-2 Sec. 3721).

Central station water flow alarm service is desirable, but does not waive the local alarm requirement (RS 17-2 Sec. 3721).

17.2 SMOKE AND HEAT DETECTOR LOCATIONS

Heating, Ventilating, and Air Conditioning (HVAC) Systems (C26-1300.7(a), RS 13-1):

1. In HVAC systems over 2,000 cfm capacity, approved smoke detectors shall be provided for automatic fan shut-down in (RS 13-1 Sec. 4-3 and 4-4):

    a. The main supply duct on the downstream side of the filters.

    b. The return air stream, prior to exhausting from the building or being diluted by outside air.

        Exception 1: The smoke detector in the return air stream may be omitted in systems of less than 15,000 cfm capacity.

        Exception 2: Both detectors may be omitted provided that the system is less than 15,000 cfm capacity, the entire system is within the space served and such space is protected by an area smoke detection system.

2. In HVAC systems serving more than the floor on which the equipment is located, an approved product of combustion ionization detecting device or a combination of an approved smoke detecting device and an approved fixed temperature thermostatic device shall be located at the return shaft at each floor and so located as to monitor each inlet to the air return shaft (RS 13-1 Sec. 4-3.2(c)).

3. In HVAC systems utilizing recirculated air, smoke detectors shall be provided for automatic fan shut-down when any of the following conditions exists (RS 13-1 Sec. 4-5.4):

    a. System supplies an exit passageway, or a space leading from elevators to a street or to the exterior.

    b. System supplies spaces on more than one story or spaces in different fire areas in the same story.

    c. Where the area of a building or space served is over 15,000 ft^2 in mercantile or indoor assembly occupancies.

    d. Where there is a duct opening in a required 2 h fire resistance rated interior fire division.

    e. Where a duct passes through a firewall.

    f. Where a corridor is used as a plenum.

Specific occupancy requirements:

1. In a Class E fire alarm system, ceiling mounted ionization smoke detectors or combination smoke/heat detectors shall be installed at each elevator landing immediately above a call button (C26-1704.5(f)(8)). A building equipped throughout with an automatic sprinkler system including a water flow alarm shall be exempt from the installation of the detectors provided the water flow alarm has the same effect mentioned below (C26-1704.5(f)(10)).

2. The activation of a smoke detector in any elevator lobby shall only annunciate at the fire command station. The activation of both smoke detectors in any elevator lobby shall cause selected elevators to return non-stop to the designated level (RS 18-1, Rule 211.3b(6)(a and b)).

3. Activation of an elevator landing detector shall (C26-1704.5(f)(8)):

    a. Sound continuously throughout the floor of alarm and floor above.

    b. Sound fire alarm signal at the fire command station, mechanical control center and regularly assigned location of the fire safety director.

    c. Operate the information display system.

    d. Stop the air supply into and air return from the floor where activated by approved remote control reversible fire shutters or by automatically shutting down supply and return air fans.

    e. Activate air exhaust fans and dampers in smoke shafts and/or pressurizing fans in stair enclosures.

4. In addition to the smoke detector requirement, in a building equipped throughout with an automatic sprinkler system, a waterflow alarm when activated shall initiate Phase I emergency recall operation (RS 18-1, Rule 211.3).

17.3 MANUAL FIRE ALARM BOXES

The boxes shall be installed in accordance with NFPA 72.

At least one fire alarm sending station shall be provided in each story located in each path of escape with additional stations installed so that no point on any floor is more than 200 ft from the nearest station (RS 17-3A, Sec. 7(a)).

Operation of a manual station shall automatically transmit a fire alarm signal to the fire department via a central station and sound an alarm continuously on the floor where activated and the floor above (C26-1704.5(f)(4)).

Fire alarm (Class E) sending stations shall be painted red with a diagonal white stripe painted or applied to sending stations which transmit a fire alarm signal to the fire department via a central station (C26-1704.6(e)).

17.4 AUDIBLE/VISUAL ALARM NOTIFICATION APPLIANCES

In a Class E fire alarm system, loudspeakers capable of being operated from the fire command station should be provided on each floor, and in each elevator and stair enclosure (C26-1704.8(a)).

Loudspeakers shall be located so that their operation will be heard clearly above ambient noise (C26-1704.5(f)(5)).

The loudspeaker amplifier system shall be so designed and installed that approximately 50 percent of the system shall remain operable for the transmission and audibility of signal and intelligibility of voice communication over the loudspeaker system throughout the building, in the event the other 50 percent becomes inoperable (C26-1704.5(f)(7)).

Recessed speakers shall be located not more than 10 ft from the entrance to each required exit (RS 17-3A, Sec. 8(b)).

17.5 COMMUNICATION SYSTEMS

In every building more than 300 ft high, a telephone and signaling system shall be provided for fire department use in operating the standpipe system (C26-1702.21, C26-1704.7(a)).

Standpipe Telephone System:

1. System shall permit communication by permanent telephones in the following locations (C26-1704.7(b)):

    a. Pump rooms.

    b. Entrance floor.

    c. Gravity tank rooms.

d. Each floor near main standpipe riser.

2. The system shall be a selective ringing, common talking system supplied by a 24-volt direct current power source (C26-1704.7(b)).

3. Permanent wall telephones shall be provided with 6 inch gongs except in the pump room where a loud speaking receiver should be provided (C26-1704.7(c)).

4. The telephones in the pump room shall be equipped with a loudspeaking receiver so that a voice can be distinctly heard at a distance of at least 15 ft from the receiver.

5. Where portable phones are used, jacks protected by break-glass boxes shall be provided (C26-1704.7(c)):

   a. At least three portable phones shall be provided for each standpipe installation, kept in a dedicated, locked cabinet located in the main hall of the entrance floor (C26-1704.7(d)).

   b. A pilot light shall be provided over the cabinet to indicate if the system is in use or a receiver is off the hook (C26-1704.7(e)).

Standpipe Signaling Devices:

1. Manual, individually coded sending stations shall be located in the main corridor of the building arranged to transmit a signal to alarm sounding devices (C26-1704.7(f)(1)). System shall be installed in accordance with RS 17-3 (C26-1704.7(f), C26-1704.8).

2. An 8 inch gong shall be provided in the pump rooms and in elevator shafts at intervals not exceeding 10 floors (C26-1704.7(f)(1)).

3. Adjacent to each telephone station and near the main standpipe riser, a closed circuit strap key connected in series with the box circuit of the signal sending station shall be provided (C26-1704.7(f)(2)).

In a Class E fire alarm signal system, the standpipe fire line telephone and signaling system may be combined with the fire alarm system provided (C26-1704.7(g)):

1. The alarms and two-way voice communication with the fire command station include the pump and gravity tank rooms.

2. A designated floor station of the Class E system is located at or near the main standpipe riser on every floor.

A two-way communication capability shall be provided between the fire command station and the following locations (C26-1704.8(a)(2)):

1. A designated floor warden station on each floor.

2. Mechanical control center.

3. Elevators.

4. Air-handling control rooms.

5. Elevator machine rooms.

A floor warden station shall be located between required stairways, vertical exits or other exits (RS 17-3B 7.b):

1. System shall include a telephone type handset at the floor warden station with integral signaling to the fire command station.

2. Warden stations may be part the speaker system.

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Chapter 18
ELEVATORS AND HOISTWAYS

18.1 GENERAL

Elevators or escalators shall be provided in accordance with Section C26-1800.1 and RS 18-1 in all new buildings exceeding four stories in height (C26-604.1(a), C26-1800.6(d)):

1. When Areas of Refuge are provided above the 11th floor of a building, they shall be served by at least one elevator (C26-604.5(c)).

2. Escalators may be used as exits in lieu of interior stairs (C26-604.11 and C26-1800.6(g)).

In every building exceeding 175 ft in height, at least one elevator shall be kept available for immediate use by the fire department during all hours (C26-1702.22, C26-1800.8).

In buildings exceeding 150 ft in height, there shall be an operator available at all times (C26-1800.8).

Automatic passenger elevators shall be equipped with emergency controls for fire department use (Reference Standard [RS] 18-1 Rule 210.13):

1. A two-position keyed switch shall be provided at a main floor of each elevator or group of elevators for recall to the main floor in accordance with RS 18-1 Rule 210.13.a.

2. A keyed switch shall be provided in or adjacent to an operating panel of each elevator to initiate emergency service in accordance with RS 18-1 Rule 210.13.b.

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Chapter 19
EMERGENCY, ELECTRICAL, AND STANDBY POWER SYSTEMS

19.1 EMERGENCY POWER SYSTEMS

An emergency power system shall be provided in high-rise buildings in occupancy group E and have capacity to operate equipment such as (C26-610.1, C26-610.3):

1. Fire pumps.
2. At least three elevators at one time, with manual transfer to other elevators.
3. Alarm systems.
4. Communications systems.
5. Emergency lighting, if battery packs are not available.
6. Ventilating systems used for smoke venting or control.
7. Stair pressurization.

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Chapter 20
SPECIAL FEATURES

20.1 SMOKE AND HEAT VENTING

Elevator and dumbwaiter shafts shall be vented in accordance with Reference Standard (RS) 18-1.

Other closed shafts shall be vented as follows:

1. All closed shafts having an area exceeding 4 ft^2 shall be provided with a smoke vent having an area of at least 3½ percent of the maximum shaft area at any floor but not less than ½ ft^2 (C26-504.6(d)).

2. Smoke vents may be windows, louvers, skylights, vent ducts, or similar devices (C26-504.6(d)).

3. Vent ducts shall be enclosed by construction having the same fire resistance rating as required for the shaft and extend vertically, diagonally, or horizontally in accordance with Sections C26-504.6(d)(1 and 2).

4. Of the total required vent area for shafts at least one-third shall be clear to the outdoors either in the form of fixed louvers, ridge vents, or hooded or goose-necked openings (C26-504.6(e)).

5. As an alternate, skylights or trap doors may be used arranged to open automatically by fusible link or other mechanical device when subjected to 160 °F fixed temperature or 15 °F to 20 °F per min temperature rise (C26-504.6(e)).

6. The remaining portion of the required vent area may be a window or skylight glazed with plain glass not more than 1/8 in. thick or slow burning plastic (C26-504.6(e)).

Machine Rooms:

1. Any compartment containing machinery that communicates with a shaft enclosure shall comply with all requirements for shafts (C26-504.6(f)).

2. The required louver or glazing shall not be located in any door leading into such compartment (C26-504.6(f)).

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Chapter 21
INSPECTIONS

21.1 INSPECTION REQUIREMENTS

The following requirements shall apply to the inspection of all materials which, in their use, are regulated by the provisions of the code:

1. Controlled inspection – All such materials which are designated for "controlled inspection" under the provisions of the code shall be inspected and/or tested to verify compliance with code requirements. Unless otherwise provided by code provisions, all required inspection and test of materials designated for "controlled inspection" shall be made and witnessed by or under the direct supervision of an architect or engineer retained by or on behalf of the owner or lessee, who shall be, or shall be acceptable to, the architect or engineer who prepared or supervised the preparation of the plans; and the architect or engineer by whom, or under whose direct supervision, the required inspections and tests are made and witnessed shall file with the department signed copies of all required inspection and test reports, together with his signed statement that the material and its use or incorporation into the work comply with code requirements, unless the filing of such reports and statements is specifically waived by code provisions (C26-106.3(a)).

2. Semi-controlled inspection – All such materials that are not designated for controlled inspection under the provisions of the code shall be subject to semi-controlled inspection and, as such, shall be inspected and/or tested to verify compliance with code requirements by the person superintending the use of the material or its incorporation into the work, except that all required inspections and tests may, at the option of the owner or lessee, be made and witnessed by or under the direct supervision of any architect or engineer retained by or on behalf of the owner or lessee, who shall be, or shall be acceptable to, the architect or engineer who prepared or supervised the preparation of the plans. The person superintending the use of the material or its incorporation into the work, or the architect or engineer by or under whose direct supervision the required inspections and tests are made and witnessed, as the case may be, shall file with the department signed copies of all required inspection and test reports, together with his signed statement that the material and its use or incorporation into the work comply with code requirements, unless the filing of such reports and statement is specifically waived by code provisions (C26-106.3(b)).

3. Off-site inspection – In all cases where code provisions require that the inspection and/or test of materials be made off-site, or prior to actual use or incorporation into the work, the inspector shall mark or cause to be marked for identification all units (or packages of units) of the material inspected; and the reported results of such inspection shall state that the material was so marked for identification (C26-106.3(c)).

21.2 MATERIALS REQUIRING INSPECTION

The installation of all required sprayed fire-resistive material of structural members except those encased in concrete shall be subject to the controlled inspection requirements (C26-502.2(f)).

The installation of all required firestopping shall be subject to the controlled inspection requirements (C26-504.7(h)).

Chapter 22
REFERENCES

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SECTION III
POST-CONSTRUCTION FIRE PROTECTION AND LIFE SAFETY PROVISIONS FOR WORLD TRADE CENTER 1, 2, AND 7

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EXECUTIVE SUMMARY

As part of the analysis of building and fire codes and standards of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation, this report supports the effort to document the change in building code regulations that occurred after the construction of WTC 1, 2, and 7. The purpose of this report is to summarize the applicable fire protection (both passive and active) and life safety provisions that were adopted after the design and construction of the WTC 1, 2, and 7.

The WTC complex was a network of buildings constructed and maintained under the jurisdiction of the Port Authority of New York and New Jersey (PANYNJ). Facilities of the PANYNJ are not subject to the requirements of the local building codes, although the PANYNJ voluntarily followed the New York City codes where applicable. In accordance with the instructions issued by the Port Authority at the start of the WTC project, construction drawings for the WTC were to conform to the requirements of the Building Code of the City of New York (BCNYC).

The City of New York does not use a national model building code. Since the first published model building code in the United States in 1905, municipalities have been given the opportunity to adopt a model building code(s) or develop their own code(s). New York City has taken the approach to develop their own building code while incorporating technical and installation requirements by referencing nationally recognized standards (National Fire Protection Association, ASTM International, American National Standards Institute, etc.) and New York City developed reference standards (denoted by RS).

As time passed and experience was gained, the provisions of the BCNYC changed. Depending on the requirements of the changes in the BCNYC, new buildings (and some existing buildings) were required to meet the revised design and construction provisions. Generally, changes to the building code effect new buildings and only affect existing buildings when a major alteration or a change in occupancy occurs. However, some of the provisions of the BCNYC were made retroactive, thus, effecting existing buildings. The revised provisions in the BCNYC that were applicable to WTC 1, 2, and 7 are summarized in this report.

Determination of the applicable building provisions was a multi-step task. First, documentation, such as drawings, memorandums and New York City building regulations, were analyzed to identify the initial construction provisions at the times of construction of WTC 1, 2, and 7. Second, New York City building regulations, published since the times of construction, were analyzed to identify the new and amended building provisions. Third, the building provisions were analyzed to determine their applicability to the building characteristics of WTC 1, 2, and 7.

The revised provisions of the building code affect WTC 1 and WTC 2 differently from WTC 7. All of the requirements that were adopted by the City of New York subsequent to the 1968 edition of the Building Code should have been implemented in the original design of WTC 7 since the local laws containing the revised construction provisions all predate the time of construction (1985) of WTC 7. However, all of the code provisions that were passed subsequent to the 1968 edition of the Building Code were not required to be implemented in WTC 1 and WTC 2 since the local laws came into effect after the time of

construction (1971) of WTC 1 and WTC 2. Only the applicable retroactive provisions were required to be implemented.

The applicable local laws that provided changes to fire protection and life safety provisions in the BCNYC are as follows:

- Local Law No. 5, Fire Safety Requirements and Controls (effective date immediately except as noted), January 18, 1973.
- Local Law No. 16, Local Laws of the City of New York for the Year 1984 (effective date immediately except as noted), March 27, 1984.
- Local Law No. 33, Local Laws of the City of New York for the Year 1978 (effective date immediately), October 6, 1978.
- Local Law No. 54, Local Laws of the City of New York for the Year 1970 (effective date immediately), November 17, 1970.
- Local Law No. 55, Local Laws of the City of New York for the Year 1976 (effective date immediately), November 1, 1976.
- Local Law No. 84, Fire Safety Pressurization Requirements in Certain Office Buildings (effective date immediately), December 13, 1979.
- Local Law No. 86, Dates for Compliance with the Local Laws Enacted for Fire Safety Requirements and Controls in Certain Buildings (effective date immediately), December 13, 1979.

The following is a summary of the post construction (retroactive) provisions that were required to be implemented in WTC 1 and WTC 2. These provisions should have been implemented in the initial construction of WTC 7.

- Compartmentation of floor areas creating areas of refuge, unless complete sprinkler protection is provided. The commissioner may waive the compartmentation provision and accept an alternative measure fulfilling the intent of the code. One-third of the total floor area must be in compliance by February 7, 1973, with at lest two-thirds of the total floor area in compliance by August 7, 1984. Full compliance must be provided by February 7, 1988.
- Stair and elevator signs are required to be provided for by October 1, 1985.
- Emergency lighting shall be provided with secondary power by April 1, 1987.
- Exit signs shall be provided with secondary power by April 1, 1987.
- Provide sprinklers for showroom spaces over 7,500 ft^2 in area and located more than 40 ft above curb level.

- Provide sprinklers for catering establishments and banquet halls with an occupant load of 300 or more persons.

- Provide sprinklers for spaces in occupancy group F-4 (Assembly) located more than 75 ft above curb level.

- Install a Class E or modified Class E fire alarm and communication system including loud speakers, two-way voice, manual fire alarm boxes and a fire command station.

- Provide the appropriate number of elevators ready for immediate use by the fire department.

- Provide a fire safety plan.

- Remove locks from elevator and hoistway doors, except elevators used exclusively for freight, by April 1, 1987.

- Provide at least one smoke shaft by which smoke and heat can be mechanically vented to the outdoors by September 13, 1982. In lieu of the smoke shaft, a stair pressurization system(s) can be installed in all interior enclosed stairs. Or, provide a sprinkler system throughout. One-third of the sprinkler system must be installed by December 13, 1981, with two-thirds of the system completed by December 13, 1982. Full compliance must be provided by December 13, 1983. The commissioner may extend the time requirements upon approval.

In addition to the retroactive provisions incorporated since the 1968 BCNYC, Local Laws added requirements for new construction that were applicable to the design and construction of WTC 7, but were not applicable to the design and construction of WTC 1 and WTC 2. These requirements are identified below:

- Class I-B, unsprinklered, occupancy group E (Business) was changed from allowing unlimited height and area to limiting Class I-B unsprinklered buildings to 75 ft in height with an unlimited area.

- All hollow spaces shall be firestopped or filled with noncombustible materials, where combustible trim and finish is permitted.

- Only wool carpet assemblies are permitted to be installed in lobby areas, exit passageways and convenient stairs.

- Flammability requirements of carpets and carpet assemblies were changed.

- Provisions for adequate means of egress in the opinion of the commissioner or fire protection as the commissioner shall direct. Provisions include:

  – Stair doors may be locked on the stair side above the street floor except that at intervals of four stories or less, the doors shall be openable from the stair side without the use of a key. Doors with automatic unlocking systems that are activated by the fire alarm system, are deemed as openable from the stair side.

- The minimum distance between vertical exits shall be the greater of 30 ft or one-third the maximum travel distance of the floor.
- New high-rise buildings in occupancy group E (Business) shall be sprinklered.
- An emergency power system shall be provided in all group E (Business) high-rise buildings.
- A smoke control system shall be provided for in all group E (Business) occupancies.
- A smoke purge system shall be provided for in all group E (Business) occupancies.
- All sprayed fire-resistive material shall be subject to the controlled inspection requirements of the BCNYC.

The PANYNJ and various consultants continuously evaluated the life safety and fire protection features of the WTC. Chapter 12 of this report contains a summary of how the local law provisions were complied with. Some of the local law provisions were complied with prior to the passage of the local law requirements. During the time of the 1975 WTC fire, the New York Board of Fire Underwriters stated, "The Fire Safety Program of the World Trade Center is an excellent one" and "In the overall, these towers may be considered as among the safest buildings in New York City" (refer to Appendix A in NIST NCSTAR 1-1H). However, the same report cites problem areas such as , "… fireproofing of the steel may be missing in places; … fire rating of shafts is just above minimum requirements; wiring ducts under the floor (as in many other buildings), have questionable fire resistance and construction hazards and deficiencies due to incomplete construction are still present."

Chapter 23
INTRODUCTION

The regulation of building construction results from the recognition that life safety is served by the best available knowledge and practice. As technology changes and serious incidents occur, such as fires, building codes are developed and revised. Model codes have been published throughout the United States since 1905 (Boring 1981). Referenced standards adopted by the codes provide a technical basis for implementation of the code requirements and provide detailed methods of testing, installation, and maintenance. Municipalities can either adopt a model building code(s) or develop their own code(s). Additionally, many municipalities throughout the United States adopt model building codes and amend the code as deemed necessary. New York City, however, has taken the approach to develop their own building code while providing technical support and installation requirements from a mixture of nationally recognized standards (National Fire Protection Association, ASTM International, American National Standards Institute, etc.) and New York City developed reference standards (denoted by RS).

The World Trade Center (WTC) complex was constructed under the jurisdiction of the Port Authority of New York and New Jersey (PANYNJ or Port Authority). Facilities of the PANYNJ are not technically subject to the requirements of the local building codes, although the PANYNJ voluntarily followed the New York City codes where applicable. In accordance with the instructions issued by the Port Authority at the start of the WTC project, construction drawings for the WTC were to conform to the requirements of the Building Code of the City of New York (BCNYC) (Solomon 1975).

New technology and serious incidents, such as fires, bring about the need for change in the provisions of the BCNYC. As the years pass, the building code becomes outdated and requires revisions. In the city of New York, local laws are passed to address the changes and are later incorporated in the BCNYC. The requirements in the local laws generally affect only new construction and major alteration projects. However, in some cases, requirements include retroactive provisions that are applicable to existing buildings within the effective date. The effective date of a local law is a crucial piece of information that will determine how a local law will affect a building.

WTC 1, 2, and 7 were affected differently by the local laws presented herein since the buildings were constructed under different editions of the BCNYC. WTC 1 and WTC 2 were constructed under the 1968 edition of the BCNYC. The 1968 edition of the BCNYC, including amendments to January 1, 1985, was used to provide the fire protection and life safety provisions during the design and construction phases (base building) of WTC 7. It is important to understand that all of the local laws in this report dated before the amended date above have already been included in the base building construction of WTC 7. In contrast, there are certain local laws in this report, with retroactive requirements, that are applicable to the base building of WTC 1 and WTC 2. Without an applicable retroactive effective date, existing conditions are permitted to remain, even if a new provision has changed the requirements of the BCNYC. However, when tenant modifications or major alterations to the base building are performed, the modification (or major alteration) is required to meet the most current provision at the time of installation.

The reference standards within the BCNYC have been dealt with differently throughout the years and are complex to summarize. Amendments, deletions, and additions to the reference standards of the BCNYC have been adopted through Local Laws, Board of Standards and Appeals calendar numbers, and Building Department amendments. As previously stated, reference standards within the BCNYC contain both nationally recognized standards and New York City developed reference standards. Due to the complex manner with which reference standards are dealt with in the BCNYC, a complete detail of the revised provisions within the BCNYC reference standards cannot be detailed in this report. Where a specific section of the New York City developed reference standard has been amended, deleted, or added, it shall be noted in this report. Otherwise, it is understood that the reference standard of the BCNYC refers to a nationally recognized standard and has merely been updated to a more recent edition of the national standard. Since nationally recognized standards do not contain retroactive effective dates, an updated edition of a nationally recognized standard would therefore only affect major renovations or tenant modifications.

Chapters 3 through 11 present a summary of the minimum requirements of the revised BCNYC provisions that have been added or amended by the Local Laws. Chapter 12 is a brief summary of how the revised provisions were implemented in WTC 1 and WTC 2.

Chapter 24
GENERAL

24.1 LOCAL LAWS WITH APPLICABLE FIRE PROTECTION/LIFE SAFETY PROVISIONS

1. Local Law No. 5, Fire Safety Requirements and Controls (effective date immediately except as noted), January 18, 1973.

2. Local Law No. 16, Local Laws of the City of New York for the Year 1984 (effective date immediately except as noted), March 27, 1984.

3. Local Law No. 33, Local Laws of the City of New York for the Year 1978 (effective date immediately), October 6, 1978.

4. Local Law No. 54, Local Laws of the City of New York for the Year 1970 (effective date immediately), November 17, 1970.

5. Local Law No. 55, Local Laws of the City of New York for the Year 1976 (effective date immediately), November 1, 1976.

6. Local Law No. 84, Fire Safety Pressurization Requirements in Certain Office Buildings (effective date immediately), December 13, 1979.

7. Local Law No. 86, Dates for Compliance with the Local Laws Enacted for Fire Safety Requirements and Controls in Certain Buildings (effective date immediately), December 13, 1979.

24.2 BUILDING SUMMARIES

Table 24–1. Building characteristics.

Building	Height	Number of Floors Above Grade	Footprint	Construction Type (1968 BCNYC)	Primary Occupancy Classification
WTC 1	1,368 ft	110	42,900 ft^2	I-B	Group E (Business)
WTC 2	1,362 ft	110	42,900 ft^2	I-B	Group E (Business)
WTC 7	618 ft	47	48,000 ft^2	I-C (some documents cite 1-B)	Group E (Business)

Source: Merrit 2000a, 2000b; PANYNJ.

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Chapter 25
CONSTRUCTION

25.1 CONSTRUCTION CLASSIFICATION

The Building Code of the City of New York (BCNYC) of December 16, 1968, did not limit the height or area of a construction Class I-B, unsprinklered, occupancy group E (Business) building. However, Local Law No. 16 amended Table 4–1, Area and Height Limitations of Unsprinklered Buildings and Spaces, and limited the height (of the previously mentioned characteristics) to 75 ft while the area remained unlimited.

25.2 COMPARTMENTATION

All new buildings classified in occupancy group E (Business),[44] and existing office buildings, 100 ft or more in height having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located, unsprinklered floor areas,[45] more than 40 ft above curb level, shall be subdivided by fire separations into spaces or compartments as required (C26-504.1, added by Local Law [LL] 5, Sec. 6):

1. All unsprinklered floor areas shall be segregated by 1 h fire separations into spaces or compartments not to exceed 7,500 ft^2.

2. Where the floor area exceeds 10,000 ft^2, at least one of the subdividing fire separations shall be of 2 h construction, creating areas of refuge, complying with section C26-604.5 except that the requirement for an elevator in each area shall not apply.

3. The floor area or any subdivided area may be increased to not more than 15,000 ft^2 if complete area protection by approved devices for the detection of products of combustion other than heat is provided within such increased area and provided further that at least one of the subdividing fire separations shall be of 2 h construction where the floor area exceeds 15,000 ft^2, creating areas of refuge complying with C26-604.5 as noted in 2 above. The activation of the detectors shall have the same effect as section C26-1704.5(f).

4. In existing building, existing 1 h fire separations may be accepted in lieu of the 2 h fire separation provided all of the requirements of 2 and 3 above are complied with.

5. Compartmentation is not required when complete sprinkler protection is provided.

[44] LL 16/1984 removed 'all new buildings classified in occupancy group E (Business)' leaving the compartmentation requirements of C26-504.1 to existing office buildings 100 ft or more in height due to sprinkler requirements.

[45] The floor area shall be defined as the area within exterior walls and excluding any areas enclosing stairs, corridors, elevators, and shafts.

6. Existing office buildings 100 ft or more in height shall comply with the requirements as follows:

    a. At least one-third of the total floor area of the building not in compliance with the requirements above on February 7, 1973, shall comply with the requirements above by December 13, 1981. Complete plans showing such compliance shall be filed with, and a permit secured from the commissioner, by September 13, 1980 (LL 5, Sec. 6, dates revised by LL 86, Sec. 1).

    b. At least two-thirds of the total floor area of the building not in compliance with the requirements above on February 7, 1973, must be in compliance on or before August 7, 1984 (LL 5, Sec. 6, dates revised by LL 86, Sec. 1).

    c. Full compliance must be provided on or before February 7, 1988 (LL 5, Sec. 6, dates revised by LL 86, Sec. 1).

7. In existing office building 100 ft or more in height, the commissioner may waive or modify the above requirements and accept alternatives fulfilling the intent of the requirements if compliance would cause practical difficulty or undue hardship. Where compliance with the time requirements above would cause undue hardship, the commissioner, with the approval of the fire commissioner, may extend the time for compliance (LL 5, Sec. 6, revised by LL 86, Sec. 1).

25.3 FIRESTOPPING

Where combustible trim and finish is permitted, all hollow spaces shall be firestopped at 10 ft intervals or shall be solidly filled with noncombustible materials (C26-504.7(f), added by LL 16, Sec. 28).

Chapter 26
INTERIOR FINISH

26.1 FLOOR FINISH

Carpets and carpet assemblies shall not be installed in required exits, except that wool carpeting may be installed in lobby areas, exit passageways and convenient stairs (C26-504.13(d), added by LL 16, Sec. 32).

The flammability requirements of carpets and carpet assemblies, when used as a floor covering, shall be as follows (C26-504.13(d), added by LL 16, Sec. 32):

1. All carpets and underlayments shall pass a methanine pill test in accordance with RS 5-20.

2. Carpets and carpet assemblies shall be tested for at least a 15 min critical radiant flux exposure in accordance with RS 5-20:

    a. Where carpets and carpet assemblies are installed in corridors, the minimum critical radiant flux shall be 0.5 W/cm^2.

    b. Where carpets and carpet assemblies are installed in other general areas, the minimum critical radiant flux shall be 0.4 W/cm^2.

3. Carpets and carpet assemblies shall be tested for smoke development ratings in accordance with RS 5-20 and shall not exceed 300 within the first 4 min for the flaming or no-flaming mode.

4. The manufacturer of the carpets and carpet assemblies shall submit a certificate from an independent laboratory acceptable to the commissioner showing the complete test data results, prior to final acceptance.

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Chapter 27
MEANS OF EGRESS

27.1 GENERAL

Every structure existing on December 6, 1968, that does not provide exit facilities in accordance with the Building Code of the City of New York (BCNYC) provisions and contain, in the opinion of the commissioner, inadequate means of egress shall be provided with such means of egress or fire protection as the commissioner shall direct (C26-600.3, added by Local Law [LL] 54, Sec. 5).

27.2 EXITS

The minimum distance between vertical exit doors shall be the greater of 30 ft or one-third the maximum travel distance of the floor, provided, however, that where such distance will result in travel distances exceeding those authorized in section C26-601.1, additional vertical exits shall be provided (C26-602.3 amended by LL 16, Sec. 35).

27.3 DOORS

Doors opening into interior stair enclosures shall not be locked from either side with the following exceptions (C26-604.4(j)(1)(b), amended by LL 5, Sec. 9):

1. Doors may be locked to prevent access to the stair at the street floor.

2. In buildings classified in occupancy group E, 100 ft or more in height and existing office buildings 100 ft or more in height, the doors may be locked on the stair side above the street floor except that at intervals of four stories or less, doors shall be openable from the stair side without the use of a key to permit reentry at such floors.

3. The door on every floor where a keyed switch is required by the provisions of article 18 shall be openable from the stair side without the use of a key to permit reentry at such floors.

4. When a locked door is provided with an automatic fail safe system for opening such door in the event of the activation of any automatic fire detecting device or when any elevator in readiness as provided in section C26-1800.8 is activated, such door shall be deemed as openable from the stair side. Stair reentry signs required by C26-608.5 shall specify that reentry is provided only during fire emergencies.

27.4 STAIR AND ELEVATOR SIGNS

Buildings classified in occupancy group E (Business), occupied or arranged to be occupied for an occupant load of more than 100 persons above or below the street level or more than a total of

500 persons in the entire building and any existing office building with an occupant load more than 100 persons shall be provided with signs as follows (C26-608.1, added by LL 5, Sec. 11):

1. A sign shall be posted and maintained on every floor at the elevator landing. The sign shall read "IN CASE OF FIRE, USE STAIRS UNLESS OTHERWISE INSTRUCTED". (C26-608.2, added by LL 5, Sec. 11).

2. Floor numbering signs on every floor (C26-608.3, added by LL 5, Sec. 11).

3. Stair and elevator identification signs (C26-608.4, added by LL 5, Sec. 11).

4. Stair reentry signs (C26-608.5, added by LL 5, Sec. 11).

5. All existing buildings not already subject to the requirements of this section as of January 18, 1973 shall comply with these requirements by October 1, 1985 (C26-608.7(c), amended by LL 16, Sec. 49).

27.5 MEANS OF EGRESS LIGHTING

Where a total of more than four lights are required, exit lighting shall be connected to an emergency power source or to storage battery equipment. The exit lighting may be on circuits that are separate from the general lighting and power circuits, taken off ahead of the main switch. The requirements of this section shall be provided by April 1, 1987 (C26-605.2, added by LL 16, Sec. 45).

Where a total of more than four exit signs are required, the signs shall be connected to an emergency power source or to storage battery equipment. The exit lighting may be on circuits that are separate from the general lighting and power circuits, taken off ahead of the main switch. The requirements of this section shall be provided by April 1, 1987 (C26-606.2(b), added by LL 16, Sec. 46).

Chapter 28
FIRE SUPPRESSION

28.1 AUTOMATIC SPRINKLER PROTECTION

New automatic sprinkler system requirements were added to section C26-1703.1 of the Building Code of the City of New York (BCNYC) as follows (Local Law [LL] 5, Sec. 15 and LL 16, Sec. 64). Automatic sprinklers are required in the following locations:

1. Showroom spaces exceeding 7,500 ft^2 in area located more than 40 ft above curb level in new and existing buildings classified in occupancy group E (Business), 100 ft or more in height having air-conditioning and/or mechanical ventilation systems that serve more than the floor in which the equipment is located (LL 5, Sec. 15). This existing condition must be corrected by January 18, 1976.

2. Catering establishments and banquet halls with an occupancy load of 300 or more persons (LL 16, Sec. 64).

3. Spaces in occupancy group F-4 (Assembly) located more than 75 ft above curb level (LL 16, Sec. 64).

4. Notwithstanding the requirements of showrooms above, new high-rise buildings in occupancy group E (Business) (LL 16, Sec. 64).

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Chapter 29
FIRE DETECTION AND ALARM

29.1 FIRE ALARM SYSTEM

New buildings classified in occupancy group E (Business), 75 ft or more in height and existing buildings in occupancy group E (Business) 100 or more ft in height are required to be provided with a Class E fire alarm and communication system including loud speakers, two-way voice and a fire command station in accordance with RS 17-3A. (C26-1704.1(a)(9), C26-1704.4(g), C26-1704.5 (f), added by Local Law [LL] 5, Sec. 21, 23, and 25, amended by LL 16, Sec. 72):

1. It shall be a special electrically supervised approved direct wire, radio or combination thereof fire alarm system consisting of an interior fire alarm and voice communicating system so arranged that the operation of any station will identify its location at the fire command station, at the mechanical control center and at the regularly assigned location of the fire safety director (C26-1704.5(f)(1), added by LL 5, Sec. 25).

2. Audible signal devices indicating operation of the fire alarm signal system shall be provided at the fire command station, mechanical control center and the regularly assigned location of the fire safety director (C26-1704.5(f)(3), added by LL 5, Sec. 25).

3. The fire alarm system may be sounded over loud speakers in accordance with RS 17-3A so located that their operation will be heard clearly above any ambient noise, and shall be controlled from the fire command station in such a manner that the fire alarm signal can be sounded on the individual floors or throughout the building (C26-1704.5 (f)(5), added by LL 5, Sec. 25).

4. Provision shall be made whereby the fire command station may permit the floor station to make announcements over the loud speaker system (C26-1704.5(f)(6), added by LL 5, Sec. 25).

5. Existing office buildings 100 ft or more in height shall comply with the requirements of this section by September 13, 1981 (C26-1704.5(f)(12), added by LL 5, Sec. 25, amended by LL 86, Sec. 3).

6. In existing office buildings 100 ft or more in height where compliance would cause practical difficulty or undue hardship, the commissioner may waive or modify the requirements of C26-1407.5(f)(1-9) and accept alternatives fulfilling the intent of the requirements (C26-1704.5(f)(11), added by LL 5, Sec. 25).

Fire alarm or communication systems installed prior to December 13, 1980, in existing office buildings 100 ft or more in height, may be incorporated or installed in a modified Class E fire alarm signal system in accordance with RS 17-3B (C26-1704.5(g), added by LL 5, Sec. 25). The requirements of the modified Class E system are the same as the Class E system mentioned above except:

1. The provision whereby the fire command station may permit the floor station to make announcements over the loud speaker system is not required.

2. Other differences mentioned below.

A fire command station shall be located in the lobby of the building on the entrance floor as part of the elevator control panel or immediately adjacent thereto. The fire command station shall contain the following (C26-1704.8(b), added by LL 5, Sec. 30):

1. The loud speaker and communication capability described in section C26-1704.8(a).

2. The audible alarm signal required in section C26-1704.5(f)(g).

3. Manually reset information display system to indicate the floor where the alarm was activated.

4. Means to control the sounding devices on any floor or throughout the building.

5. Means to manually transmit a fire alarm signal to the fire department.

6. Means for silencing the audible alarm signals when the loud speakers are in use and for activating the audible alarm systems automatically when use of the loud speakers are terminated.

7. Display lamps to include on/off condition of air-handling systems unless such lamps are provided in the mechanical control center.

8. Existing office buildings 100 ft or more in height shall comply with the requirements by September 13, 1981 (C26-1704.8(c), added by LL 5, Sec. 30, amended by LL 86, Sec. 3).

29.2 SMOKE AND HEAT DETECTOR LOCATIONS

An approved products of combustion ionization detecting device or a combination of an approved smoke detecting device and an approved fixed temperature thermostatic device shall be installed at each elevator landing. The device shall be located in the ceiling immediately above a call button (C26-1704.4(h), C26-1704.5(f)(8), added by LL 5, Sec. 25).

Activation of an elevator landing detector should (C26-1704.5(f)(9), added by LL 5, Sec. 25):

1. Sound continuously throughout the floor of alarm and floor above.

2. Cause a fire alarm signal to be transmitted to the fire department.

3. Sound fire alarm signal at the fire command station, mechanical control center and regularly assigned location of the fire safety director.

4. Operate the information display system.

5. Stop the air supply into and air return from the floor where activated by approved remote control reversible fire shutters or by automatically shutting down supply and return air fans.

6. Activate air exhaust fans and dampers in smoke shafts and/or pressurizing fans in stair enclosures.

An approved products of combustion ionization detecting device or a combination of an approved smoke detecting device and an approved fixed temperature thermostatic device shall be located at the air return shaft at each floor and so located as to monitor each inlet to the air return shaft (RS 13-1 Sec. 1006, added by LL 5, Sec. 34).

A building equipped throughout with an automatic sprinkler system including a water flow alarm shall be exempt from the installation of any detectors required at each elevator landing and return air shaft, as mentioned above, provided (C26-1704.5(f)(10), added by LL 5, Sec. 25):

1. The water flow alarm has the same effect specified for the elevator landing detector mentioned above.

2. In addition to the smoke detector requirement, in a building equipped throughout with an automatic sprinkler system, a waterflow alarm when activated shall initiate Phase I (Rule 211.3a) emergency recall operation (RS18-1, Rule 211.3b(2)).

Approved and operational smoke detecting devices shall be installed in mechanical rooms, electrical switch gear rooms and electric and telephone closets over 75 ft^2 in all buildings in all occupancy groups (C26-1705.2(b), added by LL 16, Sec. 78).

29.3 MANUAL FIRE ALARM BOXES

At least one fire alarm sending station shall be provided in each story located in each path of escape with additional stations installed so that no point on any floor is more than 200 ft from the nearest station (RS 17-3A and B, Sec. 7(a), added by LL 5, Sec. 39 and 40).

Operation of a manual station shall automatically transmit a fire alarm signal to the fire department via a central station and sound an alarm continuously on the floor where activated and the floor above (C26-1704.5(f)(4), added by LL 5, Sec. 25).

Fire alarm (Class E) sending stations shall be painted red with a diagonal white stripe painted or applied to sending stations which transmit a fire alarm signal to the fire department via a central station (C26-1704.6(e), amended by LL5, Sec. 27).

All fire alarm stations installed or relocated after April 1, 1984, shall be installed so that the handle is approximately 4 ft from the floor (C266-1704.6, amended by LL 16, Sec. 76).

A designated station on each floor shall have the capability of operating the loud speakers for that floor (RS 17-3A, Sec. 7(i), added by LL 5, Sec. 39). This is not a requirement of the modified class E fire alarm system.

29.4 AUDIBLE/VISUAL NOTIFICATION APPLIANCES

In a Class E fire alarm system, loudspeakers capable of being operated from the fire command station shall be provided on each floor, and in each elevator and stair enclosure (C26-1704.8(a), added by LL 5, Sec. 30).

The loudspeaker amplifier system shall be so designed and installed that approximately 50 percent of the system shall remain operable for the transmission and audibility of signal and intelligibility of voice communication over the loudspeaker system throughout the building, in the event the other 50 percent becomes inoperable (C26-1704.5(f)(7), added by LL 5, Sec. 25). This is not a requirement of the modified Class E fire alarm system.

Loudspeakers shall be located so that their operation will be heard clearly above ambient noise (C26-1704.5(f)(5), added by LL 5, Sec. 25).

Recessed and surface mounted speakers shall be located not more than 10 ft from the entrance to each required exit (RS 17-3A and B, Sec. 8(b), added by LL 5, Sec. 39 and 40).

The alarm sounding devices may be utilized for other audio purposes including building security if means are provided to insure fire alarm priority (RS 17-3A and B, Sec. 8(c), added by LL 5, Sec. 39 and 40).

29.5 COMMUNICATION SYSTEM

In a Class E fire alarm signal system, the standpipe fire line telephone and signaling system may be combined with the fire alarm system provided (C26-1704.7(g), added by LL 5, Sec. 28):

1. The alarms and two-way voice communication with the fire command station include the pump and gravity tank rooms.

2. A designated floor station of the Class E system is located at or near the main standpipe riser on every floor.

New and existing buildings classified in occupancy group E (Business), 100 ft or more in height shall be provided with the following (C26-1704.8, added by LL 5, Sec. 30):

1. Loudspeakers on each floor of the building, in each elevator and each stair enclosure, which shall be capable of being operated from the fire command station.

2. A two-way communication with capability between the fire command station and the following locations:

    a. A designated floor warden station on each floor.

    b. Mechanical control center.

    c. Elevators.

    d. Air-handling.

    e. Elevator machine rooms.

A floor warden station shall be located between required stairways, vertical exits, or other exits (RS 17-3A and B, Sec. 7(b), added by LL 5, Sec. 39 and 40):

1. System shall include a telephone type handset at the floor warden station with integral signaling to the fire command station.

2. Warden station may be part of the speaker system.

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Chapter 30
ELEVATORS AND HOISTWAYS

30.1 ELEVATOR IN READINESS

In buildings classified in occupancy group E (Business), 100 ft or more in height, and in existing office buildings 100 ft or more in height, the number of elevators that shall be kept available for immediate use by the fire department is as follows (C26-1800.8, added by Local Law [LL] 5, Sec. 31):

1. Where a floor is serviced by three or less elevator cars, every car shall be kept available.

2. Where a floor is serviced by more than three elevator cars, at least three elevator cars with a total rated load capacity of not less than 6,000 lb shall be kept available for every floor. Such cars shall include not more than two cars which service all floors and at least one other car in another bank servicing that floor. If the total load capacity of all cars servicing the floor is less than 6,000 lb, all cars shall be kept available.

3. Elevators which have automatic or continuous pressure operation shall be controlled by keyed switches meeting the requirements of RS 18-1.

4. In high-rise buildings classified in occupancy group E (Business), all other automatically operated cars shall have manual operation capability.

Notwithstanding the retroactive provisions in C26-1801.1, existing office buildings 100 ft or more in height shall comply with the requirements of this section by September 13, 1981.

30.2 LOCKS

In high-rise buildings and existing high-rise buildings, no switch, lock, or device of any kind shall be installed on any floor on or above the street floor on any elevator car or elevator hoistway door, except elevators used exclusively for freight, that shall prevent opening of such doors by anyone not having a key, unless fire department access to cars and hoistways is provided for by a city-wide standard key. Existing high-rise buildings shall comply with this requirement by April 1, 1987 (C26-1801.4, added by LL 16, Sec. 80).

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Chapter 31
EMERGENCY, ELECTRICAL, AND STANDBY POWER SYSTEMS

31.1 EMERGENCY POWER SYSTEMS

An emergency power system shall be provided in high-rise buildings in occupancy group E (Business) (C26-610.3, added by Local Law [LL] 16, Sec. 50).

Emergency power shall be provided having the capacity to operate the following equipment, where such equipment is installed (C26-610.1, added by LL 16, Sec. 50):

1. Fire pumps.
2. At least three elevators at one time, with manual transfer to other elevators.
3. Alarm systems.
4. Communications systems.
5. Emergency lighting, if battery packs are not provided.
6. Ventilating systems used for smoke venting or control.
7. Stair pressurization.

Emergency power generation equipment shall be registered with the Department of Environmental Protection, Bureau of Air Resources in accordance with the requirements of Section 1403.2-3.09 of the Administrative Code (C26-610.2, added by LL 16, Sec. 50).

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Chapter 32
SPECIAL FEATURES

32.1 SMOKE AND HEAT VENTING

Buildings classified in occupancy group E (Business), 100 ft or more in height, having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located, shall be provided with at least one smoke shaft by means of which smoke and heat shall be mechanically vented to the outdoors as provided in RS 5-17 (C26-504.15(b)) (Local Law [LL] 5, Sec. 7). RS 5-17 was added by LL 5, Sec. 32.

Existing office buildings, 100 ft or more in height, having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located, shall be provided with at least one smoke shaft by means of which smoke and heat shall be mechanically vented to the outdoors as provided in RS 5-17 or in lieu of such smoke shaft(s), all interior enclosed stairs other than a fire tower or access stairs may be provided with a system of pressurization for fire emergency use (C26-504.15(c)) (LL 5 Sec. 7, revised by LL 86, Sec. 2):

1. Where the pressurization system(s) option has been chosen, the system(s) shall be provided in accordance with RS 5-18.

2. The smoke and heat venting requirements shall be completed by September 13, 1982.

New Buildings that are sprinklered throughout shall be exempt from the smoke shaft requirements (C26-504.15(b)) (LL 5, Sec 7).

Existing buildings that are sprinklered throughout shall be exempt from the smoke shaft and optional stair pressurization requirements under the following conditions (C26-504.15(b)) (LL 86, Sec 2):

1. The installation shall proceed in conformance with a schedule acceptable to the commissioner.

2. At least one-third of the total floor area of the building, including but not limited to the entrance lobby, corridors and elevator landing areas, is sprinklered by December 13, 1981.

3. At least two-thirds of the total floor area of the building is sprinklered by December 13, 1982.

4. The building is sprinklered throughout by December 13, 1983.

5. Where compliance with the time requirements would cause undue hardship, the commissioner, with approval of the fire commissioner, may extend the time for compliance.

32.2 SMOKE CONTROL

Smoke control shall be installed in all buildings classified in occupancy group E (Business) as follows (C26-1300.8(a), added by LL 16, Sec. 53):

1. Ventilation systems supplying different occupancy groups shall not be interconnected, provided however that a ventilation system may serve two occupancy groups located on the same floor when the accessory use occupies less than 20 percent of the floor area occupied by the principal use.

2. Ventilation systems supplying corridors shall not be interconnected with systems serving other spaces, except that this requirement shall not apply to floors used exclusively as office space in buildings classified in occupancy group E (Business) which are fully sprinklered.

3. A ventilation system supplying any part of a means of egress shall not be interconnected with any other ventilation system.

4. A ventilation system supplying public areas and assembly spaces shall have smoke detecting devices that will shut down the system upon detecting smoke.

5. Either a combined heat and smoke damper or independent heat and smoke dampers shall be installed at any penetration of construction required to have a fire resistance rating., unless otherwise provided by section C26-504.5.

32.3 SMOKE PURGE

In all buildings classified in occupancy group E (Business), there shall be provided a system of mechanical means of sufficient capacity to exhaust 6 air changes per hour or 1 cfm/ft^2, whichever is greater, from the largest floor in the building, using either dedicated fan equipment or the building ventilation system arranged to shut down automatically with manual override capability to exhaust one floor at a time through a roof or an approved location on an exterior wall other than a lot line wall (C26-1300.8(b), added by LL 16, Sec. 53).

32.4 STAIR PRESSURIZATION

Stair pressurization is not directly required by code in an occupancy classified as group E (Business). As previously stated in Section 32.1 of this report, stair pressurization can be used to eliminate the requirement of smoke and heat venting. If stair pressurization is provided, each stair shall be protected in accordance with RS 5-18 (RS 5-18 added by LL 5, Sec. 33, amended by LL 84, Sec. 3).

32.5 FIRE SAFETY PLAN

A fire safety plan for fire drill and evacuation procedures shall be submitted to the commissioner. The applicable parts of the fire safety plan shall be distributed to the tenants and service employees. All occupants of the building shall participate and cooperate in carrying out the provisions of the fire safety plan (C19-161.2, added by LL 5, Sec. 1).

One employee (of the building owner) shall be designated as fire safety director and one or more employees as deputy fire safety director. Such employees shall each have a certificate of fitness, qualifying him to conduct fire drills, evacuations, and related activities such as organizing, training and supervising a fire brigade.

During fire emergencies, the primary responsibility of the fire safety director shall be the supervision and manning of a fire command station and the direction and execution of the evacuation as provided in the fire safety plan. Such activities shall be subject to fire department control.

A fire brigade consisting of qualified building service employees shall be selected by the fire safety director.

Fire drills shall be conducted in accordance with the fire safety plan at least once every 3 months for existing building during the first 2 years. Thereafter, fire drills shall be conducted at least once every 6 months. The occupants of the building, other than building service employees, shall not be required to leave the floor or use the exits during the drill.

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Chapter 33
INSPECTIONS

33.1 MATERIALS REQUIRING INSPECTION

The installation of all required sprayed fire-resistive material of structural members except those encased in concrete shall be subject to the controlled inspection requirements in C26-106.3(a), C26-502.2(f), added by Local Law No. 55.

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Chapter 34
RESPONSE TO RETROACTIVE PROVISIONS

The Port Authority of New York and New Jersey (PANYNJ) and various consultants continuously evaluated the life safety and fire protection features of the World Trade Center (WTC). In response to the Local Laws of New York City, a fire in 1975, a bombing in 1993, and many other fires, the life safety and fire protection features of WTC 1 and WTC 2 were enhanced. Throughout the years, numerous studies and plans were created. The reports generated by the studies gave recommendations with numerous alternatives to equivalently comply with the intent of the code. Eventually, for one reason or another, the provisions of these Local Laws were addressed, and in many instances were exceeded (see Table 12–1). Additionally, since the PANYNJ did not merely comply with the minimum requirements, some of the local law provisions were complied with prior to the development of the Local Law requirements. During the time of the 1975 WTC fire, the New York Board of Fire Underwriters stated, "The Fire Safety Program of the World Trade Center is an excellent one" and "In the overall, these towers may be considered as among the safest buildings in New York City" (stated in a document contained in Appendix A of NIST NCSTAR 1-1H).

Table 34–1. Life safety and fire protection provisions required by Local Laws.

Provision	Approach adopted by PANYNJ
Compartmentation	No (sprinkler alternative was chosen)[a]
Stair and elevator signs	Yes
Secondary power supply for exit signs and lights	Exceeded[b]
Smoke and heat shaft or stair pressurization	Exceeded[c] (not required since building was sprinklered)
Elevators in readiness	Exceeded[d]
Class E fire alarm system	Exceeded[e]
Fire command station	Yes[f]
Removal of locks on elevators and hoistway doors	Yes
Fire protection and fire safety plans	Yes
Emergency power	Exceeded[g]

a. In 1976, a plan to vertically compartmentalize WTC 1 and WTC 2 was chosen. But, in the mid-1980s, a program to fully sprinkler WTC 1 and WTC 2 was initiated, eliminating the compartmentation requirements. Documentation indicates that in 1993, WTC 1 was approximately 95 percent completed and approximately 85 percent complete in WTC 2. By 2000, the office floors of WTC 1 and WTC 2 were sprinklered except for electric and telephone closets, most toilet rooms, the main lobby and the B-6 Level Mechanical Equipment Room (Merritt 2000a, 2000b).
b. Provided with separate feeders and emergency generators.
c. Smoke purge and pressurization of corridors with 100 percent fresh air was provided.
d. All passenger elevators are capable of being recalled and makes the car available for manual operation by the Fire Department.
e. Many components of the fire alarm system were above code requirements at the time of Local Law No. 5. After the 1993 bombing, a completely new system was installed complying with the most current provisions at the time of installation.
f. Each tower did not have an individual fire command station at the time of the 1993 bombing. Part of the enhancement after the bombing included providing Fire Command Stations in the lobby of each building.
g. Was not retroactively required, but was provided.

Sources: PANYNJ; Appendix A, NIST NCSTAR 1-1H; Rivera 1993; Merritt 2000a, 2000b.

Chapter 35
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NIST NCSTAR 1-1E

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Comparison of Codes, Standards, and Practices in Use at the Time of the Design and Construction of World Trade Center 1, 2, and 7

Joseph C. Razza
Raymond A. Grill

NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

NIST NCSTAR 1-1E

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September 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
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In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

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NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

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ABSTRACT

This report was prepared to support the goals and objectives of the analysis of building and fire codes and practices of the National Institute of Standards and Technology World Trade Center (WTC) Investigation. The report provides a comparison and summary of significant differences between the 1968 Building Code of the City of New York (determined to be the current building code at the time of construction of WTC 1 and WTC 2), the provisions of the New York State Building Construction Code, and the City of Chicago Building Code that were available at that time.

Keywords: Building code, emergency power, fire alarm, fire protection, fire suppression, interior finish, means of egress, reference standard, sprinklers, standpipe, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

ASTM	ASTM International
BBC	Basic Building Code
BCNYC	Building Code of the City of New York (Local Law 76)
BOCA	Building Officials and Code Administrators
HVAC	heating, ventilating, and air conditioning
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NYC	New York City
RS	Reference Standard to the Building Code of the City of New York
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

cfm	cubic feet per minute
ft	feet
ft^2	square feet
gpm	gallons per minute
h	hour
in.	inch
min	minute
psi	pounds per square inch
V	volt

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GLOSSARY

combustible – A material that is not determined to be noncombustible.

fire resistance rating – The time in hours that materials or their assemblies will withstand fire exposure as determined by a standard fire test.

fireproofing – Materials or assemblies used to provide a fire resistance rating to a building component.

firestop – A solid or compact, tight closure to retard the spread of flames or hot gases within concealed spaces.

noncombustible – A material that, in the form in which it is used in construction, will not ignite and burn when subjected to fire. However, any material which liberates flammable gas when heated to any temperature up to 1,380 ºF for 5 min shall not be considered noncombustible.

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PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

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Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

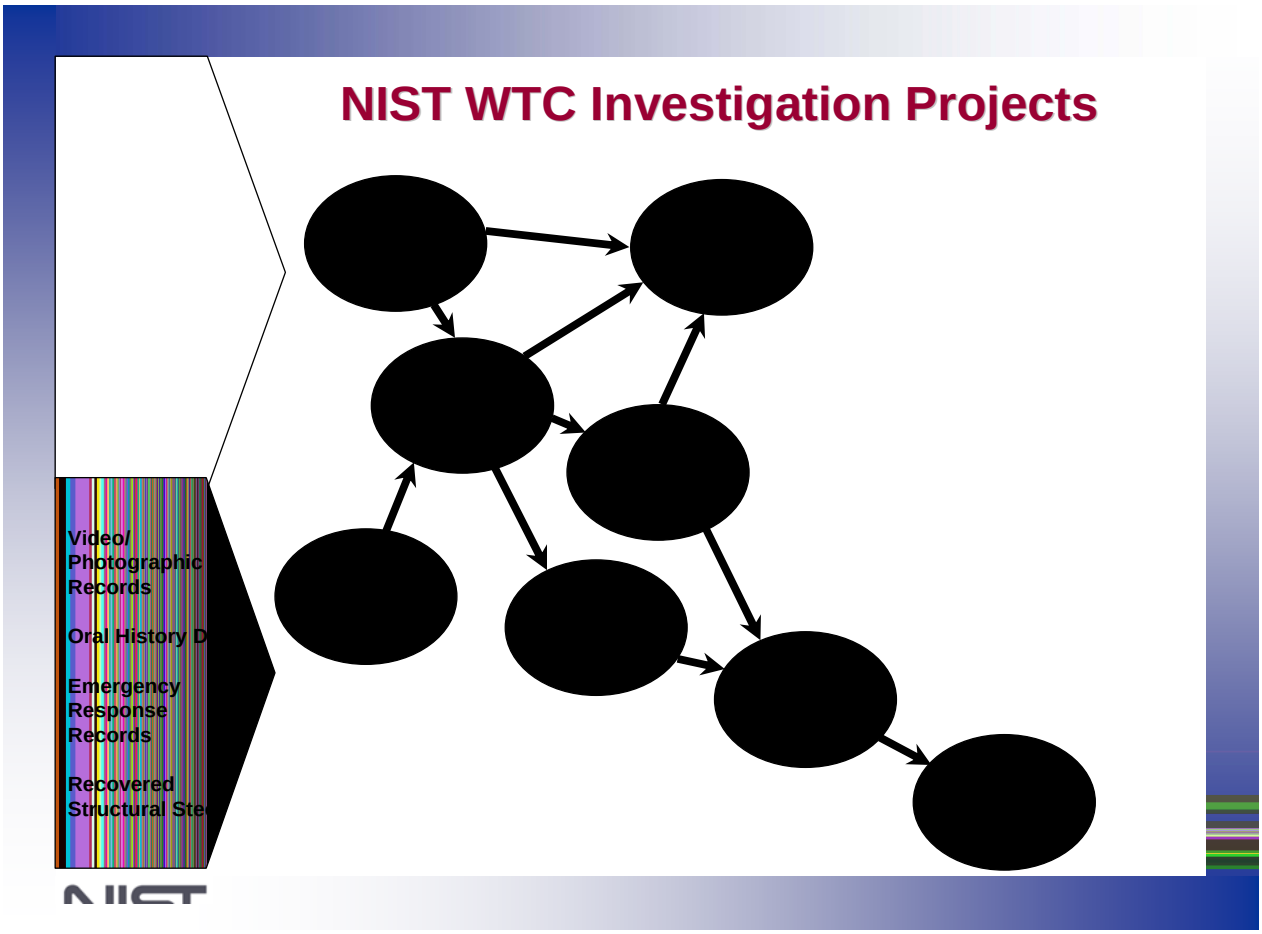

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

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EXECUTIVE SUMMARY

As part of the analysis of building and fire codes and practices of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation, this report supports the effort by providing a summary of the relevant provisions of the Building Code of the City of New York (BCNYC) that was in effect at the time of the design of the WTC. This report also documents the requirements of the 1956 New York State Building Code that was amended through December 1, 1964; the 1966 edition of the Chicago Building Code; the 1965 edition of the Building Officials and Code Administration (BOCA) Basic Building Code (BBC); and the 1966 edition of the Code for Safety to Life from Fire in Buildings and Structures (National Fire Protection Association [NFPA] 101). The purpose of this report is to provide a comparison of these codes vis-à-vis the relevant requirements and to identify significant differences.

It has been previously established that WTC 1 and WTC 2 were designed and constructed in accordance with the BCNYC as enacted by Local Law 76 for the year 1968, effective December 6, 1968. The Building Code is a part of the Administrative Code of the City of New York.

The code requirements identified and compared in this report focus fire protection and life safety related issues. These include but are not limited to:

- Use and occupancy criteria.
- Height and area limitations and associated construction types.
- Fire resistance ratings for various building elements.
- Fire protection system requirements. (Project 1 focuses on the requirements for fire protection systems in the WTC buildings reflecting requirements in codes, standards, and practices. Project 4 focused on the design and performance on September 11, 2001, of the various fire protection systems.)
- Means of egress requirements including occupant load determination and egress capacity and travel distance limitations.
- Emergency lighting and power requirements.
- Elevator provisions in case of emergency.

It is important to note that NFPA 101 is focused in life safety and does not include general fire resistance requirements for construction in most types of occupancies as would typically be found in a building code. Fire resistance requirements in the 1966 edition of NFPA 101 are focused on maintaining egress and minimizing fire and smoke spread to allow for egress during fire emergencies.

Of the codes compared in this report, the then current BCNYC provided the most detailed and comprehensive requirements vis-à-vis the requirements addressed in the report. The level of detail is

apparent in the body of the code. The BCNYC also includes numerous reference standards that were based on nationally recognized standards at the time such as ASTM International (ASTM) and NFPA Standards. Some examples of detailed requirements found solely in the New York City Code were in the area of smoke and fire dampers and through penetration protection of fire rated assemblies.

While the requirements of the then current New York State Code were comparable to those of the New York City Code, they were less detailed and did not address many of the specific issues addressed by the BCNYC. An example of this is in the area of through penetration protection. The then current New York State Code had no specific requirements.

The then current Chicago Building Code is also not as detailed as the then current BCNYC. The one area that the then current Chicago Building Code was more restrictive than both the then current New York City and New York State Codes was in the area of fire resistance. Minimum fire resistance ratings for structural elements, floors, and exterior walls (where ratings are required based on separation distances) are required to be one hour higher by the Chicago Building Code. Columns under the then current Chicago Building Code would be required to be 4 h rated versus 3 h rated by the then current New York City or New York State Code.

The 1965 edition of BOCA provided more performance oriented requirements versus the then current BCNYC. The then current BCNYC and the 1965 edition of the BOCA Code both include numerous reference standards that were based on nationally recognized standards at the time such as ASTM and NFPA Standards. Examples of more detailed requirements found in the then current BCNYC compared to BOCA and NFPA 101 can be found in the sections on firestopping, through penetration protection of fie rated assemblies, interior finish criteria, and fire fighter communications related to standpipe use.

Chapter 1
INTRODUCTION

One of the goals of the World Trade Center (WTC) Investigation led by the National Institute of Standards and Technology (NIST) is to recommend appropriate revisions to current codes, standards, and practices used in the industry. Prior to recommending such changes, one of the objectives of the Investigation is to identify the codes and standards that were used during the design and construction of the WTC complex, identify local and national codes and standards that were available at that time, and identify areas in current building and fire codes, standards, and practices that warrant revision.

As part of the Investigation, it has been determined that WTC 1 and WTC 2 were constructed in accordance with the Building Code of the City of New York (BCNYC) that was enacted by Local Law 76 for the year 1968.

NIST reviewed and documented relevant provisions of the building codes for the WTC complex and summarized significant differences. This report provides a comparison of the 1968 (then current) BCNYC and other "local" and "national" building codes available at that time, including the New York State Building Construction Code Applicable to General Building Construction, the City of Chicago Building Code, the Building Officials and Code Administrators' Basic Building Code, and the National Fire Protection Association 101 Code for Safety to Life from Fire in Buildings and Structures.

The comparison is in tabular format and provides a comparison of the following fire protection and life safety related topics: building codes, reference standards, occupancies, construction, interior finish, means of egress, fire suppression systems, fire alarm, detection and signaling systems, elevators and escalators, emergency electrical and standby power systems, and special features such as parking garages and atria.

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Chapter 2
CODE COMPARISON AND SUMMARY OF SIGNIFICANT DIFFERENCES

This chapter summarizes key differences between the codes compared in this report. The side-by-side comparison of the requirements is provided in tabular format in Appendix A of this report.

2.1 GENERAL DIFFERENCES

The requirements of the 1965 edition of Building Officials and Code Administrators (BOCA) are more performance oriented than prescriptive in many areas of the document. The then current Building Code of the City of New York (BCNYC) is more prescriptive in its requirements. The requirements of National Fire Protection Association (NFPA) 101, Code for the Safety to Life, is focused on maintaining the integrity of egress elements and control of fire growth and spread to allow for occupant egress. Therefore, there are limited requirements for fire resistance of typical building elements as would be found in a typical building code. NFPA 101 is not intended to be used as a building code.

2.2 REFERENCED STANDARDS

The then current BCNYC and BOCA Code reference numerous nationally recognized standards that were available at the time, addressing areas of material testing, various building system installations, and system design. These referenced standards were incorporated as part of the BCNYC. The then current New York State Building Code and Chicago Building Codes did not have referenced standards as part of their codes. The State of New York published a Code Manual for the purpose of assisting with the application and enforcement of the State Building Code and they also published a list of "Generally Accepted Standards."

2.3 OCCUPANCY SEPARATIONS

The then current BCNYC included detailed requirements for treating mixed occupancy buildings which were not found in the other codes compared in this report. The Chicago Building Code did contain a specific requirement for a 4 h separation between buildings and below-grade public space (i.e., subways). There is no requirement of this nature in either the BCNYC or New York State Building Codes.

NFPA 101 permits the provision of fire sprinklers in lieu of 1 h fire rated construction for separations of occupancies having different hazard levels.

2.4 CONSTRUCTION

The then current BCNYC and New York State Building Codes allowed Type IA or Type IB construction for the World Trade Center (WTC) buildings. The then current Chicago Building Code would have required Type IA construction. The Chicago Building Code would require 4 h fire resistance ratings for

structural elements such as columns and bearing walls versus 3 h fire resistance required by the BCNYC or the New York State Building Code.

The BOCA Building Code allowed Type IA or Type IB construction for the World Trade Center buildings. Fire resistance rating requirements in the BOCA Building Code are almost identical to the then current New York City Building Code. One are of deviation is that the then current New York City building Code required 1 h fire rated tenant separations versus ¾ h fire rated tenant separations in BOCA. NFPA 101 does not contain construction requirements for the types of occupancies that were included in the WTC Buildings.

2.5 FIRE AND SMOKE DAMPERS

The then current BCNYC included comprehensive requirements for the use and installation of fire and smoke dampers. Smoke dampers were required at the main supply and return ducts. The other codes reviewed in this report did not have any requirements for fire and smoke dampers.

2.6 FIRESTOPPING AND THROUGH PENETRATION PROTECTION

The then current BCNYC included comprehensive requirements identifying when and where firestopping was required. The then current New York State Building Code addressed the issue in less detail and the Chicago Building Code had no requirements. NFPA 101 has limited requirements for firestopping (exterior and interior partitions at floor levels and unoccupied attic spaces) and does allow a trade off in this area for sprinklered concealed spaces.

2.7 INTERIOR FINISH AND SMOKE DEVELOPMENT RATINGS

The requirements for flame spread of interior finish are similar amongst the codes reviewed in this report. The then current BCNYC is more detailed in specifying requirements based on use of spaces and is the only code of those reviewed in this report that included requirements for maximum smoke development ratings for interior finish.

2.8 MEANS OF EGRESS

The then current BCNYC provided detailed requirements for the design of the various elements of the egress system. This includes detailed occupant loading criteria based on use, egress element widths, continuity of egress path, and criteria for horizontal egress. The then current New York State Building Code and Chicago Building Code did not have detailed requirements for the means of egress.

The then current BCNYC requirements for egress were consistent with the BOCA Building Code and NFPA 101 with minimal differences in technical requirements. The travel distance requirement of the then current BCNYC (200 ft) is less restrictive than BOCA (150 ft) but consistent with the requirement of NFPA 101.

Requirements for illumination of egress elements are most restrictive in the then current BCNYC (5 foot candle intensity) versus BOCA (3 foot candle intensity) and NFPA 101 (1 foot candle intensity).

2.9 FIRE SUPPRESSION SYSTEMS

The fire sprinkler requirements of the then current BCNYC and New York State Building Codes were driven by lack of means for exterior ventilation. The then current Chicago Building Code had no requirements for fire sprinkler protection. BOCA and NFPA 101 sprinkler requirements are driven by occupancy and area of that occupancy. Office occupancies did not require sprinkler protection by BOCA or NFPA 101. The then current BCNYC had specific design criteria within the code if a system was to be provided.

2.10 STANDPIPES AND WATER SUPPLY

The then current BCNYC and BOCA required standpipes and had detailed design and installation criteria incorporated in the code. The New York State Building Code required standpipes, but did not include design or installation criteria in the code. The then current Chicago Building Code was silent on the subject. NFPA 101 would not have required standpipes.

2.11 FIRE ALARM, DETECTION, AND SIGNALING SYSTEMS

Of the codes reviewed in this report, the then current New York State Building Code, BOCA and NFPA 101 required a fire alarm system in high rise office buildings. The BOCA requirement was triggered by height (75 ft) and the NFPA 101 requirement was driven by occupant load (greater than 200 people). The then current BCNYC and NFPA 101 had comprehensive requirements for installation of smoke detectors in heating, ventilating, and air conditioning equipment. The then current BCNYC also had requirements for a firefighter communication system with permanent telephones to provide communication between pump rooms, building entrance floor, gravity tank rooms, and at each floor near the main standpipe.

2.12 ELEVATORS AND ESCALATORS

The then current BCNYC contained the most comprehensive requirements for elevators among the codes reviewed in this report. Requirements also included application of elevators if areas of refuge were provided in buildings. Areas of refuge above the 11th floor were required to be served by at least one elevator. Emergency controls for fire department use were also required.

2.13 SMOKE AND HEAT VENTING

The then current BCNYC was the only code of the codes reviewed in this report that required smoke and heat venting of elevator, dumbwaiter, and other closed shafts including stairway enclosures. NFPA 101 required automatic smoke and heat venting for underground structures with occupant loads exceeding 1,000 people.

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Chapter 3
REFERENCES

City of Chicago Building Code. 1966.

City Publishing Center Department of General Services. 1968. The City of New York Building Code. New York, NY, December 6.

New York State Building Construction Code Applicable to General Building Construction. Effective May 1, 1956; amended April 1, 1961 and December 1, 1964.

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Appendix A
TABLE OF CODE COMPARISON AND SUMMARY OF SIGNIFICANT DIFFERENCES

The side-by-side comparison of the requirements from the different codes is provided in this appendix.

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	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
A.1 Building Codes						
	Building Code of the City of New York, (Title C of Chapter 26 of the Administrative Code as enacted by Local Law 76 for the year 1968, effective December 6, 1968)	NY State Building Construction Code Applicable to General Building Construction, effective May 1, 1956; amended April 1, 1961 and December 1, 1964	City of Chicago Building Code, 1966	BOCA Basic Building Code, 1965	1966 *Code for Safety to Life from Fire in Buildings and Structures*	
A.2 Reference Standards						
	RS 5-2 Standard Methods of Fire Tests of Building Construction Materials, ASTM E 119 - 1961; RS 5-5 Standard Method of Test for Surface Burning Characteristics of Building Materials, ASTM E84-1961, RS 5-8 Installation of Fire Doors and Windows, NFPA 80 - 1967; RS 13-1 Standard for the Installation of Air Conditioning and Ventilating Systems, NFPA 90A – 1967, as modified; RS 17-1 Standpipe Construction; RS 17-2 Standard for the Installation of Sprinkler Systems NFPA 13 - 1966, as modified; RS 17-3 Standards for the Installation of Fire, Sprinkler, Standpipe, Smoke Detection…and other Alarm and Extinguishing Systems; RS 17-5 Proprietary and Auxiliary Protective Signaling Systems, NFPA 72 – 1967; RS 18-1 USA Standard Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks, USASI 17.1 - 1965 including Supplement A17.1a-1967, as modified;	N/A A Code Manual was published by the State Building Code Council to assist in the application and enforcement of the Code. The manual indicates and illustrates acceptable methods of compliance with the performance requirements set forth in the Code, but does not exclude other possible methods. The Code is the law; the Code Manual is not. As a further guide in determining compliance with the performance requirements of the Code, the Council also publishes a list of Generally Accepted Standards.	(Chicago did not require automatic sprinklers or fire alarms in office buildings of any height until 1975. At that time and to the present, Chicago permits sprinklers or compartmentation. The following is based on a non-sprinklered building)	NFPA 73 – 1964 NFPA 71 – 1964 NFPA 72 – 1964 NFPA 90A – 1964 NFPA 90B – 1964 NFPA 80 – 1962 NFPA 10 –1963 NFPA 23 – 1963 NFPA 13 – 1964 NFPA 14 – 1963 ASA A17.1 – 1960 ASTM E-119 NFPA 54 - 1963	NFPA 13-1966, NFPA 71 & 72-1964/5/6	The NYC Building Code provided significantly more specificity of requirements through the adoption of numerous national standards addressing design and construction of buildings and systems within buildings.

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
A.3 Occupancies						
Primary Occupancy	The building is classified in Occupancy Group E (Business) with a fire index of 2, based on the dominant use, and containing the following accessory uses (C26-301.1 through C26-301.3, C26-306.1): • C4.1 – low hazard, including parking garages • C4.2 – moderate hazard	Group C1 – Business (C202.11)	Class E, Business 48-6	Chapter 13-Office Occupancies, Ordinary hazard	Chapter 13-Office Occupancies, Ordinary hazard	
Secondary/ Accessory Occupancies	Occupancy Group B-1, Storage (Moderate Hazard), Fire Index: 3	Group C4 – Storage (C202.11)	Class H-3, Garage 48-9.3	Group B, Storage (Moderate Hazard) H204.1	Chapter 15-Storage Occupancies • General storage – Low hazard – Ordinary hazard • Garages	
	Occupancy Group B-2, Storage (Low Hazard, Garage), Fire Index: 2	Group C4 – Storage (C202.11)		Group B, Storage (Low Hazard) 204.2		The Chicago Building Code does not specifically classify storage as an occupancy in office buildings.
	Occupancy Group C, Mercantile, Fire Index: 2	Group C2 – Mercantile (C202.11)	Class F, Mercantile 48-7	Group C, Mercantile 205	Chapter 12-Mercantile Occupancies, Ordinary hazard -Class A: Stores with gross area of 30,000 ft^2 or more or more than 3 floor levels. -Class B: Stores more than 3,000 ft^2 but less than 30,000 ft^2 or using any floors above or below street level for sales. -Class C: Stores less than 3000 ft^2 and at street level.	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Occupancy Group F-4, Assembly (Restaurant), Fire Index: 1	Group C5 – Assembly (C202.11) Group C5.1 – not more than 600 persons, Group C5.2 – more than 600, but not more than 1500 persons, Group C5.3 – more than 1500 persons.	Class C-1, Large Assembly 300 or more persons 48-4.1 Class C-2, Small Assembly <300 persons 48-4.2	Group F-3, Assembly (Restaurant) 208.3	Chapter 8-Assembly Occupancies -Class A: 1,000 or more occupants. -Class B: 300 to 1,000 occupants. -Class C: 100 to 300 occupants.	
Occupancy Separation	Separate Building (Building Section) - Spaces classified in occupancy groups having a higher fire index than the occupancy group classification of the building shall be separated by "Fire Divisions" constructed in accordance with Section C26-504.1(a) and treated as separate buildings (C26-301.4(a)).	Requirements in Fire Separations below.	Requirements in Fire Separations below.	When mixed uses are completely separated from adjoining occupancies by fire divisions of the highest fire grading in Table 16, each part shall be classified by use. 213.3 E – 2 B–1 – 3 B-2 - 2 C –3 F-3 – 2 Table 16	1-h enclosure or sprinklers required for occupancies that are of a higher hazard classification relative to the building occupancy (6-5111).	NFPA 101 allows fire sprinklers in lieu of fire rated separation.
	Separate Spaces – Spaces classified in occupancy groups having the same or lower fire index than the occupancy group classification of the building shall be separated by "Fire Separations" constructed in accordance with Section 27-504.1(b).		Auxiliary use, 48-12.2 <5 % of principal use: no separation required >5 % of principal use when permitted by Building and Fire Commissioners: no separation required.	Higher hazard uses incidental to main use is to be separated in accordance with Article 4 213.2	Places of assembly must be protected from all neighboring occupancies by location, separation or protection. Language in appendix section indicates flexibility on approach to protecting the place of assembly. (8-1121).	
	Separations are not required between accessory business and mercantile activities limited in area to 100 ft^2, and closets 75 ft^2 or less in area (Table 5-1 notes b,c).		Auxiliary use is defined as spaces normally provided and incidental to the principal use and under the same management and control as the principal use.		Places of assembly must be separated from storage rooms by either automatic sprinklers or by 1 h construction (8-1731 c.)	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Multiple occupancy or use - When a building or space is used for multiple purposes at different times, the building/space shall be given a separate occupancy group classification for each of the activities. The design and construction shall be in accordance with the most restrictive provisions that apply to any of the classifications (C26-301.6).		4 h separation required to public space below grade (subway). 48-12.6	Two or more use groups have the provisions of the Basic Code that apply to each use applied separately. 213.1	Boiler rooms, refrigeration machinery rooms, etc. must be enclosed in 1 h construction and cannot be located under or adjacent to exits in assembly areas (8-1731 a.)	The Chicago Building Code requirement for a 4 h separation to public space below grade was unique. The specificity of the NYC Building Code regarding the treatment of mixed use buildings was unique at the time.
	A minor variation of occupancy or use of a space is acceptable without multiple classifications if the variation is normally associated with the occupancy classification and no specific danger or hazard is created (C26-301.6).			No requirements.		
A.4 Construction						
Construction Classification	Noncombustible Construction Group I, Class IA or Class IB (unsprinklered building with unlimited height and area) in accordance with Section C26-313, C26-314 and Table 3-4 (C26-316.1, C26-403.1, C26-405.1, C26-406.1).	Noncombustible Construction, Fire Resistive Type 1a or Type 1b Permits unlimited height and fire area (C202-2, Table C202.2, C203-1(e), Table C203-1a)	Tables 51-1.2 & 51-1.3 Type I-A non-combustible fire resistive construction permits unlimited height and area except for Class F mercantile and Class H-3 garage.	Class 1A or 1B (unsprinklered building with unlimited height and area). Table 6	Not addressed for applicable occupancies and building types.	A Type I-A Construction Building under the Chicago Building Code requires some building elements to have a higher fire resistance rating than a Type IB Construction Building as defined by the NYC or NY State Building Codes. These differences are noted below.

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code		Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	This classification is based on Occupancy Group E (Business) building and Occupancy Groups B-1 (Storage, Moderate Hazard) and B-2 (Storage, Low Hazard, Parking Garage) spaces. These classifications permit unlimited height and area for the occupancy groups involved.		Height and fire area based on Group C1 occupancy (low hazard) Buildings of group C1 occupancy are classified as low hazard (C202-3(a)).	Class F is limited to a base area of 30, 000 ft^2 with a 100 % increase for automatic sprinklers and up to a 100 % increase for perimeter access. These are cumulative. For buildings over 8 stories, the area is reduced by 35 % Maximum area for Class F is 78,000 ft^2.	This classification is based on Occupancy Group E (Business) building and Occupancy Groups B-1 (Storage, Moderate Hazard) and B-2 (Storage, Low Hazard, Parking Garage) spaces. These classifications permit unlimited height and area for the occupancy groups involved.			
	The building is located inside the Borough of Manhattan Fire District without additional restrictions imposed based on its use and occupancy (C26-402.1, C26-403.1).		Fire Limits A comprising areas containing highly congested business and commercial occupancies, wherein the fire hazard is severe. (C401-2.1)	For Class G-3, base area is 25,000 ft^2 with a maximum area of 65,000 ft^2. Regardless of above, basements (all occupancies) are limited to 40,000 ft^2 between fire walls 51-2.4	No requirements.			
Minimum Fire Resistance Ratings	Element (Table 3-4) (Construction Class IB)	Hours	Structural Element Type 1b Fire-resistive (Table C202.2) Hours	Table 49-8	Element (Table 5) Type 1B		Not addressed for applicable occupancies and building types	
			Fire-resistance ratings of structural members shall be determined in conformity w/ generally accepted standard fire test procedure.					
	Exterior Walls				Exterior Walls			
	Bearing	3	3	Exterior bearing walls 4 h	Bearing	3		Chicago Building Code requirement for 4 h rated exterior bearing walls was unique. Exterior bearing walls are not common in high rise buildings.
				(Unprotected openings permitted > 12 ft separation 62-2.4)				

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code		Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Nonbearing (based on exterior separation):		(see Table C401-3.2 for minimum distance separations and Sec. C401-3.3(b))	Exterior non-bearing walls (based on exterior separation)	Nonbearing (based on exterior separation)			
	3 ft or less with 0 % openings.	2	2 (less than 5 ft)	2 h < 30 ft separation	6 ft or less	3 Bearing 2 Non-bearing		
	Greater than 3 ft up to less than 15 ft with 3½ % protected openings.	2	2 (5 ft to less than 10 ft) 0 h (with 3 ft spandrel) (10 ft or more)	2 h < 30 ft separation (Unprotected openings permitted > 12 ft separation)	Greater than 6 ft up to less than 11 ft	3 Bearing 2 Non-bearing		
	15 ft to less than 30 ft with 3½ % openings.	1½	0 h (with 3 ft spandrel) (10 ft or more)	2 h < 30 ft separation (Unprotected openings permitted > 12 ft separation)	11 ft to less than 30 ft	3 Bearing 1½ Non-bearing		NYC – 1.5 h NYS – 1 h Chicago – 2 h
	30 ft or greater with unlimited openings.	NC	0 h (with 3 ft spandrel) (10 ft or more)	1 h > 30 ft separation (Unprotected openings permitted > 12 ft separation)	30 ft or greater with unlimited openings.	NC		
	Fire Divisions				Fire Divisions	Table 16		
	Between Group B-1 and B-2, C, E or F-4.	3						
	Fire Separations		(Sec C402-4 and Table C402-4)					

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code		Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Between Groups E and B-2, C or F-4.	No requirements.	C1 and C2 – 3 h C1 and C4.1 – 2 h C1 and C4.2 – 3 h C1 and C5.1 – 2 h C1 and C5.2 – 3 h C1 and C5.3 – 4 h	Table 48-12.5 H-3 to C-1, 4 h with no openings between them H-3 to C-2, 4 h H-3 to E, 2 h H-3 to F, 3 h E to F, none required E to C-1, 4 h E to C-2, 2 h F to C-1, 4 h F to C-2, 2 h				NYC – No ratings NYS – 2 to 4 h
	Tenant Separations	1	1 (also C402-4)	2 h every 10,0000 ft^2 62.5	Tenant Separations	¾		Chicago – 2 h fire rated separation required every 10,000 ft^2.
	Constructed as Fire Separations continuous through concealed spaces of floor or roof construction above.				Constructed as Fire Separations continuous through concealed spaces of floor or roof construction above.	2		
	Interior bearing walls and partitions.	3	3	4 h Table 49-8	Interior bearing walls and partitions.	3		Chicago – 4 h
	Vertical exits and exit passageways (C26-604.8).	2	2 h on outside exposure 1 h on inside exposure	2 h > 3 stories 62-3.1 1 h < 4 stories	Vertical exits and exit passageways	2	2 h vertical exits required for noncombustible buildings 4 or more stories in height (601114). Exit passageways must be 2 h rated in buildings over 3 stories in height (5-7121(b)).	

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code		Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Separation of above and below grade portions in common enclosures (C26-602.4)	1	1 or 2 h (based on exposure) (C212-6(e), C402-4.6(g))		Separation of above and below grade portions in common enclosures			No comparable requirement in the Chicago Building Code.
	Hoistways and shafts (C26-504.6, C26-1800.6).	2	2	Hoistways 2 h 62-3.3 Shafts 1 h 62-3.4	Hoist ways and shafts	2	2 h shafts required for noncombustible buildings 4 or more stories in height (6-1113)	
	Columns, girders, trusses (other than roof trusses) and framing.			Columns	Columns, girders, trusses (other than roof trusses) and framing.			
	Supporting one floor.	2	2	- Exterior 4 h - Interior supporting floor 4 h - Interior supporting roof only 3 h	Supporting one floor.	2		Chicago – 4 h
	Supporting more than one floor.	3	3	Beams, girders, trusses Supporting roof only 2 h Supporting floor 3 h	Supporting more than one floor.	3		
	Structural members supporting walls.	3			Structural members supporting walls.	3		
	Floor Construction, including beams.	2	2	Floor construction 3 h	Floor Construction, including beams			Chicago – 3

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code		Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Ceilings that contribute to the required rating shall be continuous between exterior walls, vertical fire divisions or vertical partitions having the same rating as the ceiling (C26-502.5).							
	Roof construction including beams, trusses and framing, arches, domes, shells, cable supported roofs and roof decks (based on height of lowest member above floor).				Roof construction including beams, trusses and framing, arches, domes, shells, cable supported roofs and roof decks (based on height of lowest member above floor).			
	15 ft or less	1½	1	2 h	15 ft or less	1½		
	Greater than 15 ft up to 20 ft	1	1	1 h	Greater than 15 ft up to 200 ft	¾		
	20 ft or greater	NC	0 (C402-3(c))	NC	20 ft or greater	0		
	Exit access corridors (C26-604.2(h)).	1	1	1 h w/unlimited ¼ plate glass. 62-5	Exit access corridors	2		
	Area of refuge separation (C26-604.5, C26-604.6).	2			Area of refuge separation	2		NYC Building Code requirements addressing areas of refuge were unique.
	Escalators not used as exits (C26-604.11).	¾	0 (C211-1(b), C402-4.6)	6 ft sprinkler spacing w/18 in. draft curtain 62-3.3	Escalators not used as exits	No requirements.		
	Escalators that connect two stories may be unenclosed.		Stairs used as intercommunicating or access stairs between not more than 2 floors need not be enclosed		Escalators that connect two stories may be unenclosed	No requirements.		

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
Minimum Fire Resistance Ratings of Enclosures	Transformer vaults (greater than 35,000 V) (NEC).	3		Heating plants and boilers >15 psi & 10 HP or >200 people in building, 2 h, otherwise 1 h 62-4	Addressed above	Addressed above in "Occupancy Separations."	
	Emergency generator and fire pump rooms.	2					
	Storage rooms (B-1) greater than 75 ft^2 (Table 5-1 note c).	1					
Protection of Openings	Openings in a 3 h rated Fire Division or Fire Separation wall (Class "A") (C26-504.4 and Table 5-3).	3	3 (C402-4.10, Table C402-4.10)	Openings in 4 h wall, double Class "A" doors 62-1.5	3 908.3	Fire doors must be installed in accordance with NFPA 80 -1966 edition (6--6112).	
	Openings in 2 h or 1½ h rated Fire Division or Fire Separation wall or vertical communication enclosure (Class "B") (C26-504.4, Table 5-3, C26-604.4(a), C26-1800.6).	1½	1½	Openings in stair enclosures "B" 62-3.6	1½ 908.4	Smoke stop doors must self-closing metal or metal covered or of treated wood construction and with wired glass panels permitted (6-6111).	
	Openings in 1 h rated vertical communication enclosure (Class "B).	1		Openings in corridors equal to or > 1.75 in. solid slab doors or noncombustible doors. 62-5	1	Hazardous enclosures require self-closing or automatic fire doors (6-5112).	
	Openings in 1 h rated Fire Division or Fire Separation walls, corridors or partitions (Class "C") (C26-504.4, Table 5-3, C26-604.4(b)).	¾	¾		1	Fire doors must be positive latching. Smoke stop doors are not required to be positive latching (6-6113).	
	Non-combustible mail slots not exceeding 40 $in.^2$ may be provided in corridor doors (C26-604.4(b)).		No requirements.		No requirements.		

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Non-combustible louvers may be installed in corridor doors opening into toilets, service sink closets and electrical closets (C26-604.4(b)).				No requirements.		
	Required protected openings in exterior walls (Class "E" or Class "F") (C26-503.1(b)).	¾			Required protected openings for other than F-4, L-2 and L-3, or Type 4 construction 916		
	Openings in Fire Divisions and Fire Separations shall not exceed the size limits in Section C26-504.4(a).		Openings shall not exceed 120 ft^2 (240 ft^2 w/ sprinklers) or an aggregate width of 25 % of the length of the wall (C402-4.10i)		Openings in Fire Divisions and Fire Separations shall not exceed the size limits in 908.1 and 910.3		
	In shafts that contain only one opening below the roof, no opening protective is required (C26-504.6(c)).				Shall be in accordance with Article 8 and Table 5		
	Exterior street floor exit doors with a fire separation distance of more than 15 ft need not have a fire resistance rating (C26-604.4(a)(1).				Required protectives may be omitted for openings facing street or 30 ft wide public way and not more then 25 ft above grade 916.4		
Fire and Smoke Dampers	Fire dampers shall be provided in accordance with Reference Standard 13-1, NFPA 90A-1967 (C26-504.5(a)).				Fire dampers shall be provided in accordance with Reference Standard NFPA	Required to have means of control of smoke spread in AC systems serving Class A assembly or Class A store; smoke damper could serve this purpose (7-1123).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Duct penetrations of walls with a 2 h fire resistance rating or greater (RS 13-1 §902(a)).			Openings in fire partitions need to have opening protectives in accordance with 903 and 918 909.42	Fire dampers required in HVAC systems that serve more than one floor or fire area (7-1122).	
	Each opening in required vertical shaft enclosures (RS 13-1 §902(b)).			Openings in shafts shall be protected with approved fire doors, curtains, shutters, or fixed metal sash with wired glass. 911.7	HVAC systems shall be installed in accordance with NFPA 90A – 1966 edition; fire damper location and smoke damper locations in NFPA 90A shall be followed (7-1111).	
	Each outlet or inlet opening in vertical shaft enclosure of duct systems serving two or more floors (RS 13-1 §902(c).			See above.	Automatic fire doors (Class A) must be provided at fire walls (NFPA 90A 131).	
	As an alternate, dampers may be provided at each point where the vertical duct pierces a floor it serves (RS 13-1 §902(c).			See above.	Fire damper at fresh air intake (NFPA 90A 136).	
	Branch duct penetrations of vertical duct shaft enclosures (RS 13-1 §902(c).			See above.	Fire damper at duct shaft enclosures (NFPA 90A 135).	
	Fresh air intakes (RS 13-1 §902(e)).			Installed not less than 12 ft above grade located less than 30 ft exposure distance shall be protected with approved opening protectives.	Fire damper at fire partition penetrations (NFPA 90A 134).	
	Aluminum or Class I duct penetrations of fire resistance rated floors (RS 13-1 §902(d)).			No requirements.	Smoke dampers (or other means of smoke spread control) on main supply and return ducts suggested for systems over 15,000 cfm that serve large numbers of people or have valuable contents (NFPA 90A 135 (b)).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Fire dampers are not required at the following locations (RS 13-1 §903).			No exceptions.		
	Non-aluminum or Class I vertical shaft branch duct penetrations with a cross-sectional area of less than 20 $in.^2$ which supply only air conditioning units discharging air at not over 4 ft above the floor (RS 13-1 §903(a)).			No requirements.		
	Non-aluminum or Class 1 duct penetrations of a floor (at one place only) with a cross-sectional area of less than 20 $in.^2$ which supply air conditioning units in one story only that discharge air at not over 4 ft above the floor (RS 13-1 §903(b)).			No requirements.		
	Duct penetrations in systems serving only one floor and used only for exhaust to the outside and not penetrating a fire wall or fire partition or passing entirely through the vertical shaft enclosure (RS 13-1 §903(d)).			Exterior exhaust openings shall be located not less than 12 ft above grade and not less than 20 ft from a fire escape stairway or other required exit.		
	Branch ducts connected to a return riser where subducts are extended at least 22 in. upward (RS 13-1 §903(e)).			No requirements.		
	Fire dampers shall be automatic closing 1½ h fire rated with a fusible link or other heat actuated device rated approximately 50 °F above the maximum system operating temperature (RS 13-1 §905(a) and §905(g)).			No requirements.		
	Duct openings permitted in fire resistance rated ceilings shall be protected with fire dampers (C26-502.5(a)).			Duct openings permitted in fire resistance rated ceilings shall be protected with fire dampers (913.2).		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Smoke dampers shall be installed in the main supply duct and the main return duct in systems over 15,000 cfm capacity (RS 13-1 §1003).			No requirements.		
	Smoke dampers shall be arranged to close automatically when the system is not in operation, by the operation of duct smoke detectors, and by the manual emergency fan stop (RS 13-1 §1003).			No requirements.		
Firestopping	All firestopping or fill materials shall consist of approved noncombustible materials that can be shaped, fitted and permanently secured in place (C26-504.7(a)).	Firestopping or fill shall be nonflammable material shaped and fitted and permanently secured in position. (C402-5.2)	Only mentioned for ducts <9 ft^2 not in shafts. Space around ducts to be filled with noncombustible material securely held in place. 62-3.4	All fire stopping or fill materials shall consist of approved noncombustible materials that can be shaped, fitted and permanently secured in place (921.2).	The following concealed spaces that have materials with a flame spread rating greater than Class A must be fire-stopped unless they are sprinklered (6-1311):	The NYC Building Code included the most comprehensive requirements for firestopping.
	Concealed spaces within partitions, walls, floors, roofs, stairs, furring, pipe spaces, column enclosures, etc. that would permit passage of flame, smoke, fumes or hot gases from floor-to-floor shall be firestopped or filled with noncombustible material in the following locations (C26-504.7):	Concealed spaces within walls, partitions, floor, stair, around duct openings, etc. shall be firestopped or filled with noncombustible materials to prevent the passage of flame, smoke, fumes and hot gases. (C402-5.1)		Shall be designed and constructed to close all concealed draft opening for subdivision of attics, combustible wall partition and floor framing, ceiling spaces, open spaces behind finishes, floor sleeper spaces, pipes, ducts and for fire dampers and curtains.	Exterior and interior walls and partitions must be fire-stopped at each floor level.	
	Hollow partitions and furred spaces			See above.	Space between the ceiling and floor above for full depth of the space along the line of support for the floor or roof structural members. Areas formed must be 1,000 ft^2 or less and up to 3,000 ft^2 between ceiling and roof.	
	Concealed spaces within stair construction.			See above.		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Ceiling spaces within rated floor or roof assemblies			See above.		
	Exterior cornices			See above.		
	Duct and pipe spaces (C26-504.5 and RS 13-1 §313, §314)			See above.		
	Hollow vertical Fire Division (C26-504.2(i))			See above.		
	The concealed space above a fire resistance rated ceiling shall be firestopped into areas not exceeding 3,000 ft^2 (C26-502.5), except where:			See above.		
	Structural members within the concealed space are individually protected, or			Structural members within the concealed space are individually protected.		
	The concealed space is sprinklered.			No requirements.		
Through Penetration Protection	Noncombustible pipes and conduits may pass through fire resistance rated construction provided the following (C26-504.5):			Protect in accordance with 921.1	Not addressed.	The NYC Building Code was unique with its comprehensive requirements for through penetration protection.
	Space between the pipe or conduit and its sleeve or opening does not exceed ½-in. and is packed with noncombustible material.			Space between the pipe or conduit and its sleeve or opening does not exceed ½ in. and is packed with noncombustible material 1117.1.		
	Close-fitting metal escutcheons are provided on both sides of the construction.			No requirements.		
	Aggregate net area of openings does not exceed 25 $in.^2$ in any 100 ft^2 of wall or floor area.			No requirements.		
	Openings in excess of this limit are not permitted unless tested as part of a rated assembly and so protected.			No requirements.		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Ceilings required to have a fire resistance rating may be pierced to accommodate noncombustible electric outlet boxes, recessed lighting fixtures, pipes and ducts as follows (C26-502.5(a)):			Ceilings required to have a fire resistance rating may be pierced to accommodate noncombustible electric outlet boxes, recessed lighting fixtures, pipes and ducts as follows 913.2		
	The aggregate area of outlet boxes and lighting fixtures does not exceed 16 $in.^2$ in each 90 ft^2 of ceiling area.			The aggregate area of such openings in the ceiling shall be not greater than 100 $in.^2$ in any 100 ft^2		
	Outlet boxes and lighting fixtures are constructed of steel at least .022 in. thick and sealed tightly at the ceiling.			No requirements.		
	Additional or larger services are permitted only when tested as part of the assembly and protected as provided in the test.			No requirements.		
	The concealed space above fire resistance rated ceilings may be used as a supply and return air plenum if tested for that purpose (RS 13-1 §316), provided:			The concealed space above fire resistance rated ceilings may be used as a supply and return air plenum 1814.1		
	All openings are tested as part of the assembly and protected in the test,			No requirements.		
	The integrity of firestopping is not destroyed,			No requirements.		
	No combustible materials are incorporated in the floor and ceiling construction, and			No requirements.		
	Electrical wiring complies with NEC NFPA 70 §300-22).			No requirements.		

	Then Current NYC Building Code		Then Current NY State Building Code		Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code		Summary of Significant Differences
A.5 Interior Finish									
Interior Finish and Flame Spread Ratings	Exits and shafts (C26-504.10(c), Table 5-4, C26-604.8 (i)(3)):	Class A (0-25)	Exit stairway, passageways (C403-2, C403-3b)	Class A (0-25)	62-9.3 Class 1 0-15 Class2 16-30 Class 3 31-60 Class 4 61-160	Class I Table 16B			NYC and NYS same. The Chicago Building Code used different classifications. However, requirements are similar. The NYC Building Code is more detailed in its requirements.
								Class B; Class C if sprinklered	
	Corridors (C26-504.10(c), Table 5-4, C26-604.2(k)):		Corridors and passageways not part of enclosed exit (C403-3b)	Class A or B	Stairs, elevator shafts and stair connections to outside, Class 1 62-9.5		Class B		
							Business - including corridors (13-132)	Class A	
	Group B-1:	Class A (0-25)	See above.		Business, Class 3, 62-9.5	Class III Table 16B	Mercantile (12-132)	Class A	
							Assembly , including exit access (8-172)		

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code		Summary of Significant Differences
	Groups B-2, E, F-4	Class A or B (0-75)	See above.	Assembly and Mercantile >100 people, Class 1	Groups B-2 E Class III Table 16B	Storage	Ceilings-Class B; Class C if sprinklered Walls-Class C Exposed structural members may be heavy timber	
					F-3 Class II Table 16B	Other spaces	Class B Exposed structural members may be heavy timber	
	Group M:	Class A or B (0-75)	See above.	Public lobbies, Class 1, 62-9.5	Group C Class III Table 16B	Mercantile – Class A or B Store	Class C Exposed structural members may be heavy timber	
								Assembly - Class A & B places of assembly
	When used in corridors, Class B finish material shall not extend more than 50 ft between separations of Class A finish material that are at least 2 ft wide (Table 5-4 note b).			Class 4 permitted up to 5,000 ft^2 in each 2 h compartment. 62-9.5	No requirements.	Where Class A or B interior finish is required, up to 10 percent of wall and ceiling areas may be Class C (6-2141).		Assembly – Class C place of assembly
	Spaces through which it is necessary for occupants of an adjacent room to pass in order to reach the only exit are considered as corridors.				No requirements.	Class E interior finish is discouraged; where permitted by AHJ, Class E interior finish cannot exceed 10 percent of wall and ceiling areas (6-2153).		
	Rooms and enclosed spaces:				No requirements.			

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Rooms greater than 1,500 ft^2 (C26-504-10(c), Table 5-4):				No requirements.		
	Groups B-1, B-2, F-4	Class A or B (0-75)			See above.		
	Group E	Class A, B or C (0-225)			See above.		
	Rooms less than 1,500 ft^2 (C26-504.10(c), Table 5-4):				No requirements.		
	Group F-4	Class A, B or C (0-225)			See above.		
	Groups B-1, B-2, E	Class A, B or C (0-225)			See above.		
	Interior finish in kitchens, cooking spaces, pantries, repair and maintenance shops, boiler rooms and incinerator combustion rooms shall be Class A or B (0-75) (Table 5-4 note f).		Kitchen, pantries, repair and storage rooms – Class A or B. (C403-3c)		No requirements.		
			When sprinkler system is provided, Class B permitted where Class A required and Class C permitted where Class B required (C403-3)				
Smoke Development Ratings	25 or less in exits and corridors.				No requirements.	Not required.	The NYC Building Code was unique in having requirements for smoke development ratings. Requirement in NYC only
	100 or less in rooms where the net floor area per occupant is 10 ft^2 or less.				No requirements.		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	No material shall be used in any interior location that upon exposure to fire will produce products that are more toxic in point of concentration than those given off by wood or paper (C26-504.10(e)).			No requirements.		
Interior Trim	Up to 20 % of the aggregate wall and ceiling area of any room or corridor may be finished with Class A, B or C (0-225) materials and be exempt from the smoke developed rating requirements (C26-504.10 (c)(4), C26-504.10 (d)).	Use of interior trim (C403-4). Attachment of interior finish and trim (C403-5).	Exit enclosures and exit connections, Class 2, 62-9.6 Assembly rooms >1,000 persons, Class 2, 62-9.6 All other rooms and spaces, Class 4, 62-9.6	No requirements.	Addressed above in "Interior Finish."	
	This allowance shall include the area of doors, folding partitions, windows, glazing, skylights, luminous ceilings, trim, bases, chair rails, panels, moldings, etc.			No requirements.		
Finish Flooring	Finish flooring in all exits shall be of noncombustible material (C26-504.13, C26-604.8(h)).		Wood applied directly to noncombustible floor construction or to sleepers with all spaces filled with noncombustible material in buildings >100 ft in height. Composition flooring not exceeding 0.5 in. thickness may be used. 62-10.3	Finish flooring in all exits shall be of noncombustible material (924.0).	Finish flooring and floor coverings are exempt from interior finish requirements (6-2112).	
	In all other areas, combustible finish flooring may be used when installed in accordance with Section C26-504.13 (b).	Wood finish flooring shall be attached directly to noncombustible floor construction or to wood subfloor fastened to wood sleepers or over insulation board (C403-5f).		In all other areas, combustible finish flooring may be used when installed in accordance with (924.0).		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
A.6 Means of Egress						
General	Clear width measurement is the net, unobstructed width of a means of egress without projections in such width (C26-604.2(a), C26-604.3(b)).		Doors – nominal width Stairs – clear width with 4 in. projection on each side permitted. 67-7.3	No requirements.	Clear width measurement is the narrowest point in means of egress. A handrail may project into the measured width on each side by not more than 3½ in. A stringer may project by not more than 1½ in. (5-1152).	The NYC Building Code requirements addressing exits are more detailed as illustrated below.
	In corridors, projections up to 18 in. wide to the extent of 2 in. per unit of egress width are permitted if the total area of such projections does not exceed 5 % of the area of the wall on which they occur (C26-604.2(a)).		Corridors – Clear width with zero tolerance door projection when open to any position. 67-7.3	No requirements.		
	Handrails shall project not more than 3½ in. and stringers 2 in. (each side) into the required stair width (C26-604.8(b), C26-604.8(f)).			Projection of handrails to be not more than 3½ in. (618.5).		
	Corridor and exit passageway minimum height 7 ft - 6 in. for at least 75 % of the floor area with no point less than 7 ft (C26-604.2(b), 604.3(c)).	Minimum floor to ceiling height of 7 ft-6 in. (C212-2a)	7 ft in stairs. Other areas not mentioned. 67-10.6	A minimum clear ceiling height of 8 ft (613.2).	Ceiling height must be at least 7 ft 6 in. (5-1231).	NYC min. 7 ft 6 in. BOCA min. 8 ft NFPA min 7 ft 6 in.
	Projections from the ceiling shall be at least 7 ft above the floor and located so as not to obstruct full view of exit signs (C26-604.2(b), 604.3(c)).			No requirements.	Projections from ceiling are required to be at least 6 ft 8 in. from floor (5-1231).	NYC min. 7 ft above floor NFPA min. 6 ft 8 in. above floor
	Changes in elevation in means of egress:					
	Changes in level requiring less than two risers in a corridor or exit passageway shall be by a ramp (C26-604.2(e), C26-604.8(d)(2)).			No requirements.	Changes in level must be negotiated with stairs or ramps (5-1206).	
	Obstructions to means of egress:					

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	The required width of a means of egress shall not be obstructed or reduced in any manner (C26-604.2).			It shall be unlawful to obstruct, or reduce in any manner the clear width of any doorway, hallway, passageway or any other exit way (607.1.).		
	Corridors shall be kept free of combustible contents (C26-604.2).			No requirements.		
	All exterior means of egress elements, including exterior corridors and stairs, shall be maintained free of ice and snow accumulation (C26-604.2, C26-604.9).			All exterior means of egress elements, including exterior corridors and stairs, shall be maintained free of ice and snow (607.3).		
	Corridors may be used as supply or return air ducts or plenums if equipped with an approved smoke detector or thermostatic device to shutdown fans (C26-604.2(j), RS 13-1 Sec. 316(d).			In all corridors, hallways or exit ways which are used as return exhaust of air conditioning systems, an approved smoke detector or other device shall be provided to automatically and instantaneously stop the exhaust fan in the presence of smoke (1814.6).		
	Stairways connecting two or more stories shall not be used as plenums (RS13-1 Sec. 316(e)).					
Exits	Every floor area shall be provided with at least two approved independent exits (C26-603.2).		2 exits from every floor. 67-4	Every floor area shall be provided with at least two approved independent exits (611.1).	Every floor must have at least two exits for the occupancies and building configuration considered, including parking garages; more exits are required from Class A and Class B places of assembly (8-122 12-124 13-125	The NYC Building Code contains more detailed requirements.
	Public garages shall be provided with at least two exits from each tier of parking (C26-709.8).	Each fire area in excess of 5,000 ft^2 of a garage shall be provided with 2 exits (C213-1d).		No requirements.	Storage floors areas may have one exit if they are less than 15,000 ft^2 in area or have less than 10 persons present (15-1211).	

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	A minimum of two exits or exit access doors shall be provided from every room or space in which the occupant load exceeds the following limits (C26-603.1):			Number of exits per room only required for assembly occupancies	In business buildings not over 3 stories in height of 4,000 ft^2 in area or type 1 construction or protected noncombustible (type 2-A) construction and in other construction types not more than 2 stories in height nor more than 3,000 ft^2 in area one exit stairway is permitted (611.32) Every room with an occupancy of more than 75 or exceeds 1,500 ft^2 in area, shall have at least 2 exit doorways ((614.1)).	One exit is permitted from street level Class C Mercantile occupancies that have no portion of the store that is not within 50 ft of from the street door (12-1244)	
	Occupancy Group	Occupant Load					
	B (Storage)	50			See above.	One exit is permitted from street level office spaces having less than 100 occupants and a maximum travel distance of 100 ft	
	C (Mercantile)	75			See above.		
	E (Business)	75			See above.		
	F (Assembly)	75			See above.		
	All required exits shall be located such that they are clearly visible, accessible and unobstructed access at all times C26-602.1).				Direct access shall be provided to stairways or other required means or egress through continuous passageways, aisles, or corridors, conveniently accessible to all occupants and maintained free of obstruction. (612.1).		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	In multi-tenant configurations, each tenant shall have access to the required numbers of exits without passing through other tenant spaces (C26-602.2).					
	Whenever more than one exit or exit access is required from any room, space or floor of a building, they shall be located as remote from each other as practicable (C26-602.3).		Whenever more than one exit is required they shall be placed as far apart as practicable. 67-5.2	Whenever more than one exit or exit access is required from any room, space or floor of a building, they shall be located as remote from each other as practicable (609.2).	Exits must be remote from each other as practicable; no specific separation distances for exits.	
	Door openings to scissor stairs shall be at least 15 ft apart (C26-602.3).					
	All vertical exits shall extend in a continuous enclosure to discharge directly to an exterior space or at a yard, court, exit passageway or street floor lobby of the required width and size to provide all occupants with a safe access to an open exterior space (C26-602.4).		No requirement that stairs discharge directly to the outside.	Every required interior and exterior stairway, which does not adjoin a street, shall be directly connected to the street or to an open court leading to the street be unenclosed passageway, hallway, lobby or other unobstructed exit way (613.1)	Exits must be continuous to the exterior, except for sprinklered street floors that have a 2 h fire rated floor slab at street level (5-1222) and: -In Mercantile occupancies, 50 percent of required exit units can discharge on the street floor provided that the travel distance on the street floor is 50 ft or less. (12-1271). -In fully sprinklered Office occupancy buildings, 50 % of required exit units can discharge on the street floor provided that the travel distance on the street floor is 50 ft or less (13-1271). -Not permitted for Assembly and Storage occupancies.	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	A maximum of 50 % of the required number of vertical exits is permitted to discharge through a single exit passageway (C26-604.3).			No requirements.		
	100 % of the number of vertical exits may discharge through a street floor lobby if egress is provided in two different directions from discharge points to open exterior spaces remote from each other (C26-604.3(h)(1)).			No requirements.		
	The clear width of an exit passageway serving two or more vertical exits shall be equal to 75 % of the width of all vertical exits it serves (C26-604.3(b)).			The effective width of the lobby or other enclosed passageway shall be not less than ¾ of the aggregate width of all exit doors opening into lobby ((613.2).).		
	The width of street floor lobbies serving as exit passageways shall be increased to accommodate the occupant load of all communicating spaces on the lobby floor that exit through them (C26-604.3(h)(2)).		Grade floor exits sufficient for occupant load of grade floor plus capacity of stairs from above and below. 67-7.4	No requirements.	Street floors used for exit discharge in Mercantile occupancies must be wide enough to accommodate both exit discharge occupants and occupants of street floor (12-1271(d)).	
	No openings other than exit doors are permitted in exit passageways (C26-604.3(f)), except:			No requirements.		
	Openings between street floor lobbies serving as exit passageways and elevators or communicating spaces and show windows protected in accordance with Section C26-604.3(h)(3) are permitted (C26-			Show windows opening on lobbies that serve as exit passageways shall be protected with automatic sprinklers or shall be backed with fire partitions of 2 h rating (613.92) Sprinklered buildings are exempt from (613.42), (613.44).		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Street floor lobbies serving as exit passageways may be occupied by newsstands, candy and tobacco stands, information booths or similar occupancies if constructed of noncombustible materials, occupying not more than 5 % of the net lobby floor area, and if not reducing the required clear width at any point (C26-604.3(h)(4)).			Sales spaces not exceeding 100 ft^2 in area shall be permitted (613.0).		
	Horizontal and Supplemental Vertical Exits (C26-604.5 to C26-604.7).			Horizontal exits (616.0).	Horizontal Exits (5-5)	The NYC Building Code was unique in addressing horizontal exits.
	The occupant load capacity for vertical exits may be reduced by 50 % when one area of refuge is provided and by 66 % when two or more areas of refuge are provided (C26-603.3).			Horizontal exits shall be accepted as an approved means of exit (616.0). The capacity per story per unit exit width or stairway may be increased 50 % above the value in table 12, (610.4).	Horizontal exit may be substituted for other exits so that the exit capacity will not be reduced below half that required for the entire area of the building if there were no horizontal exits (5-5112.)	
	At least 3 ft^2 per person of clear public space, or space occupied by the same tenant or owner, shall be provided within the area of refuge for the occupant load received in addition to its own occupant load (C26-604.5(b)).			The capacity of required areas of refuge enclosed within fire partitions of firewalls shall be computed on a net floor allowance of 3 ft^2 (610.6).	The floor area on either side of a horizontal exit must be sufficient to hold occupants of both floor areas allowing not less than 3 ft^2 clear floor area per person (5-5124.)	
	Each area of refuge shall be provided with at least one vertical exit and when located above the 11th floor, the vertical exit shall be supplemented by at least one elevator (C26-604.5(c)).			There shall be at least 1 interior enclosed stairway of fire tower on each side (616.51).	Every area of refuge (fire section) must be served by a vertical exit or a door leading directly outside (5-5121).	
	Access to an area of refuge, on the same floor, through a horizontal exit, may consist of doors, balconies, bridges and tunnels (C26-604.6).			Access to an area of refuge may be accomplished by protected openings in firewall by a vestibule, or by open – air balcony or bridge (616.0).		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Doors must swing in the direction of exit travel and be self-closing having a fire resistance rating of 1½ h. Where areas of refuge are provided on both sides of a horizontal exit, two door openings shall be provided, each swinging in opposite directions (C26-604.6(b)).		Doors must swing in the direction of egress when: Outside serving > 50 people. From offices serving >100 people All exit stair enclosures 67-9.1	Shall be protected with a one by 1½ h self-closing fire doors swinging in the direction of exit travel (616.1). Where areas of refuge are provided on both sides of a horizontal exit, two door openings shall be provided, each swinging in opposite directions (616.1).		
	Balconies, bridges and tunnels serving as horizontal exits shall comply with Section C26-604.6(c).			No requirements.	Bridges and balconies serving as horizontal exits must comply with Section 5-513.	
	Access to an area of refuge on a floor nearer to the street, through a supplemental vertical exit, may consist of enclosed interior stairs, ramps, or escalators (C26-604.7).			No requirements.	If a building has horizontal exits on its upper floors and the street floor is one fire area, the street floor and floors below it must be sprinklered (5-5152).	
	Supplemental vertical exits shall comply with the requirements for interior stairs, and serve no other purpose than to connect a floor area with an area of refuge with no openings in the enclosure other than exit doors (C26-604.7).			No requirements.	If a building has horizontal exits on it's below grade floors and the street floor is one fire area, the building construction must be fire resistive or have a fully sprinklered building. Also, all required exit must discharge directly outside (5-5153).	
	Every supplemental vertical exit shall have a sign at the entrance stating EXIT TO AREA OF REFUGE ON _____ FLOOR (C26-604.7).			No requirements.		

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code		Summary of Significant Differences
Egress Width and Capacity	Occupant load - calculate based on the net floor areas in square feet divided by the occupant load factor (square foot/person) or the actual number of occupants from whom each occupied space is designed, whichever is greater (C26-601.2).			Occupant load 48-13 Business 100 ft^2/person Mercantile 30 ft^2/person first floor and basement 60 ft^2/person other floors Restaurant 15 ft^2/person	Shall be calculated by the net floor area multiplied by occupant load factor from table 10, (608.1).	Occupant load – calculate based on the load factors given below in square foot/person. Where gross and net area figures are given for the same occupancy, the gross area must be applied to the building. Then a separate net area calculation shall be performed and the higher of the two shall be used (5-1161).		The NYC Building Code provided more specificity regarding determination of egress width and capacity.
	Occupancy	Factor			Table 10	Occupancy	Factor	
		(net square foot per person)	(gross square foot per person)					NYC – net square foot NYS – gross square foot
	Business (offices)	100	C1 First/Grade 200 Above-/Below- 150		100		100 gross	NYC – 100 NYC – 150 to 200
	Conference rooms (Tables)	12	C5 With seats 6 or 10 (Table C212-8a footnote 1)			Office, factory and workroom	30 gross	
							60 gross	
	Conference rooms (movable chairs)	10	C5 With seats 6 or 10 (Table C212-8a footnote 1)	Assembly: 60 per/unit stairs 90 per/unit doors	15	Store: street floor and sales basement	100 gross	
						Store: other floor		
	Dining spaces	12	C5 (Restaurant) 15	50 % increase for sprinklers	w/ fixed seats – 6 w/out fixed seats - 15	Store: storage and shipping	15 net	
							7 net	

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code		Summary of Significant Differences
	Mercantile – 1st floor / basement All other floors	 25 50	C2 - Retail (general) 50 - Clothing, Dept.. 100 - Furniture, hardware 150		30 60	Places of assembly	3 net	
						Assembly areas of concentrated use without fixed seating		
	Assembly (fixed seats)	# of seats			6	Assembly: standing space		
	Waiting space (standing)	4	C5 - waiting/standee 3					
	Garages / parking	250	C4.1 First/Grade300 Above-/Below- 250					
	Storage rooms	200	C4.1 First/Grade300 Above-/Below- 250		300			
	Mechanical rooms	200						
	Nonsimultaneous Occupancy - The occupant load of toilets, locker rooms, meeting rooms, storage rooms, employee cafeterias, and similar rooms or spaces that are not occupied at the same time as other rooms or spaces on the same floor may be omitted from the occupant load calculation of the floor on which they are located (C26-601.2).							
	The occupant load of any space shall include the occupant load of all spaces that discharge through it in order to gain access to an exit (C26-601.2).				No requirements.			

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Where vertical exits serve more than one floor, only the occupant load of each floor considered individually is used in computing the required capacity of exits at that floor, except where one floor is used by another as a means of egress (C26-601.1).			The width of every exit door to a stairway shall not be less than the number of units of exit width required for the capacity of the stairway, which serves the floor (616.61).	Where exits serve more than one floor, only the occupant load of each floor considered individually need be used in computing the capacity of the exits at the floor (5-1162).	
	Exit capacity (width) shall not decrease in the direction of exit travel (C26-604.8).		Exit capacity cannot decrease in direction of travel. 67-7.4	No stairway shall reduce in width in direction of exit travel (618.23).	Exit capacity cannot be decreased in direction of exit travel (5-1162).	
					When exits from above and below converge, the capacity of the exit from the point of convergence is cumulative of the two exits (5-1162).	
	The width of each means of egress component shall be that computed using the appropriate egress unit factor but not less than the minimum width prescribed for the component (C26-601.1, C26-601.3).			An interior required stairway shall be no less than 44 in. in width ((618.21).		
	Where computations give fractional results, the next larger integral number of egress units or integral number plus 2 shall be used (C26-601.3).			No requirements.		
	A fraction less than ½ may be neglected when constituting less than 10 % of the total required number of egress units).			No requirements.		
	Egress capacity factors - capacity per egress unit (C26-601.1, C26-601.3).			No requirements.		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	One unit of egress width is equal to 22 in. (C26-601.3).		One unit of egress width is 22 in. One half unit is 12 in. 67-7.2	The unit of exit width for all approved types of exit and exit way facilities shall be 22 in. (610.1).	Exits and exit access are measured in units of exit width of 22 in. Fractions of a unit do not count, except that 12 in. added to one or more units' counts as ½ a unit (5-1151).	
	Doors to outdoors at grade:				Doors to outside at grade (less than 21 in. above or below grade) have the following capacity, measured in occupant per unit width:	
	Occupancy Group B (Storage) – 75 persons per unit.		60/unit doors	From the first or grade floor direct exits shall be provided consisting of 1 unit/100 occupants (611.2).	Office and Mercantile occupancies and places of assembly – 100 (8-1211, 12-1231 and 13-1241)	
	Occupancy Groups C (Mercantile), E (Business), and F (Assembly) – 100				Stairs, Class B ramps and escalators in Office occupancies – 60 (13-1241)	
	Other exit and corridor doors:				Horizontal exits in Mercantile occupancies and Class A ramps and horizontal exits in public assembly and Office occupancies – 100 (8-1211, 12-1231, 13-1241)	1 unit/100 occupants
	Occupancy Group B (Storage) – 60				Stairs and escalators in Mercantile occupancies – 60 (12-1231)	
	Occupancy Group C (Mercantile), E (Business), and F (Assembly) - 80				Stairs, Class B ramps and escalators, public assembly spaces – 75 (8-1211)	
	Stairs and escalators:				Stairs in storage areas and parking garages – 45 (5-3131).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Occupancy Group B (Storage) - 45		Office and mercantile: 40/unit stairs 60/unit smokeproof tower		A single escalator is to be given 1 unit of exit width regardless of actual width (5-8125).	
	Occupancy Groups C (Mercantile), E (Business), and F (Assembly) - 60					
	Ramps, corridors, exit passageways, horizontal exits:					
	Occupancy Group B (Storage) - 75			Door width for corridors and passageways required for egress are same as stairs ((612.3)).		
	Occupancy Groups C (Mercantile), E (Business), and F (Assembly) - 100			75		NYC – 100 persons / unit BOCA – 75 persons / unit
	When ramp slope exceeds 1 in 10, the capacity shall be reduced by 25 % (Table 6-1 note b).			For slopes exceeding 1 in 10 ramp shall be surfaced with approved non-slip materials (617.0).		
	The capacity of horizontal exits shall be based on the width of doors swinging in the direction of exit travel (C26-604.6(a)).			Area of refuge size shall be adequate to house total occupancy load of connected areas (616.3).		
	Where a door is divided by mullions into two or more door openings each opening shall be measured separately in computing the number of egress units (Table 6-1 note m).			Where a door is divided by mullions into two or more door openings each opening shall be measured separately in computing the number of egress units (614.2).	Where a door has two or more leaves divided by mullions, units of exit width for the entire door is the sum of the units calculated separately for each leaf (5-2142).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
Doors	Minimum nominal width - 32 in. except for corridor and exit door openings which shall be 36 in. (C26-604.4(e)).		Min. width 36 in. 67-7.5	Minimum width 32 in. Minimum width of retail space doors opening to street 30 in. (614.2).	Minimum width – 28 in. (5-2151).	The Chicago Building Code requirement is based on nominal width of the door. NYC – 36 in. (corridors) BOCA – 32 in. NFPA – 28 in.
	Door jambs or stops and the door thickness when open shall not reduce the required width by more than 3 in. for each 22 in. of width (C26-604.4(e)).			No requirements.		
	In all cases where a door opening is divided by mullions into 2 or more door openings, the minimum nominal width of each such opening shall be 32 in. (C26-604.4(c)).			When doorways subdivided into 2 or more separate openings minimum width is 28 in. (614.2).		NYC – 32 in. BOCA – 28 in.
	Maximum width of leaf - 48 in. (C26-604.4(e)).			Maximum width 44 in. (614.2).	Maximum width – 48 in. (5-2152).	NYC – 48 in. BOCA – 44 in. NFPA – 48 in.
	Minimum height - 6 ft, 8 in. (C26-604.4(f)).					BOCA 44 in. NYC 48 in.
	Door jambs, stops, sills and closers shall not reduce the clear opening to less than 6 ft 6 in. (C26-604.4(f)).			No requirements.		
	The floor on both sides of all exit and corridor doors shall be substantially level and have the same elevation for a distance at least equal to the width of the leaf (C26-604.4(h)).			No requirements.	The floor on both sides of all exit and corridor doors shall be substantially level and have the same elevation for a distance at least equal to the width of the leaf (5-2153).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Where doors lead out of a building, the floor level inside may be 7 ½ in. higher than the level outside (C26-604.4(h)).			No requirements.	Where doors lead out of a building, the floor level inside may be 7 ½ in. higher than the level outside (5-2153).	
	Exit doors, corridor doors serving high hazard occupancy Group A spaces, and corridor doors from rooms required to have more than one door shall swing in the direction of egress (C26-604.4(g)).			Doors shall be hung to swing in the direction of exit travel (614.1).	Exit and exit access doors must swing in the direction of exit travel when serving more than 50 persons or when serving a high hazard space (5-1202, 5-2121).	
	Vertically sliding doors, rolling shutters, and folding doors shall not be used as exit doors or as corridor doors (C26-604.4(d)).			All required exit doors shall be self closing fire doors (614.5).	Ex and exit access doors must be side-hinged, swinging doors (5-1202, 5-2121).	
	Revolving doors designed and constructed in accordance with Section C26-604.4(m) are permitted to be used as exits except that revolving doors shall not be used as interior exit access doors, at the foot of stairs, or at the head of basement stairs (C26-604.4(d)).			Revolving door constructed in accordance with 615.9 permitted as required exits except in assembly occupancies with load of more than 200 or use group H, (615.11).	Revolving doors are permitted as street level exit doors in Mercantile occupancies (5-2201, 12-1282).	
	Turnstiles designed and constructed in accordance with Section C26-604.4(n) may also be permitted.			Turnstiles that swing in direction of travel under a total pressure of not less than 15 lb (612.1)1.	Turnstiles are permitted where revolving doors are permitted in Mercantile occupancies (5-2211).	
	Power operated or power assisted manually operated doors may be used as exit or corridor doors provided they remain closed in case of power failure and are manually operable. To be credited as a required exit, power operated doors must swing in the direction of exit travel (C26-604.4(l)).			No requirements.	Power operated doors used as exit or exit access doors must be designed so that they are manually operable during a power failure and must swing in direction of exit travel (5-218).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Exit doors and corridor doors shall normally be kept in the closed position (C26-604.4(i)).			All required exit doors shall be self-closing (614.5).	Exit doors must be self-closing. In low and moderate occupancy buildings, exit doors may be held open in accordance with 5-2134 (5-2133).	
	Latch bolts shall be provided on all exit doors and corridor doors to hold them in a closed position against the pressure of expanding gases (C26-604.4(j)(1)(c)).			No requirements.	Exit doors to enclosed, which must be fire doors, are required to be positive latching	BOCA no requirement
	Obstruction of means of egress during door opening.					
	Doors providing access to stairways or ramps shall not block stairs/ramps or stair landings or reduce the width of landings/stairs/ramps to less than 75 % of the required width or to less than the width of the door opening on them (C26-604.8(g), C26-604.10(c)(4)).			Doors shall be hung to swing without obstructing the required width of exit passageway.	Doors swinging into an aisle or exit passageway must not restrict the effective width at any point during the swing to less than the minimum width required (5-1152).	NYC allows 75 % obstruction BOCA and NFPA does not allow any restriction
	No door shall swing over the sloping portion of a ramp (C26-604.8(g)).			No requirements.		
	Exit and corridor doors and doors providing access to areas of refuge shall be readily openable at all times from the side from which egress is made without the use of a key (C26-604.4(j)(1)(a), C26-604.5(d)).			Locks and fastenings on required exit doors shall be readily opened from inner side without use of keys (619.41).	Locked exit doors must not require the use of a key to open (5-2131).	
	Locks may be used in places where extra safeguards are required (banks, museums, etc.), subject to approval of the commissioner, provided the locks are equipped with electrical release devices for remote control in case of emergency (C26-604.4(j)(1)(a)(2)).			In rooms of the institutional use groups occupied as places of detention, approved releasing devices with remote control shall be provided for emergency use (614.43)		

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code		Summary of Significant Differences
	Doors opening into interior enclosed stairs shall not be locked from either side except that doors may be locked to prevent access to the stair from the outside at the street floor (C26-604.4(j)(1)(b).				No requirements.			BOCA only allow sin instructional occupancies
Exit Access Corridors	Minimum clear width of corridors (C26-604.2(a), Table 6-1):				(612.3)	Minimum width of exit access:		
	Occupancy Groups B (Storage), C (Mercantile) - 36 in.		Occupancy C1 – 22 in. (C212-2)		Mercantile 60 in. (612.3).	28 in. (5-1207).		NYC 36 in. BOCA 60 in. NFPA 28 in.
	Occupancy Groups E (Business), F (Assembly) - 44 in.				Occupancy Groups E (Business), F (Assembly) – 44 in. (612.3).	If single exit access to an exit, then exit access must have capacity of exit (5-1207).		
	The maximum length of exit access travel shall not exceed the following limits, measured from the most remote point in an area, to the center of an exit door (C26-601.4, Table 6-1, C26-709.8, C26-801.9, Table 8-1)				Maximum length of travel, measured from the most remote point to an approved exit shall not exceed distances in Table II.	The maximum length of exit access travel distance must not exceed the following limits in feet, measured from 1 ft of the most remote point, with 1 ft clearance around corners and obstructions to the center of the exit door or the plane of the tread nosing in the case of stairs (5-1181, A-5-119):		
	Occupancy Group	Distance (Feet)			Occupancy Group Distance Feet	Occupancy	Distance (feet)	
		Unsprinkler / sprinkler			Unsprinklered/ sprinkler		Unsprinklered / Sprinklered	
	B-1 (Storage)	100/150	150/200		100/150	Storage Ordinary Hazard	No requirements.	

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code		Summary of Significant Differences
	B-2 (Storage)	125/175			100/150	Storage Low Hazard	No requirements.	BOCA 100/50 NYC 125/175
	B-2 (Parking Garage)	100/150			100/150	Parking Garage	100/150 (100 below street level)	
	C (Mercantile)	150/200	150/200		100/150	Merc.	100/150	NYC 150/200 BOCA 100/150 NFPA 100/150
	E (Business)	200/300	C1 - First/Grade 175/250 - Above-/Below- 150/225		150/150	Office	200/300	NYC 200/300 BOCA 150/150 NFPA 200/300
	F (Assembly) <75 persons: >75 persons:	150/200 varies	- First/Grade 150/200 - Above-/Below 100/150		100/100	Assmbly	150/200	NYC > 75 persons - primary and secondary travel distance requirements
	Travel distance shall be measured along the natural and unobstructed path of travel. Where the path of travel is over an access stair, it shall be measured along an inclined straight line through the center of the outer edge of each tread (C26-601.4(c).				Travel distance shall be measured along the natural and unobstructed path of travel (609.3).			
	The maximum dead-end distance shall not exceed the following limits (C26-604.2(d), Table 6-1):				Dead ends in corridors shall be avoided in so far as practicable in no case Table II limits to be exceeded (612.2)	The maximum dead end distance shall not exceed the following limits (5-1192, A-5-119):		
	Occupancy Group	Distance (Feet)			BOCA does not specifically allow dead ends.	Occupancy Group	Distance (feet)	
	B-1 (Storage)	50				Storage - Ordinary	No requirements.	

	Then Current NYC Building Code		Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code		Summary of Significant Differences
	B-2 (Storage)	No requirements.				Storage -Low hazard -Parking	 No requirements. 50	
	C (Mercantile)	50				Mercantile	50	
	E (Business)	50				Office	50	
	F (Assembly)	30				Assembly	No requirements.	
	When a corridor is completely enclosed in 2 h fire resistance rated construction with 1½ h fire rated doors, the permissible length of dead ends may be increased by 100 % (C26-604.2(d)).				No requirements.			
	Exterior corridors designed and constructed in accordance with Section C26-604.2(f) may be used as a means of egress.				No requirements.			
Stairways	Minimum clear width - 44 in. (C26-604.8(b)).				Minimum clear width – 44 in. (618.21).	Minimum clear width (5-3121) - 44 in., 36 in. Class B stairs that serve 50 occupants or less on each floor that it serves		
	The width of stairs shall be the clear width between walls, grilles, guard, or newel posts (C26-604.8(b)).				No requirements.			
	Stair stringer projections which do not exceed 2 in. on each side and handrail projections of 3½ in. are permitted (C26-604.8(b), C26-604.8(f)).				Handrail projections of 3½ in. are permitted (618.5).	Stair stringer projection of up to 1½ in. permitted on each side (5-1152). Stair width may have handrail projection of 3½ in. on each side (5-3121).		
	Vertical exits in public garages may be 36 in. wide (C26-709.8).				No requirements.			

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	The minimum width of landings and platforms shall be at least the required width of the stairway (C26-604.8(d)(1)).			The minimum width of landings and platforms shall be at least the required width of the stairway (618.31).	The minimum dimension of landings in direction of exit travel is 44 in. (5-3121).	
	On a straight run stair, landing and platform widths need not be more than 44 in.					
	Minimum headroom - 7 ft (C26-604.8(c).			Minimum headroom 6 ⅔ ft	Minimum headroom – 6 ft 8 in. (5-3121)	NYC – 7 ft BOCA - 6 2/3 ft NFPA – 6 ft 8 in.
	Maximum vertical rise between landings - 12 ft (C26-604.8(d)(2)).			Maximum vertical rise between landings 12 ft (618.32).	Maximum height between landings 8 ft Class A stairs, 12 ft Class B stairs (5-3121)	
	Treads and risers (C26-604.8(e), Table 6-4).			Treads and risers (618.4).	Treads and risers (5-3121)	
	Maximum riser height - 7 ¾ in.			Maximum riser height 7¾ in. (618.41)	Maximum riser height – 7½ in. Class A stairs, 8 in. Class B stairs	
	Except - Occupancy Group F (Assembly) - 7½ in.			Except - Occupancy Group F (Assembly) – 7½ in. (618.41).		
	Minimum tread depth – 9½ in. plus nosing			Minimum tread depth 9½ in. plus nosing (618.41).	Minimum tread depth, exclusive of nosing – 10 in. Class A stairs, 9 in. Class B stairs	
	The sum of two risers plus one tread exclusive of the nosing shall not be less than 24 nor more than 25½ in. (C26-604.8(e)(1)).			No requirements.	The height of a riser and the depth of a tread exclusive of nosing cannot be less than 24 nor more than 25 in.	
	Stair riser and tread dimensions shall be constant in any flight of stairs from story to story (C26-604.8(e)(2)).			No requirements.	No variation of more than 3/16 in. tread width or riser height of risers in any flight, except as permitted for monumental stairs (5-3153).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Curving or skewed stairs that conform to Section C26-604.8(e)(4) are permitted to be used as exits.			No winders shall be permitted in required stairways (618.42.	Winders are not permitted except that monumental stairs can be curved with a radius of 25 ft or more at the inner edges (5-3121, 5-3181).	NYC permits curving stairs BOCA – not permitted
	Where exit stairways serving floors above grade continue in the same enclosure to serve floors below grade, the above and below grade portions shall be separated by 1 h fire resistance rated construction with a ¾ h door (C26-602.4).			No requirements.		
	Section C26-608.4 was added in 1973 by Local Law #5 and renumbered 27-393 in 1985.			No requirements.	Exit doors designed to be closed must have a sign stating “FIRE EXIT – Please keep door closed” (5-2133).	
	In buildings or in building sections more than three stories or 40 ft high with roofs having a slope of less than 20 degrees, access to the roof shall be provided by at least one interior stair (C26-604.8(k)).			In building more than 3 stories in height with roofs having a less than 20 degrees, access to be provided by stairway, ladder or scuttle (619.1)		
	Access to set back roof areas may be through a door or window opening to the roof (C26-604.8(k)).			No requirements.		
	No openings of any kind are permitted into stair enclosures other than windows, fire department access panels and exit doors (C26-604.8(j)).			No requirements.		
	Exterior stairs designed and constructed in accordance with Section C26-604.9 may be used as exits in lieu of interior stairs (C26-604.9).			Designed in accordance with 621.1. (621.1)	Outside stairs that serve as an exit must be designed and constructed in accordance with Section 5-4.	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	No exterior stair shall exceed 75 ft or 6 stories in height (C26-604.9).			No exterior stair shall exceed 65 ft or 5 stories (621.1).		NYC – 75 ft or 6 stories BOCA – 65 ft or 5 stories
	Escalators designed and constructed in accordance with Section C26-604.11 may be used as exits in lieu of interior stairs.			Escalators designed and constructed in accordance with (622.1). Acceptable as mean or egress (622.1).	An exit escalator must be designed and constructed in accordance with Section 5-8.	
Ramps	The minimum clear width of exit ramps is 44 in. (C26-604.10).			Shall meet width requirements of stair (617.0).	Class A ramps must be at least 44 in. wide and Class B ramps must be at least 30 in. wide (5-6121).	
	Level platforms or landings at least as wide as the ramp shall be provided at the top and bottom of all ramps and at intermediate levels as necessary (C26-604.10(c)(3)).			Shall meet width requirements of stair (617.0).		
	Level platforms shall be provided on each side of door openings into or from ramps.			Shall meet width requirements of stair (617.0).		
	Platforms shall be at least as wide as the ramp with a minimum length in the direction of travel of 3 ft (5 ft when a door swings on the platform).			Shall meet width requirements of stair (617.0).		
	Minimum headroom - 6 ft 8 in. (C26-604.10).			Shall meet width requirements of stair (617.0).	Headroom of 7 ft 6 in. minimum in exit ramps with projection from ceiling being at least 6 ft 8 in. from floor (5-1231).	
	Ramps shall be straight. Changes in direction of travel shall be made only at landings or platforms (C26-604.10(c)(1).			No requirements.	Changes in direction of travel must be made only at landing (5-6142).	
	Except - Ramps with a slope not greater than 1 in 12 at any place may be curved.			Except ramps with a slope greater than 1 in 10 (617.0).		NYC – 1 in 12 BOCA – 1 in 10

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Ramps shall not have a slope steeper than 1 in 8 (C26-604.10(b)) and sloping portions shall be at least 3 ft but not more than 30 ft long between platforms or landings (C26-604.10(c)(2)).			Slope not to exceed 1¾ in./ft (617.0).	Class A ramps must have a slope of 1 to 12 to 1 3/8 to 12 and Class B ramps must have a slope of 1 3/16 to 2 in 12. There is no limit in height between landings in Class A ramps and 12 ft maximum height between landings for Class B ramps (5-6121).	NYC 1 in 8 Boca 1¾ in 12 NFPA between 1 to 12 and 1 3/8 to 12
	Level and ramped moving walkways designed and constructed in accordance with Section C26-604.12 may be used as exits.			No requirements.	Moving walks designed and constructed in accordance with Section 5-8 may be used as exits.	
Handrails and Guardrails	Continuous handrails are required on both sides of all stairs and all ramps with a slope exceeding 1 in 12 (C26-604.8(f), C26-604.10(c)(5))			Handrails are required on both sides of stairways (618.5).	Handrails are required on both sides of Class B exit ramps and in stairs (5-6145, 5-3161).	
	Stairs less than 44 in. wide may have a handrail on one side only (C26-604.8(f)).			No requirements.		BOCA required in all
	Intermediate handrails shall be provided to divide stairs more than 88 in. wide into widths that maintain nominal multiples of 22 in. and widths not greater than 88 in. nor less than 44 in. (C26-604.8(f)(1)).			Stair widths that exceed 88 in. need an intermediate handrail with a maximum lateral spacing of 66 in. (618.5).	Every stairway that is required to be more than 88 in. in width must have intermediate handrails dividing the stairway into portions not more than 88 in. in width, with the exception of monumental stairs (5-3164(d)).	
	Handrail height shall be 30 to 34 in. measured vertically above the nosing of treads (C26-604.8(f)(2)).			Height 30 to 33 in. (618.5).	Handrails must be 30 to 34 in. from the top of the handrail to a point on the tread 1 in. back from the leading edge (5-3164(a)).	
	Handrail ends shall be returned to walls and posts when terminated (C26-604.8(f)(3).			Handrail ends shall be returned to walls and posts when terminated (618.5).	Handrails must be designed as to permit continuous sliding of the hands on them (5-3164(c)).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Handrails shall provide a finger clearance of 1½ in. and shall project not more than 3½ in. into the required stair width (C26-604.8(f)).			No requirements.	Handrails must provide a clearance of at least 1½ in. between the handrail and wall to which it is attached (5-3164(a)).	
	Stair landings and platforms shall be enclosed on sides by walls, grilles, or guards at least 3 ft height (C26-604.8(d)(3)).			No requirements.	Stairs, stair landings must have guards that at least 42 in. in height (5-3161, 5-3165(c)).	
Exit Signs and Lights	In all buildings, the location of every exit on every floor shall be clearly indicated by approved EXIT signs (C26-606.1).	Exit and directional signs, visible from the approach to the exits are required as follows (C507-2.3). Group Fire area exceeds C1, C2 2500 ft^2 C5 0 ft^2		Stair widths that exceed 88 in. need an intermediate handrail with a maximum lateral spacing of 66 in. (618.5).	Every required exit must be marked by a readily visible sign (5-11111).	
	EXIT signs shall be placed at an angle with the exit opening if such placement is required for the signs to serve their purpose (C26-606.1).			No requirements.		
	In areas where the location of the exit may not be readily visible or understood (including long corridors and open floor areas), directional signs shall be provided to serve as guides from all portions of the corridor or floor (C26-606.1).			Visible from the exit approach and, when necessary, supplemented by directional signs (626.1).		
	The size, color and illumination of EXIT signs shall conform to Section C26-606.3. Directional signs shall conform to Section C26-606.4.			The size, color and illumination of EXIT signs shall conform to Section (626.1).		
	All EXIT signs shall be illuminated at all times when the building is occupied (C26-606.3).			All EXIT signs shall be illuminated at all times when the building is occupied (626.2).		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Where a total of more than four signs (exit and/or directional) are required, all EXIT signs shall be connected to circuits that are separate from the general lighting and power circuits. These circuits shall be taken off ahead of the main switch or connected to an emergency lighting power source when such source is provided (C26-606.2).			No requirements.		NYC – exit sign power circuits ahead of main switch or emergency power source.
	Any door, passageway, stair, or other means of communication that is not an exit shall be so identified with a "NOT AN EXIT" sign, a sign indicating its use or purpose or a directional exit sign shall be provided (C26-606.5).			No requirements.		
Means of Egress Lighting	Corridors and exits shall be equipped with artificial lighting facilities to provide at least 5 foot candle intensity floor lighting continuously during occupancy (C26-605.1).	During period of occupancy, electric light of intensity sufficient for safe travel is required throughout exits, and for spaces which the public has access or in which persons work, including elevators and escalators (C507-2.1b).		Corridors and exits shall be equipped with artificial lighting facilities (627.1). Intensity of floor lighting to be 3 foot candles (627. 2).	Exit and exit access must be illuminated in all buildings to provide at least 1 foot candle measured at the floor (5-10111 and 5-10113).	NYC – 5 foot candle. BOCA 3 foot candle. NFPA – 1 foot candle.
	Lighting shall be provided to illuminate changes in direction in and intersections of corridors, balconies, exit passageways, stairs, ramps, escalators, bridges, tunnels, landings and platforms.			No requirements.	Lighting must be provided so all points such as angles and intersection of corridors, stairways, stair landings and doors (5-10113).	
	Illumination shall be arranged so that failure of any one light does not leave any area in darkness.	Artificial lighting equipment must be designed and installed to avoid glare and objectionable shadow.		Lighting shall be from an independent power source to assure continued illumination (627.4).	Illumination must be arranged so that the failure of any one lighting unit will not leave any area in darkness (5-10115).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Means of egress lighting in all buildings, where a total of more than four lights is required, shall be connected to circuits that are separate from the general lighting and power circuits. These circuits shall be taken off ahead of the main switch or connected to an emergency lighting power source when such source is provided (C26-605.2).			No requirements.	Emergency lighting must be provided in places of assembly, Class A and Class B stores and office buildings with 1,000 or more occupants (5-10211, 12-129, 13-1283).	
A.7 Fire Suppression Systems						
Automatic Sprinkler Protection	Automatic sprinkler protection shall be designed and installed in accordance with Section C26-1703.1 and RS 17-2 in the following areas: Spaces in group B-2 > 5,000 ft^2; Spaces in group C > 7,500 ft^2; Any story above grade and the 1st story below grade w/o required ventilation; All other stories below grade.	A sprinkler system is required in: GroupC1, C2, C4 and C5 where fire areas or height are increased per Sec. C203-1.2. Groups C1 through C6.3 in cellar areas of 5,000 ft^2 or more used for garage or for storage of combustible materials. Groups C1 through C6.3 in buildings more than two stories in height or having a fire area of more than 2,500 ft^2 above the first story without exterior access openings on each story for firefighting. (C405-3a)		Automatic sprinkler protection shall be designed and installed in accordance with 1213 One source sprinkler system in B-2>10,000 ft^2 (1213.13) C>20,000 ft^2 (1213.16)	Sprinklers installed in accordance with Section 6-41 and NFPA 13 1966 edition. Sprinklers are required in : Mercantile buildings that are 1 story and over 15,000 ft^2; in Mercantile buildings over 1 story and over 30,000 gross ft^2; in Mercantile basements over 2,500 ft^2 used for manufacture, sale, storage or handling of goods and merchandise (12-1331). Class A and Class B places of assembly located below grade (8-1111). Underground structures that serve more than 100 persons and from which there is no direct access to the outside or another fire area and has no outside light or ventilation (16-4111).	NYS Building Code – sprinklers required in office buildings > two stories without exterior access openings on each story for firefighting. The NYC Building Code requirements for design and installation of sprinkler systems are comprehensive. Storage NYC - > 5,000 ft^2. BOCA > 10,000 ft^2. Mercantile NYC > 7,500 ft^2 BOCA > 20,000 ft^2 NFPA > 15,000 ft^2 NYC – above grade w/o required ventilation NYC – all stories below grade

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	A wet-pipe sprinkler system shall be provided throughout all areas requiring automatic sprinkler protection (C26-1703.13).			Approved automatic sprinkler systems shall be provided in all buildings specified (1213.1).		
	In areas subject to freezing the sprinkler system shall be protected (insulation, heat trace, antifreeze) or a dry-pipe system shall be provided (C26-1703.13).			In areas subject to freezing a dry-pipe system shall be provided (1215.0).		
	A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or section (C26-1703.4).			No requirements.	Every automatic sprinkler system must be provided with a water-flow alarm device (6-4112).	NYC - >36 heads BOCA – no requirement NFPA – every system
Standpipes	Wet standpipes designed and installed in accordance with Section (C26-1702.1 and RS 17-1 shall be provided (C26-1702.1(a)(1)).	A standpipe system with outlets on each story for first-aid hose and for municipal fire department is required in: Groups C1 through C6.3 in buildings of type 1 or 2a construction more than 70 ft in height (C405-4a).		All buildings shall be provided with a wet-pipe system (1207.1).	Standpipe system is not required. However, standpipe systems, if installed, are to be designed and installed in accordance with NFPA 14, 1963 edition (Appendix B.)	The NYC Building Code provides comprehensive criteria for design and installation. NYC and BOCA – required NFPA – not required
	The number and location of standpipes shall be such that every point of every floor can be reached by a 20 ft stream from a nozzle attached to not more than 125 ft of hose connected to a riser outlet valve (C26-1702.4).			The number and location of standpipes shall be such that every point of every floor can be reached by a 30 ft hose stream from nozzle attached to a 100 ft hose (1207.31).		NYC – 125 + 20 BOCA 100 + 30
	Standpipe risers and 2½ in. hose valves shall be located within stairway enclosures (C26-1702.5(a)).			Standpipes shall be located in stairwells where practicable ((1207.4)).		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	When stairway enclosures are not available within the 125 plus 20 (145) ft distance, risers and valves shall be located as near to the enclosure as practicable (C26-1702.5(a)).			When stairway enclosures are not available, the standpipes shall be located in a public corridor or accessible from an interior or exterior stairway; or a smoke proof tower ((1207.4)).		
	The highest riser shall be extended above the roof with a 3-way manifold with 2½ in. hose valves (C26-1702.11(a)(2)).			No requirements.		
	A 2½ in. hose outlet shall be provided at each standpipe riser on each floor served, and on the entrance floor above the riser control valve, located between 5 ft and 6 ft above the landing or floor (C26-1702.11(a)(1)).			A 2½ in. hose outlet shall be provided at each standpipe riser on each floor served, and on the entrance floor above the riser control valve located 5 ft above floor level.		
	Hose stations shall be located at the standpipe risers, either inside or adjacent to the entrance of stairway enclosures (C26-1702.11(b)).			No requirements.		NYC required hose stations
	Hose stations shall be located to satisfy the 125 plus 20 (145) ft requirement (C26-1702.11 (b)(1)).			No requirements.		
	Hose shall be 1½ in. “flax-line” unlined linen hose in Groups C, E and F; 2½ in. (unlined) in Group B(C26-1702.11(c)).			Hose shall be no less than 100 ft in length and have a diameter of 1½ in. (1207.7).		
	Auxiliary hose stations equipped with 1½ in. (unlined) hose are permitted in Groups C, E and F (C26-1702.11(c)(4), C26-1702.11 (d)).			No requirements.		
	Standpipe systems that include more than one riser shall have all risers cross-connected at, or below, the street entrance floor level (C26-1702.10(a)).			When more than one standpipe is required in a building they shall be interconnected at their base by pipes of size equal to largest riser (1207.62).		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Standpipe systems having more than one zone shall be arranged such that the risers supplied from each zone are cross-connected below, or in, the story of the lowest hose outlets from the water source in each zone (C26-1702.10(b)).			No requirements.		
	Standpipe risers shall be at least 4 in. in diameter where the riser height is 150 ft or less from the highest hose outlet to the level of the entrance floor, 6 in. in diameter where greater than 150 ft (C26-1702.7, Table 17-1).			Buildings more than two stories or 30 ft in height and 10,000 ft^2. 2½ in. standpipes over four stories or 50 ft. 4 in. standpipes over six stories or 75 ft, 6 in. stand pipes. Over 250 ft 8 in. standpipes (1207.11) – (1207.14).		NYC – 4 in. up to 150 ft 6 in. > 150 ft BOCA – 4 in. up to 250 ft 8 in. > 250 ft
Water Supply	Standpipe systems shall have a primary water supply available at all times to every hose outlet or made available automatically when the hose valve at any outlet is opened (C26-1702.14).			Automatic sprinkler systems must be supplied by at least one of the following: public water system, gravity tank or pressure tank or fire pump (1214.1)-(1214.4).	Automatic sprinkler systems must be supplied by at least one of the following: public water system, gravity tank or pressure tank. Pressure tanks are encouraged to be used in buildings of "small" or "moderate" size where public water supply is inadequate (6-4121, A-6-4121).	The NYC Building Code has comprehensive requirements for water supplies for fire protection systems.
	Combinations of two or more of the following sources shall serve as the primary water supply, including siamese connections (C26-1702.14 (b)).			No requirements.	Sprinkler system water supply to be provided with continuous and automatic pressure (6-4121).	
	Direct connection to city water system			Direct connection to city water shall provide 15 psi at most remote head (1214.1).	Sprinkler system water supply must comply with NFPA 13 1966 edition (Appendix B).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Direct connection to a private yard main			No requirements.	Standpipe system water supply must comply with NFPA 14 1963 edition (Appendix B).	
	Pressure tank(s)					
	Automatic fire pump (C26-1702.14(b)(5)).				Fire pumps are to comply with NFPA 20 1966 edition (Appendix B).	
	In buildings higher than 300 ft, the automatic fire pump shall be used only for the lower 300 ft. Zones above 300 ft shall be supplied by either a gravity or pressure tank.			No requirements.		NYC > 300 ft – manual fire pump and gravity or pressure tanks
	An additional standpipe system water supply shall be provided for standpipes in buildings over 300 ft high (C26-1702.15(a)).			No requirements.		
	The primary water supply to the standpipe system shall be supplemented by one or more manually operated fire pumps (C26-1702.15(a)).			No requirements.		
	At least one of the following automatic source of water supply shall be provided for sprinklers (C26-1703.8(a)):			No requirements.		
	Gravity tank(s)					
	Pressure tank(s)					
	Automatic fire pump					
	Direct connection to public water system					

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Domestic water supply may be used to supply cooling tower sprinklers and sprinklers installed in buildings classified in Occupancy Group E (Business) in accordance with Section C26-1703.9(e) (C26-1703.9(c) and (d)).			No requirements.		NYC – domestic water supply permitted
	Auxiliary sources of water supply for sprinkler systems may include a manually actuated fire pump or siamese connection (C26-1703.8(b)			No requirements.		
	Combined Water Supplies					
	Fire pumps may simultaneously serve as the required auxiliary water supply for standpipe and sprinkler systems in accordance with Section C26-1702.15(d).			No requirements.		NYC – combination sprinkler/standpipe system permitted
	Tanks used to provide the required primary water supply to a standpipe system may also be used as a supply for an automatic sprinkler system (C26-1703.8(c)).			When sprinklers and standpipes are supplied from one tank the standpipe supply shall be drawn from the top (1214.5)		
	One standpipe system and one sprinkler system siamese connection shall be provided for each 300 ft of exterior building wall or fraction thereof facing each street or public space (C26-1702.9(a), C26-171703.6(a)(1)).			For standpipes (1207.8) For sprinklers (1213.8)		
	Modifications based on street frontage as permitted by Sections C26-1702.9(b)-(f).			No requirements.		
	Each siamese connection shall be connected to a riser or to a cross connection connecting other siamese connections or risers (C26-1702.10(f)).			No requirements.		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	In below grade sprinkler systems for garage occupancies, a sprinkler siamese connection shall be provided within 50 ft of every exit or entrance used by motor vehicles (C26-1703.6 (a)(2)).			No requirements.		
	Siamese connections for partial sprinkler systems shall be in accordance with Section C26-1703.6(a)(3).			No requirements.		
A.8 Interior Fire Alarm, Detection and Signaling Systems						
Fire Alarm Systems	No specific requirement for a fire alarm system unless other systems are provided that drive the requirement. See below.	A fire alarm system is required in Group C1 buildings more than six stories in height. A fire-detecting system or a sprinkler system is permitted in lieu of a required fire alarm system. (C405-1).		Mercantile buildings with two or more departments above second floor shall have fire alarm systems when not sprinklered 1219.15. Business building 75 or more than 6 stories shall be provided with fire alarm when not sprinklered 1219.17,	A manual fire alarm system is required in Office buildings with over 1,000 occupants or over 200 occupants employed above or below street level. Exception to requirement if building has an automatic sprinkler system or an automatic fire alarm system.	The NYS Building Code required a fire alarm system. If fire alarm systems are provided, the NYC Building Code has comprehensive requirements for their design and installation. NYC – No requirement for business occupancy BOCA – required > 75 ft (>6 stories) NFPA - required > 200 occupants above or below street or > 1,000 occupants in entire building NYC retroactive requirement added Local Law 5/1973 Section amended Local Law 16/1984
	A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or section (C26-1703.4).			No requirements.	Every automatic sprinkler system must be provided with a water-flow alarm device (6-4112).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	A local water flow alarm unit shall be provided (outdoor water motor or electric alarm gongs) where there is no watchman with watch service (RS 17-2, Sec. 3722).			No requirements.		
	Central station water flow alarm service is desirable but does not waive the local alarm requirement (RS 17-2, Sec. 3721).			No requirements.		
Smoke and Heat Detector Locations	HVAC Systems (C26-1300.7(a), RS 13-1).	A fire-detecting system shall be provided in kitchens, boiler rooms, storage rooms, laundry rooms and maintenances shops (C405-2).			HVAC Systems (7-112, NFPA 90A)	The NYC Building Code required has comprehensive requirements for fire-detection in HVAC systems. BOCA – no requirement
	In systems over 5,000 cfm capacity, thermostatic devices shall be provided for automatic fan shut-down as follows (RS 13-1, Sec. 1002):			No requirements.	HVAC systems that serve more than one floor or fire area must be provided with duct smoke detection that will shut down fans in case of fire (7-1122).	
	125 °F (max) devices located in the return air stream prior to exhaust or dilution by outside air (RS 13-1, Sec. 1002(a)).			No requirements.	An AC system that serves a Class A place of assembly or Class A department store must be provided with means of stopping smoke spread through system via smoke detection in the system. Smoke detectors shall be provided at system returns and downstream of system filters. System would automatically shut down on smoke detection (7-1123).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	50 °F (max) above maximum operating temperature devices located in the main supply duct down stream of the filters (RS 13-1, Sec. 1002(b)).			No requirements.	Manual shut down permitted in lieu of automatic detection and shut down in Class A Assembly and Class A store if qualified personnel are on duty while spaces are occupied (7-1123).	
	Where thermostatic devices are installed in systems utilizing recirculated air on floors protected by sprinkler or fire alarm systems, fans shall automatically shut-down on alarm (RS 13-1, Sec. 1005).			No requirements.	NFPA 90A Section 201(c) suggests smoke detection in the main supply duct downstream of filters and also upstream of filters if filters can effectively filter smoke.	
	In systems over 15,000 cfm capacity smoke detectors shall be provided for automatic fan shut-down as follows (RS 13-1, Sec. 1003).			No requirements.		
	Smoke detectors shall be located in the main supply duct downstream of the filters (RS 13-1, Sec. 1003.b).			No requirements.		
	Smoke detectors shall be arranged to provide audible and visual annunciation at a local supervisory control board in the building in accordance with RS 13-1, Sec. 1003.c.			No requirements.		
	In systems utilizing recirculated air, smoke detectors shall be provided for automatic fan shut-down when any of the following conditions exists (RS 13-1, Sec. 1003.a):			No requirements.		
	System supplies an exit passageway, or a space leading from elevators to a street or to the exterior.			No requirements.		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	System supplies spaces on more than one story or spaces in different fire areas in the same story.			No requirements.		
	Where the area of a building or space served is over 20,000 ft^2 in mercantile or indoor assembly occupancies.			No requirements.		
	Where there is a duct opening in a required 2 h fire resistance rated interior Fire Division.			No requirements.		
	Where a duct passes through a firewall.			No requirements.		
	Where a corridor is used as a plenum.			No requirements.		
	Systems incorporating automatic exhaust in lieu of automatic fan shutdown are acceptable provided they are equipped with smoke detectors (RS 13-1, Sec. 1004).			No requirements.		
	Each installation shall be equipped with a manual emergency stop for quick shutdown of the fan(s) in case of fire (RS 13-1, Sec. 1001).			No requirements.		
	No requirements.				Elevator lobby smoke detection is not required.	
Manual Fire Alarm Boxes	No requirements.	Manually operated fire alarm signaling devices required (C511-2.2).			A manual fire alarm system is required in Office buildings with over 1,000 occupants or over 200 occupants employed above or below street level. Exception to requirement if building has an automatic sprinkler system or an automatic fire alarm system.	The NYS Building Code required manual alarm boxes. NFPA – required in office buildings with > 200 occupants above or below street or > 1,000 occupants in entire building

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
Audible/Visual Alarm Indicating Appliances	No requirements.	Sounding devices designed to sound a clear audible alarm signal that is distinct from all signals of other sounding devices in the vicinity (C511-2.3)			Alarm sounding devices must be of character and distribution so that they can be heard above all other sounds and they must be distinctive in pitch and quality from surrounding devices (6-3131, 6-3133).	The NYS Building Code required sounding devices.
	No requirements.				Visible alarm devices may be used in lieu of audible devices in public assembly areas (6-3132).	
	No requirements.					
Communication Systems	Standpipe Fire Line Telephone and Signaling Systems				Communication systems are not required.	This requirement is unique to the NYC Building Code.
	In every building more than 300 ft high, a telephone and signaling system shall be provided for fire department use in operating the standpipe system (C26-1702.21, C26-1704.7(a)).			No requirements.		
	Standpipe Telephone System			No requirements.		
	System shall permit communication by permanent telephones in the following locations (C26-1704.7(b):					
	Pump rooms					
	Entrance floor					
	Gravity tank rooms					
	Each floor near main standpipe riser					
	The system shall be a selective ringing, common talking system supplied by a 24 V direct current power source (C26-1704.7(b)).			No requirements.		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Permanent wall telephones shall be provided with 6 in. gongs except in the pump room where a loud speaking receiver shall be provided (C26-1704.7(c)).			No requirements.		
	Where portable phones are used, jacks protected by break-glass boxes shall be provided (C26-1704.7(c)).			No requirements.		
	At least three portable phones shall be provided for each standpipe installation, kept in a dedicated, locked cabinet located in the main hall of the entrance floor (C26-1704.7(d)).			No requirements.		
	A pilot light shall be provided over the cabinet to indicate if the system is in use or a receiver is off the hook (C26-1704.7 e)).			No requirements.		
	Standpipe Signaling Devices					
	Manual, individually coded sending stations shall be located in the main corridor of the building arranged to transmit a signal to alarm sounding devices (C26-1704.7(f)(1)).			No requirements.		
	System shall be installed in accordance with RS 17-3 (C26-1704.7(f), C26-1704.8).			No requirements.		
	An 8 in. gong shall be provided in the pump rooms and in elevator shafts at intervals not exceeding 10 floors (C26-1704.7(f)(1)).			No requirements.		
	Adjacent to each telephone station and near the main standpipe riser, a closed circuit strap key connected in series with the box circuit of the signal sending station shall be provided (C26-1704.7(f)(2)).			No requirements.		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
A.9 Elevators and Escalators						
General	Elevators or escalators shall be provided in accordance with Section C26-1800.1 and RS 18-1 in all new buildings exceeding four stories in height (C26-604.1(a), C26-1800.6(d)).	Elevators, dumbwaiters and escalators shall conform to the requirements of C501 (C512-1).		In every structure over 150 ft in height, a competent elevator operator shall be available (1608.2).	Automatic elevators must be provided with manual recall via fireman's key at street level (7-1181(a).	The NYC Building Code was unique in its requirements for elevators and controls of elevators for emergency use.
	When Areas of Refuge are provided above the 11th floor of a building, they shall be served by at least one elevator (C26-604.5(c).	When horizontal exits are provided on stories located 16 or more stories above grade, each required stairway shall be supplemented by at least one passenger elevator (C212-2g).		When horizontal exits are provided in floors located 12 stories above grade, the required stairway shall be supplemented by at least one elevator (616.52).	Elevator cars must be equipped with fireman's key service to allow exclusive fire department operation of elevator car (7-1181(b),(c),(d)).	
	Escalators may be used as exits in lieu of interior stairs (C26-604.11 and C26-1800.6(g)).	Escalators, other than required enclosed exits, shall be protected by enclosures or other means to retard the spread of fire from story to story. (C512-3.1h, C402-4.6c).		Escalators may be used as an approved exit way in all but assembly and institutional buildings (622.1).		
	In every building exceeding 100 ft in height, at least one elevator shall be kept available for immediate use by the fire department during all hours (C26-1702.22, C26-1800.8).			No requirements.		
	In buildings exceeding 150 ft in height, there shall be an operator available at all times (C26-1800.8).			Every power elevator except automatic and continuous-pressure operation types and sidewalk elevators shall be in charge of a competent designated operator (1608.1)		
	Automatic passenger elevators shall be equipped with emergency controls for fire department use (RS 18-1 Rule 210.13).			In buildings exceeding 150 ft in height, there shall be an operator available at all times (1608.2).		

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	A two-position keyed switch shall be provided at a main floor of each elevator or group of elevators for recall to the main floor in accordance with RS 18-1, Rule 210.13.a.			No requirements.		
	A keyed switch shall be provided in or adjacent to an operating panel of each elevator to initiate emergency service in accordance with RS 18-1, Rule 210.13.b.			No requirements.		
A.10 Emergency Electical and Standby Power Systems						
Emergency Power Systems	No requirements.	Emergency lighting and emergency power is required in: Group C2 – Mercantile, three stories or more in height, having more than 5000 ft^2 of floor area on any story, and in below-grade sales spaces exceeding 2500 ft^2 in floor area. Group C5.1, C5.2, C5.3 and C5.5 – Assembly occupancies with spaces intended for occupancy by 200 or more in one room or enclosure. (C507-2.2)			Electrical system has to comply with the 1965 edition of NFPA 70, National Electric Code The following must be on emergency power: Exit lighting (where required for particular occupancies) (5-10211). Exit signs, where emergency exit lighting is required by particular occupancies (5-11121).	
A.11 Special Features						
Public Garages	A public garage used exclusively for parking of vehicles having fuel storage tanks of 26 gal capacity or less is classified in storage Occupancy Group B-2 (C26-709.2(b)).	Space for parking motor vehicles are classified in group C4.1 and are required to be separated from other occupancies by fire separations per Table C402-4. (C402-4.9b)			Garages are considered as such if there are no repair operations (15-2111).	

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	All floors shall be concrete or equivalent noncombustible material and columns shall be protected from vehicle impact or designed to resist lateral forces in accordance with Section C26-902.4 (C26-709.3).					
	Public garages shall be ventilated in accordance with Section C26-709.7.	Ventilating systems for garages are required in accordance with C508-3.1b, Table C508-3.3h, Table 508-3.3i).				
	Ramps serving as required exits shall be enclosed in 2 h fire resistance rated construction with vehicle openings at each parking tier protected by a 3 gpm/ft deluge type sprinkler water curtain (C26-709.9).				Ramps may serve as a second exit on above grade floors and the first below grade floor if the ramps are not subject to closure (15-2212, 15-2213).	
Smoke and Heat Venting	No requirements.			Required for H-1 & H 2, all hotels and apartment houses, which exceed three stories of 40 ft, with more than 25 sleeping rooms, with an occupancy load exceeding 50 or which exceed 10,000 ft area (521.1).	Automatic smoke venting is required for underground structures serving more than 1,000 people (16-4112).	These requirements were unique to the NYC Building Code.
	Elevator and dumbwaiter shafts.				Automatic smoke venting must comply with 7-113.	
	In accordance with RS 18-1.					
	Other closed shafts, including stairway enclosures:					
	All closed shafts having an area exceeding 4 ft^2 shall be provided with a smoke vent having an area of at least 3½ % of the maximum shaft area at any floor but not less than ½ ft^2 (C26-504.6(d)).					

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
	Smoke vents may be windows, louvers, skylights, vent ducts or similar devices.					
	Vent ducts shall be enclosed by construction having the same fire resistance rating as required for the shaft and extend vertically, diagonally, or horizontally in accordance with Sections C26-504.6(d)(1) , C26-504.6(d)(2).					
	Of the total required vent area for shafts, at least 1/3 shall be clear to the outdoors, either in the form of fixed louvers, ridge vents, or hooded or goosenecked openings (C26-504.6(e)).					
	As an alternate, skylights or trap doors may be used arranged to open automatically by fusible link or other mechanical device when subjected to 160 °F fixed temperature or 15-20 °F/min temperature rise (C26-504.6(e)).					
	Of the total required vent area for shafts up to 2/3 may be a window or skylight glazed with plain glass not more than 1/8 in. thick or slow burning plastic (27-344(e)).					
	Vents shall not be located in doors leading to machine rooms which communicate with the shaft (27-344(f)).					

	Then Current NYC Building Code	Then Current NY State Building Code	Then Current Chicago Building Code	Then Current BOCA Building Code	Then Current NFPA 101 Life Safety Code	Summary of Significant Differences
Atria and Floor Openings	No requirements.				Three communicating floor levels are permitted without enclosure or protection between areas in fully sprinklered moderate hazard buildings (e.g., Office) if the following is met (6-1112):	
					The lowest or next to lowest level is at street level.	
					The entire area including communicating levels is open and unobstructed so that a fire or other dangerous condition will be obvious to occupants of all communicating areas.	
					Sufficient exit capacity for simultaneous evacuation of all occupants of all communicating levels. All communicating levels in the same fire area will be considered a single floor for determining required. exit capacity.	
					Each floor level has at least ½ of required exit capacity leading directly out of open area.	
					All other code requirements with respect to interior finish, protection of hazards, construction and other features are observed without waivers.	

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U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

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Pursuant to section 7 of the National Construction Safety Team Act, the NIST Director has determined that certain evidence received by NIST in the course of this Investigation is "voluntarily provided safety-related information" that is "not directly related to the building failure being investigated" and that "disclosure of that information would inhibit the voluntary provision of that type of information" (15 USC 7306c).

In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

Use in Legal Proceedings

No part of any report resulting from a NIST investigation into a structural failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a; as amended by P.L. 107-231).

National Institute of Standards and Technology National Construction Safety Team Act Report 1-1F
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ABSTRACT

This report was prepared to support the analysis of building and fire codes and practices of the National Institute of Standards and Technology World Trade Center (WTC) Investigation. The report provides a comparison and summary of significant differences between the 1968 Building Code of the City of New York (determined to be the current building code at the time of construction of WTC 1 and WTC 2) and the provisions of the 2003 (current) edition of the Building Code of the City of New York.

Keywords: Building code, emergency power, fire alarm, fire protection, fire suppression, interior finish, means of egress, reference standard, sprinklers, standpipe, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

ASTM	ASTM International
BCNYC	Building Code of the City of New York (Local Law No. 76)
HVAC	heating, ventilating, and air conditioning
LL	Local Law to amend the Administrative Code of the City of New York
MER	Mechanical Equipment Room
NC	noncombustible
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
NR	no requirement
NR	not rated
PANYNJ	Port Authority of New York and New Jersey
RS	Reference Standard to the Building Code of the City of New York
UL	Underwriters Laboratories, Inc.
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

cfm	cubic feet per minute
ft	foot
ft^2	square foot
gal	gallon
gpm	gallons per minute
h	hour
in.	inch
$in.^2$	square inches
psi	pounds per square inch

rpm	revolutions per minute
V	volt

GLOSSARY

combustible – A material that will ignite and burn when subjected to fire or heat.

fire resistance rating – The time in hours that materials or their assemblies will withstand fire exposure as determined by a fire test.

fireproofing – A method used to provide a fire resistance rating to a building component.

firestop – A solid or compact, tight closure to retard the spread of flames or hot gases within concealed spaces.

noncombustible – A material that does not ignite or burn when subjected to fire and heat.

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PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

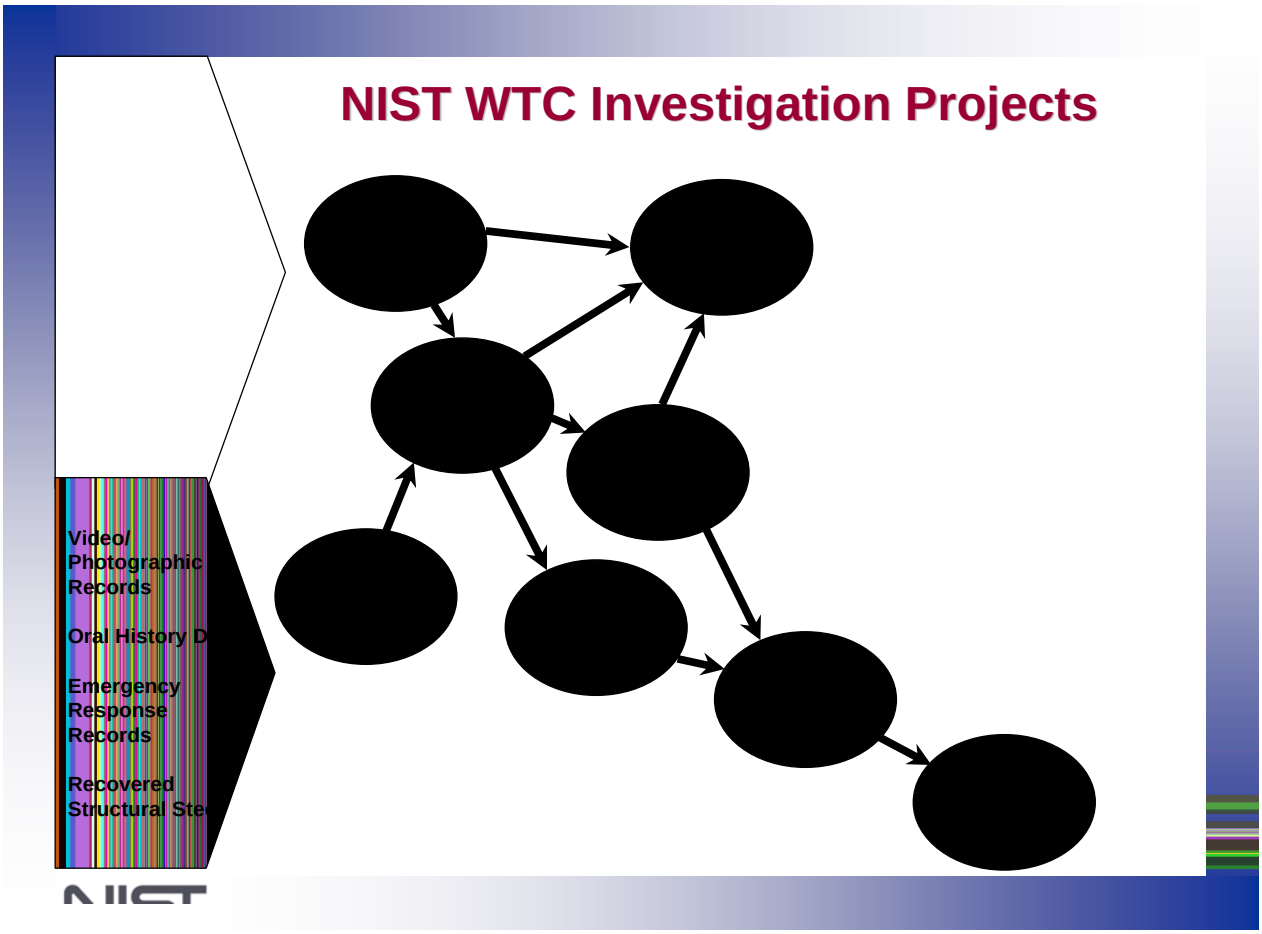

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

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EXECUTIVE SUMMARY

As part of the analysis of building and fire codes and standards of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation, this report supports the effort by providing a summary of the relevant provisions of the Building Code of the City of New York (BCNYC) that was in effect at the time of the design of the WTC buildings. This report also documents the requirements of the 2003 BCNYC. The purpose of this report is to provide a comparison of these codes vis-à-vis the relevant requirements and to identify significant differences.

It has been previously established that WTC 1 and WTC 2 were designed and constructed in accordance with the BCNYC as enacted by Local Law No. 76 for the year 1968, effective December 6, 1968. The Building Code is a part of the Administrative Code of the City of New York.

The code requirements identified and compared in this report focus on fire protection and life safety related issues. These include but are not limited to:

- Use and occupancy criteria.
- Height and area limitations and associated construction types.
- Fire resistance ratings for various building elements.
- Fire protection system requirements. (Project 1 of the NIST WTC Investigation focuses on the macro requirements for fire protection systems in the WTC buildings. Other projects are focused on the specific requirements of the various fire protections systems.)
- Means of egress requirements including occupant load determination and egress capacity and travel distance limitations.
- Emergency lighting and power requirements.
- Elevator provisions in case of emergency.

The 2003 BCNYC is the 1968 Code incorporating amendments enacted through 2003. Changes to the 2003 BCNYC have been made over time through passage of Local Laws. The report, NIST NCSTAR 1-1G, *Amendments to the Fire Protection and Life Safety Provisions of the New York City Building Code by Local Laws Adopted While WTC 1, 2, and 7 Were in Use*, discusses the evolution of the changes of the BCNYC. This report documents the differences in the areas of fire protection and life safety between the 1968 and 2003 codes.

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Chapter 1
INTRODUCTION

One of the goals of the World Trade Center (WTC) Investigation led by the National Institute of Standards and Technology (NIST) was to recommend appropriate revisions to current codes, standards, and practices used in the industry. Prior to recommending such changes, one of the objectives of the investigation was to identify the codes and standards that were used during the design and construction of the WTC, identify local and national codes and standards that were available at that time, and identify areas in current building and fire codes, standards, and practices that warrant revision.

As part of the Investigation, it has been determined that WTC 1 and WTC 2 were constructed in accordance with the Building Code of the City of New York (BCNYC) that was enacted by Local Law No. 76 for the year 1968, effective December 6, 1968.

One of the tasks of the Investigation was to review and document relevant provisions of the building codes relevant to the WTC and to summarize significant differences. This report provides a comparison of the 1968 (then current) BCNYC and the 2003 (current) edition of the BCNYC.

The comparison is in tabular format and provides a comparison of the following fire protection and life safety related topics: building codes, reference standards, occupancies, construction, interior finish, means of egress, fire suppression systems, fire alarm, detection and signaling systems, elevators and escalators, emergency electrical and standby power systems, and special features such as parking garages and atria.

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Chapter 2
CODE COMPARISON AND SUMMARY OF SIGNIFICANT DIFFERENCES

This chapter summarizes key differences between the codes compared in this report. The side-by-side comparison of the requirements is provided in tabular format in Appendix A of this report.

2.1 REFERENCED STANDARDS

Referenced standards have been updated to later editions of the national standards.

2.2 COMPARTMENTATION

The 2003 Building Code of the City of New York (BCNYC) includes a requirement for compartmentation (subdivision of floors by fire rated construction) for new and existing unsprinklered Class E (Office) buildings exceeding 100 ft in height.

2.3 CONSTRUCTION

The height and area limits in the 2003 BCNYC are reduced from the 1968 BCNYC. New office buildings exceeding 75 ft in height are required to be provided with automatic sprinklers by the 2003 BCNYC. The 2003 BCNYC would have allowed the WTC buildings to be constructed as Type IC Construction. This would allow reductions in fire resistance for various elements of the structure as identified in the comparison in Appendix A.

2.4 MEANS OF EGRESS

The 1968 BCNYC required doors in scissor stairs to be at least 15 ft apart. The 2003 BCNYC requires exits to be separated by the greater of 30 ft or one-third the maximum exit travel distance of the floor.

The 2003 BCNYC requires exit signs and exit illumination in new buildings and existing Class E buildings to be provided with emergency power. This was not required in the 1968 BCNYC.

2.5 FIRE SUPPRESSION SYSTEMS

Automatic fire sprinklers are required by the 2003 BCNYC in new Class E buildings exceeding 75 ft height or exceeding 100,000 ft^2 in total area and in existing Class E buildings exceeding 100 ft in height if the floors are not provided with compartmentation. The 1968 BCNYC only required sprinklers in underground spaces.

2.6 FIRE ALARM, DETECTION, AND SIGNALING SYSTEMS

The 2003 BCNYC requires a Class E fire alarm system in new Class E buildings more than 75 ft in height and existing Class E buildings more than 100 ft in height. The systems are required to include loud speakers for voice communication, two-way voice communication, and a fire command station. The 1968 BCNYC contained no requirements for fire alarm or voice communication systems.

Requirements for elevator lobby smoke detectors and elevator recall criteria were added to BCNYC by Local Law No. 5 (1973).

2.7 EMERGENCY POWER

The 2003 BCNYC requires emergency power in new Class E high-rise buildings with capacity to simultaneously supply fire pumps, at least three elevators at one time with manual transfer to all elevators, alarm and communication equipment, emergency lighting, ventilation systems used for smoke venting or control and stair pressurization equipment. The 1968 BCNYC had no requirements for emergency power.

2.8 SMOKE AND HEAT VENTING

The 2003 BCNYC includes requirements for smoke and heat venting for new and existing Class E office buildings that were not in the 1968 BCNYC. Requirements for smoke shafts and stair pressurization are provided. Smoke shafts were required in the 1968 BCNYC and stair pressurization was added as an alternative to these shafts by Local Law No. 5 (1973).

Chapter 3
REFERENCES

1. Building Code of the City of New York. 2003. New York City Department of Buildings.

2. City Publishing Center Department of General Services. 1968. The City of New York Building Code. New York, NY, December 6.

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Appendix A
TABLE OF CODE COMPARISON AND SUMMARY OF SIGNIFICANT DIFFERENCES

This is a side-by-side comparison of requirements from the 1968 (then current) and 2003 (current) edition of the Building Code of the City of New York.

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	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
A.1 BUILDING CODES	Building Code of the City of New York, (Title C of Chapter 26 of the Administrative Code as enacted by Local Law No. 76 for the year 1968, effective December 6, 1968)	Building Code of the City of New York, effective December 6, 1968 edited and amended to 2003	
A.2 REFERENCE STANDARDS			
	RS 5-2 Standard Methods of Fire Tests of Building Construction Materials, ASTM E 119 - 1961; RS 5-5 Standard Method of Test for Surface Burning Characteristics of Building Materials, ASTM E84 - 1961; RS 5-8 Installation of Fire Doors and Windows, NFPA 80 - 1967; RS 13-1 Standard for the Installation of Air Conditioning and Ventilating Systems, NFPA 90A – 1967, as modified; RS 17-1 Standpipe Construction; RS 17-2 Standard for the Installation of Sprinkler Systems NFPA 13 -1966, as modified; RS 17-3 Standards for the Installation of Fire, Sprinkler, Standpipe, Smoke Detection and other Alarm and Extinguishing Systems; RS 17-5 Proprietary and Auxiliary Protective Signaling Systems, NFPA 72 – 1967; RS 18-1 USA Standard Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks, USASI 17.1 - 1965 including Supplement A17.1a-1967, as modified.	RS 5-2 Standard Methods Fire Test of Building Construction Materials, ASTM E-119 - 1988; RS 5-5 Standard Method For Surface Burning Characteristics of Building Materials, ASTM E84, 1987; RS 5-8 Standard for Fire Doors and Windows, NFPA 80 – 1986; RS 13-1 Standard for the Installation of Air Conditioning and Ventilating Systems, NFPA 90A – 1996, as modified; RS 17-1 Standpipe System Construction; RS 17-2 Standard for the Installation of Sprinkler Systems, NFPA 13-1989, as modified; RS 17-3 Standards for the Installation of Fire, Sprinkler, Standpipe, Smoke Detection and other Alarm and Extinguishing Systems; RS 17-5 National Fire Alarm Code, NFPA 72 – 1993, as modified; RS 18-1 Safety Code for Elevators and Escalators ANSI/ASME A17.1-1996 and Supplement A17.1a-1997, as Modified.	All Reference Standards have been updated to later standards. Standpipe requirements are not based on NFPA 14

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
A.3 OCCUPANCIES			
Primary Occupancy	The building is classified in Occupancy Group E (Business) with a fire index of 2, based on the dominant use, and containing the following accessory uses (C26-301.1 through C26-301.3, C26-306.1):	The building is classified in Occupancy Group E (Business) with a fire index of 2, based on the dominant use, and containing the following accessory uses (27-237, 27-238, 27-239, 27-253):	BCNYC was renumbered but the requirement was unchanged
Secondary/Accessory Occupancies	Occupancy Group B-1, Storage (Moderate Hazard), Fire Index: 3	Occupancy Group B-1, Storage (Moderate Hazard), Fire Index: 3	
	Occupancy Group B-2, Storage (Low Hazard, Garage), Fire Index: 2	Occupancy Group B-2, Storage (Low Hazard, Garage), Fire Index: 2	
	Occupancy Group C, Mercantile, Fire Index: 2	Occupancy Group C, Mercantile, Fire Index: 2	
	Occupancy Group F-4, Assembly (Restaurant), Fire Index: 1	Occupancy Group F-4, Assembly (Restaurant), Fire Index: 1	
Occupancy Separation	Separate Building (Building Section) - Spaces classified in occupancy groups having a higher fire index than the occupancy group classification of the building shall be separated by "Fire Divisions" constructed in accordance with Section C26-504.1(a) and treated as separate buildings (C26-301.4(a)).	Separate Building (Building Section) - Spaces classified in occupancy groups having a higher fire index than the occupancy group classification of the building shall be separated by "Fire Divisions" constructed in accordance with Section 27-339(a) and treated as separate buildings (27-340(a)).	
	Separate Spaces – Spaces classified in occupancy groups having the same or lower fire index than the occupancy group classification of the building shall be separated by "Fire Separations" constructed in accordance with Section 27-504.1(b).	Separate Spaces – Spaces classified in occupancy groups having the same or lower fire index than the occupancy group classification of the building shall be separated by "Fire Separations" constructed in accordance with Section 27-339(b) .	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Occupancy Separation (continued)	Separations are not required between accessory business and mercantile activities limited in area to 100 ft^2, and closets 75 ft^2 or less in area (Table 5-1 notes b,c).	Separations are not required between accessory business and mercantile activities limited in area to 100 ft^2, and closets 75 ft^2 or less in area (Table 5-1 notes b,c).	
	Multiple occupancy or use - When a building or space is used for multiple purposes at different times, the building/space shall be given a separate occupancy group classification for each of the activities. The design and construction shall be in accordance with the most restrictive provisions that apply to any of the classifications (C26-301.6).	Multiple occupancy or use - When a building or space is used for multiple purposes at different times, the building/space shall be given a separate occupancy group classification for each of the activities. The design and construction shall be in accordance with the most restrictive provisions that apply to any of the classifications (27-242).	
	A minor variation of occupancy or use of a space is acceptable without multiple classifications if the variation is normally associated with the occupancy classification and no specific danger or hazard is created (C26-301.6).	A minor variation of occupancy or use of a space is acceptable without multiple classifications if the variation is normally associated with the occupancy classification and no specific danger or hazard is created (27-242).	
		Compartmentation – All new buildings classifed in occupancy group E and existing office buildings 100 ft or more in height having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located, unsprinklered floor areas, more than 40 ft above curb level, shall be subdivided by fire separations into spaces or compartments as required by paragraphs 1 through 5 (27-339(c)).	This section was added to the code in 1973 under Local Law #5. It provided an option to automatic sprinklers in new and existing office buildings 100 ft or more in height.

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
A.4 CONSTRUCTION					
Construction Classification	Noncombustible Construction Group I, Class IA or Class IB (**unsprinklered** building with unlimited height and area) in accordance with Section C26-313, C26-314 and Table 3-4 (C26-316.1, C26-403.1, C26-405.1, C26-406.1).		Noncombustible Construction Group I, Class IA or Class IB or IC (**sprinklered** building with unlimited height and area) in accordance with Section 27-269 through 27-276 and Table 3-4 (27-286, 27-296, 27-301, 27-305).		Local Law 5/1973 and Local Law 16/1984 requires sprinklers in all new office buildings over 75 ft in height. Height and area limits reduced for unsprinklered buildings and spaces.
	This classification is based on Occupancy Group E (Business) building and Occupancy Groups B-1 (Storage, Moderate Hazard) and B-2 (Storage, Low Hazard, Parking Garage) spaces. These classifications permit unlimited height and area for the occupancy groups involved.		This classification is based on Occupancy Group E (Business) building and Occupancy Groups B-1 (Storage, Moderate Hazard) and B-2 (Storage, Low Hazard, Parking Garage) spaces. These classifications permit unlimited height and area for the occupancy groups involved.		
	The building is located inside the Borough of Manhattan Fire District without additional restrictions imposed based on its use and occupancy (C26-402.1, C26-403.1).		The building is located inside the Borough of Manhattan Fire District without additional restrictions imposed based on its use and occupancy (27-293, 27-296).		
Minimum Fire Resistance Ratings	Element (Table 3-4) (Construction **Class IB**)	Hours	Element (Table 3-4) (Construct **Class IC**)	Hours	Minimum Class IB required in 1968 without sprinklers. Minimum Class IC required in current code with sprinklers.
	Exterior Walls		Exterior Walls		
	Bearing	3	Bearing	2	Reduced hourly rating with sprinklers in current NYC.
	Nonbearing (based on exterior separation)		Nonbearing (based on exterior separation)		

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Minimum Fire Resistance Ratings (continued)	Element (Table 3-4) (Construction **Class IB**)	Hours	Element (Table 3-4) (Construct **Class IC**)	Hours	Minimum Class IB required in 1968 without sprinklers. Minimum Class IC required in current code with sprinklers.
	3 ft or less with 0 % openings.	2	3 ft or less with 0 % openings.	2	
	Greater than 3 ft up to less than 15 ft with 3½ % protected openings.	2	Greater than 3 ft up to less than 15 ft with 3½ % protected openings.	2	
	15 ft to less than 30 ft with 3½ % openings.	1½	15 ft to less than 30 ft with 3½ % openings.	1	Reduced hourly rating with sprinklers in Current NYC.
	30 ft or greater with unlimited openings.	NC (noncomb-ustible)	30 ft or greater with unlimited openings.	NC	
	Fire Divisions		Fire Divisions		
	Between Group B-1 and B-2, C, E or F-4.	3	Between Group B-1 and B-2, C, E or F-4.	3	
	Fire Separations		Fire Separations		
	Between Groups E and B-2, C or F-4.	NR (not rated)	Between Groups E and B-2, C or F-4.	NR	
	Tenant Separations	1	Tenant Separations	1	
	Constructed as Fire Separations continuous through concealed spaces of floor or roof construction above.		Constructed as Fire Separations continuous through concealed spaces of floor or roof construction above.		
	Interior bearing walls and partitions.	3	Interior bearing walls and partitions.	2	Reduced hourly rating with sprinklers in Current NYC.

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Minimum Fire Resistance Ratings (continued)	Element (Table 3-4) (Construction **Class IB**)	Hours	Element (Table 3-4) (Construct **Class IC**)	Hours	Minimum Class IB required in 1968 without sprinklers. Minimum Class IC required in current code with sprinklers.
	Vertical exits and exit passageways (C26-604.8).	2	Vertical exits and exit passageways (27-375).	2	
	Separation of above and below grade portions in common enclosures (C26-602.4)	1	Separation of above and below grade portions in common enclosures (27-364).	1	
	Hoistways and shafts (C26-504.6, C26-1800.6).	2	Hoistways and shafts (27-344, 27-987).	2	
	Columns, girders, trusses (other than roof trusses) and framing.		Columns, girders, trusses (other than roof trusses) and framing.		
	Supporting one floor.	2	Supporting one floor.	1½	Reduced hourly rating with sprinklers in Current NYC.
	Supporting more than one floor.	3	Supporting more than one floor.	2	Reduced hourly rating with sprinklers in Current NYC.
	Structural members supporting walls.	3	Structural members supporting walls.	2	Reduced hourly rating with sprinklers in Current NYC.
	Floor construction, including beams.	2	Floor construction, including beams.	1½	Reduced hourly rating with sprinklers in Current NYC.
	Ceilings that contribute to the required rating shall be continuous between exterior walls, vertical fire divisions or vertical partitions having the same rating as the ceiling (C26-502.5).		Ceilings that contribute to the required rating shall be continuous between exterior walls, vertical fire divisions or vertical partitions having the same rating as the ceiling (27-327).		

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Minimum Fire Resistance Ratings (continued)	Element (Table 3-4) (Construction **Class IB**)	Hours	Element (Table 3-4) (Construct **Class IC**)	Hours	Minimum Class IB required in 1968 without sprinklers. Minimum Class IC required in current code with sprinklers.
	Roof construction including beams, trusses and framing, arches, domes, shells, cable supported roofs and roof decks (based on height of lowest member above floor).		Roof construction including beams, trusses and framing, arches, domes, shells, cable supported roofs and roof decks (based on height of lowest member above floor).		
	(height of lowest member above floor of) 15 ft or less	1½	15 ft or less	1	Reduced hourly rating with sprinklers in Current NYC.
	Greater than 15 ft up to 20 ft	1	Greater than 15 ft up to 20 ft	1	
	20 ft or greater	NC	20 ft or greater	NC	
	Exit access corridors (C26-604.2(h)).	1	Exit access corridors (27-369(h)).	1	
	Area of refuge separation (C26-604.5, C26-604.6).	2	Area of refuge separation (27-372, 27-373).	2	
	Escalators not used as exits (C26-604.11).	¾	Escalators not used as exits (27-278(c)).	¾	
	Escalators that connect two stories may be unenclosed.		Escalators that connect two stories may be unenclosed.		

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Minimum Fire Resistance Ratings of Enclosures	Element (Table 3-4) (Construction **Class IB**)	Hours	Element (Table 3-4) (Construct **Class IC**)	Hours	Minimum Class IB required in 1968 without sprinklers. Minimum Class IC required in current code with sprinklers.
	Transformer vaults (greater than 35,000 V) (National Electrical Code).	3	Transformer vaults (greater than 35,000 V) (NEC).	3	
	Emergency generator and fire pump rooms.	2	Emergency generator and fire pump rooms.	2	
	Storage rooms (B-1) greater than 75 ft^2 (Table 5-1 note c).	1	Storage rooms (B-1) greater than 75 ft^2 (Table 5-1 note c).	1	
Protection of Openings	Openings in a 3 h rated Fire Division or Fire Separation wall (Class "A") (C26-504.4 and Table 5-3).	3	Openings in a 3 h rated Fire Division or Fire Separation wall (Class "A") (27-342 and Table 5-3).	3	
	Openings in 2 h or 1½ h rated Fire Division or Fire Separation wall or vertical communication enclosure (Class "B") (C26-504.4, Table 5-3, C26-604.4(a), C26-1800.6).	1½	Openings in 2 h or 1½ h rated Fire Division or Fire Separation wall or vertical communication enclosure (Class "B") (27-342,Table 5-3, 27-371(a), 27-987).	1½	
	Openings in 1 h rated vertical communication enclosure (Class "B").	1	Openings in 1 h rated vertical communication enclosure (Class "B").	1	

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Protection of Openings (continued)	Openings in 1 h rated Fire Division or Fire Separation walls, corridors or partitions (Class "C") (C26-504.4, Table 5-3, C26-604.4(b)).	¾	Openings in 1 h rated Fire Division or Fire Separation walls, corridors or partitions (Class "C") (27-342, Table 5-3, 27-371(b)).	¾	
	Non-combustible mail slots not exceeding 40 in.^{2} may be provided in corridor doors (C26-604.4(b)).		Non-combustible mail slots not exceeding 40 in.^{2} may be provided in corridor doors (27-371(b)).		
	Non-combustible louvers may be installed in corridor doors opening into toilets, service sink closets and electrical closets (C26-604.4(b)).		Non-combustible louvers may be installed in corridor doors opening into toilets, service sink closets and electrical closets (27-371(b)).		
	Required protected openings in exterior walls (Class "E" or Class "F") (C26-503.1(b)).	¾	Required protected openings in exterior walls (Class "E" or Class "F") (27-331(b)).	¾	
	Openings in Fire Divisions and Fire Separations shall not exceed the size limits in Section C26-504.4(a).		Openings in Fire Divisions and Fire Separations shall not exceed the size limits in Section 27-342(a).		
	In shafts that contain only one opening below the roof, no opening protective is required (C26-504.6(c)).		In shafts that contain only one opening below the roof, no opening protective is required (27-344(c)).		

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Protection of Openings (continued)	Exterior street floor exit doors with a fire separation distance of more than 15 ft need not have a fire resistance rating (C26-604.4(a)(1).	Exterior street floor exit doors with a fire separation distance of more than 15 ft need not have a fire resistance rating (27-371(a)(1).	
Fire and Smoke Dampers	Fire dampers shall be provided in accordance with Reference Standard 13-1, NFPA 90A-1967 (C26-504.5(a)).	Fire dampers shall be provided in accordance with Reference Standard 13-1, NFPA 90A-1996 (27-343(a)).	
	Duct penetrations of walls with a 2 h fire resistance rating or greater (RS 13-1 §902(a)).	Duct penetrations of walls with a 2 h fire resistance rating or greater (RS 13-1 §2-3.8).	
	Each opening in required vertical shaft enclosures (RS 13-1 §902(b)).	Each opening in required vertical shaft enclosures (RS 13-1 §).	
	Each outlet or inlet opening in vertical shaft enclosure of duct systems serving two or more floors (RS 13-1 §902(c).	Each outlet or inlet opening in vertical shaft enclosure of duct systems serving two or more floors (RS 13-1 §).	
	As an alternate, dampers may be provided at each point where the vertical duct pierces a floor it serves (RS 13-1 §902(c).	As an alternate, dampers may be provided at each point where the vertical duct pierces a floor it serves (RS 13-1 §).	
	Branch duct penetrations of vertical duct shaft enclosures (RS 13-1 §902(c).	Branch duct penetrations of vertical duct shaft enclosures (RS 13-1).	
	Fresh air intakes (RS 13-1 §902(e)).	Fresh air intakes (RS 13-1).	
	Aluminum or Class I duct penetrations of fire resistance rated floors (RS 13-1 §902(d)).	Aluminum Class I duct penetrations of fire resistance rated floors (RS 13-1).	
	Fire dampers are not required at the following locations (RS 13-1 §903).	Fire dampers are not required at the following locations (RS 13-1).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Fire and Smoke Dampers (continued)	Non-aluminum or Class I vertical shaft branch duct penetrations with a cross-sectional area of less than 20 in.^{2} which supply only air conditioning units discharging air at not over 4 ft above the floor (RS 13-1 §903(a)).	Non-aluminum or Class I vertical shaft branch duct penetrations with a cross-sectional area of less than 20 in.^{2} which supply only air conditioning units discharging air at not over 4 ft above the floor (RS 13-1).	
	Non-aluminum or Class 1 duct penetrations of a floor (at one place only) with a cross-sectional area of less than 20 in.^{2} which supply air conditioning units in one story only that discharge air at not over 4 ft above the floor (RS 13-1 §903(b)).	Non-aluminum or Class 1 duct penetrations of a floor (at one place only) with a cross-sectional area of less than 20 in.^{2} which supply air conditioning units in one story only that discharge air at not over 4 ft above the floor (RS 13-1).	
	Duct penetrations in systems serving only one floor and used only for exhaust to the outside and not penetrating a fire wall or fire partition or passing entirely through the vertical shaft enclosure (RS 13-1 §903(d)).	Duct penetrations in systems serving only one floor and used only for exhaust to the outside and not penetrating a fire wall or fire partition or passing entirely through the vertical shaft enclosure (RS 13-1).	
	Branch ducts connected to a return riser where subducts are extended at least 22 in. upward (RS 13-1 §903(e)).	Branch ducts connected to a return riser where subducts are extended at least 22 in. upward (RS 13-1).	
	Fire dampers shall be automatic closing 1½ h fire rated with a fusible link or other heat actuated device rated approximately 50 ºF above the maximum system operating temperature (RS 13-1 §905(a) and §905(g)).	Fire dampers shall be automatic closing 1½ h fire rated with a fusible link or other heat actuated device rated approximately 50 ºF above the maximum system operating temperature (RS 13-1).	
	Duct openings permitted in fire resistance rated ceilings shall be protected with fire dampers (C26-502.5(a)).	Duct openings permitted in fire resistance rated ceilings shall be protected with fire dampers (27-327(b)).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Fire and Smoke Dampers (continued)	Smoke dampers shall be installed in the main supply duct and the main return duct in systems over 15,000 cfm capacity (RS 13-1 §1003).	Smoke dampers shall be installed in the main supply duct and the main return duct in systems over 15,000 cfm capacity (RS 13-1).	
	Smoke dampers shall be arranged to close automatically when the system is not in operation, by the operation of duct smoke detectors, and by the manual emergency fan stop (RS 13-1 §1003).	Smoke dampers shall be arranged to close automatically when the system is not in operation, by the operation of duct smoke detectors, and by the manual emergency fan stop (RS 13-1).	
Firestopping	All firestopping or fill materials shall consist of approved noncombustible materials that can be shaped, fitted and permanently secured in place (C26-504.7(a)).	All firestopping or fill materials shall consist of approved noncombustible materials that can be shaped, fitted and permanently secured in place (27-345(a)).	
	Concealed spaces within partitions, walls, floors, roofs, stairs, furring, pipe spaces, column enclosures, etc. that would permit passage of flame, smoke, fumes or hot gases from floor-to-floor shall be firestopped or filled with noncombustible material in the following locations (C26-504.7):	Concealed spaces within partitions, walls, floors, roofs, stairs, furring, pipe spaces, column enclosures, etc. that would permit passage of flame, smoke, fumes or hot gases from floor-to-floor shall be firestopped or filled with noncombustible material in the following locations (27-345):	
	Hollow partitions and furred spaces	Hollow partitions and furred spaces	
	Concealed spaces within stair construction.	Concealed spaces within stair construction.	
	Ceiling spaces within rated floor or roof assemblies	Ceiling spaces within rated floor or roof assemblies	
	Exterior cornices	Exterior cornices	
	Duct and pipe spaces (C26-504.5 and RS 13-1 §313, §314)	Duct and pipe spaces (27-343(b) and RS 13-1)	
	Hollow vertical Fire Division (C26-504.2(i))	Hollow vertical Fire Division (27-340(i))	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Firestopping (continued)	The concealed space above a fire resistance rated ceiling shall be firestopped into areas not exceeding 3,000 ft^2 (C26-502.5), except where:	The concealed space above a fire resistance rated ceiling shall be firestopped into areas not exceeding 3,000 ft^2 (27-327) except where:	
	Structural members within the concealed space are individually protected, or	Structural members within the concealed space are individually protected, or	
	The concealed space is sprinklered.	The concealed space is sprinklered.	
Through Penetration Protection	Noncombustible pipes and conduits may pass through fire resistance rated construction provided the following (C26-504.5):	Noncombustible pipes and conduits may pass through fire resistance rated construction provided the following (27-343):	
	Space between the pipe or conduit and its sleeve or opening does not exceed ½ in. and is packed with noncombustible material.	Space between the pipe or conduit and its sleeve or opening does not exceed ½ in. and is packed with noncombustible material.	
	Close-fitting metal escutcheons are provided on both sides of the construction.	Close-fitting metal escutcheons are provided on both sides of the construction.	
	Aggregate net area of openings does not exceed 25 $in.^2$ in any 100 ft^2 of wall or floor area.	Aggregate net area of openings does not exceed 25 $in.^2$ in any 100 ft^2 of wall or floor area.	
	Openings in excess of this limit are not permitted unless tested as part of a rated assembly and so protected.	Openings in excess of this limit are not permitted unless tested as part of a rated assembly and so protected.	
	Ceilings required to have a fire resistance rating may be pierced to accommodate noncombustible electric outlet boxes, recessed lighting fixtures, pipes and ducts as follows (C26-502.5(a)):	Ceilings required to have a fire resistance rating may be pierced to accommodate noncombustible electric outlet boxes, recessed lighting fixtures, pipes and ducts as follows (27-327(b)):	

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Through Penetration Protection (continued)	The aggregate area of outlet boxes and lighting fixtures does not exceed 16 $in.^2$ in each 90 ft^2 of ceiling area.		The aggregate area of outlet boxes and lighting fixtures does not exceed 16 $in.^2$ in each 90 ft^2 of ceiling area.		
	Outlet boxes and lighting fixtures are constructed of steel at least .022 in. thick and sealed tightly at the ceiling.		Outlet boxes and lighting fixtures are constructed of steel at least .022 in. thick and sealed tightly at the ceiling.		
	Additional or larger services are permitted only when tested as part of the assembly and protected as provided in the test.		Additional or larger services are permitted only when tested as part of the assembly and protected as provided in the test.		
	The concealed space above fire resistance rated ceilings may be used as a supply and return air plenum if tested for that purpose (RS 13-1 §316), provided:		The concealed space above fire resistance rated ceilings may be used as a return air plenum if listed (tested) for that purpose provided (RS 13-1):		
	All openings are tested as part of the assembly and protected in the test,		All openings are tested as part of the assembly and protected in the test,		
	The integrity of firestopping is not destroyed,		The integrity of firestopping is not destroyed,		
	No combustible materials are incorporated in the floor and ceiling construction, and		No combustible materials are incorporated in the floor and ceiling construction, and		
	Electrical wiring complies with NEC NFPA 70 §300-22).		>Electrical wiring is plenum rated (NEC).		NEC added a classification for plenum cables.
A.5 INTERIOR FINISH					
Interior Finish and Flame Spread Ratings (as defined in ASTM E84)	Exits and shafts (C26-504.10(c), Table 5-4, C26-604.8 (i)(3)):	Class A (0-25)	Exits and shafts (27-348(c), Table 5-4, 27-375(i)(3)):	Class A (0-25)	
	Corridors (C26-504.10(c), Table 5-4, C26-604.2(k)):		Corridors (27-348(c), Table 5-4 27-369(k)):		

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Interior Finish and Flame Spread Ratings (as defined in ASTM E84) (continued)	Group B-1:	Class A (0-25)	Group B-1:	Class A (0-25)	
	Groups B-2, E, F-4	Class A or B (0-75)	Groups E, B-2, F-4	Class A or B (0-75)	
	Group M:	Class A or B (0-75)	Group C:	Class A or B (0-75)	
	When used in corridors, Class B finish material shall not extend more than 50 ft between separations of Class A finish material that are at least 2 ft wide (Table 5-4 note b).		When used in corridors, Class B finish material shall not extend more than 50 ft between separations of Class A finish material that are at least 2 ft wide (Table 5-4 note b).		
	Spaces through which it is necessary for occupants of an adjacent room to pass in order to reach the only exit are considered as corridors.		Spaces through which it is necessary for occupants of an adjacent room to pass in order to reach the only exit are considered as corridors.		
	Rooms and enclosed spaces:		Rooms and enclosed spaces:		
	Rooms greater than 1,500 ft^2 (C26-504-10(c), Table 5-4):		Rooms greater than 1,500 ft^2 (27-348(c), Table 5-4):		
	Groups B-1, B-2, F-4	Class A or B (0-75)	Groups B-1, B-2, F-4	Class A or B (0-75)	
	Group E	Class A, B or C (0-225)	Group E	Class A, B or C (0-225)	
	Rooms less than 1,500 ft^2 (C26-504.10(c), Table 5-4):		Rooms less than 1,500 ft^2 (27-348(c), Table 5-4):		
	Group F-4	Class A, B or C (0-225)	Group F-4	Class A, B or C (0-225)	

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Interior Finish and Flame Spread Ratings (as defined in ASTM E84) (continued)	Groups B-1, B-2, E	Class A, B or C (0-225)	Groups B-1, B-2, E	Class A, B or C (0-225)	
	Interior finish in kitchens, cooking spaces, pantries, repair and maintenance shops, boiler rooms and incinerator combustion rooms shall be Class A or B (0-75) (Table 5-4 note f).		Interior finish in kitchens, cooking spaces, pantries, repair and maintenance shops, boiler rooms and incinerator combustion rooms shall be Class A or B (0-75) (Table 5-4 note f).		
Smoke Development Ratings	25 or less in exits and corridors.		25 or less in exits and corridors.		
	100 or less in rooms where the net floor area per occupant is 10 ft^2 or less.		100 or less in rooms where the net floor area per occupant is 10 ft^2 or less.		
	No material shall be used in any interior location that upon exposure to fire will produce products that are more toxic in point of concentration than those given off by wood or paper (C26-504.10(e)).		No material shall be used in any interior location that upon exposure to fire will produce products that are more toxic in point of concentration than those given off by wood or paper (27-348(e)).		
Interior Trim	Up to 20 % of the aggregate wall and ceiling area of any room or corridor may be finished with Class A, B or C (0-225) materials and be exempt from the smoke developed rating requirements (C26-504.10 (c)(4), C26-504.10 (d)).		Up to 20 % of the aggregate wall and ceiling area of any room or corridor may be finished with Class A, B or C (0-225) materials and be exempt from the smoke developed rating requirements (27-348(c)(4), 27-348(d)).		
	This allowance shall include the area of doors, folding partitions, windows, glazing, skylights, luminous ceilings, trim, bases, chair rails, panels, moldings, etc.		This allowance shall include the area of doors, folding partitions, windows, glazing, skylights, luminous ceilings, trim, bases, chair rails, panels, moldings, etc.		

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Finish Flooring	Finish flooring in all exits shall be of noncombustible material (C26-504.13, C26-604.8(h)).	Finish flooring in all exits shall be of noncombustible material (27-351, 27-375(h)).	
	In all other areas, combustible finish flooring may be used when installed in accordance with Section C26-504.13 (b).	In all other areas, combustible finish flooring may be used when installed in accordance with Section 27-351(b).	
A.6 MEANS OF EGRESS			
General	Clear width measurement is the net, unobstructed width of a means of egress without projections in such width (C26-604.2(a), C26-604.3(b)).	Clear width measurement is the net, unobstructed width of a means of egress without projections in such width (27-369(a), 27-370(b))	
	In corridors, projections up to 18 in. wide to the extent of 2 in. per unit of egress width are permitted if the total area of such projections does not exceed 5 % of the area of the wall on which they occur (C26-604.2(a)).	In corridors, projections up to 18 in. wide to the extent of 2 in. per unit of egress width are permitted if the total area of such projections does not exceed 5 % of the area of the wall on which they occur (27-369(a)).	
	Handrails shall project not more than 3½ in. and stringers 2 in. (each side) into the required stair width (C26-604.8(b), C26-604.8(f)).	Handrails shall project not more than 3½ in. and stringers 2 in. (each side) into the required stair width (27-375(b), 27-375(f)).	
	Corridor and exit passageway minimum height 7 ft 6 in. for at least 75 % of the floor area with no point less than 7 ft (C26-604.2(b), 604.3(c)).	Corridor and exit passageway minimum height 7 ft 6 in. for at least 75 % of the floor area with no point less than 7 ft (27-369(b), 27-370(c)).	
	Projections from the ceiling shall be at least 7 ft above the floor and located so as not to obstruct full view of exit signs (C26-604.2(b), 604.3(c)).	Projections from the ceiling shall be at least 7 ft above the floor and located so as not to obstruct full view of exit signs (27-369(b), 27-370(c)).	
	Changes in elevation in means of egress:	Changes in elevation in means of egress:	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
General (continued)	Changes in level requiring less than two risers in a corridor or exit passageway shall be by a ramp (C26-604.2(e), C26-604.8(d)(2)).	Changes in level requiring less than two risers in a corridor or exit passageway shall be by a ramp (27-369(e), 27-375(d)(2)).	
	Obstructions to means of egress:	Obstructions to means of egress:	
	The required width of a means of egress shall not be obstructed or reduced in any manner (C26-604.2).	The required width of a means of egress shall not be obstructed or reduced in any manner (27-369).	
	Corridors shall be kept free of combustible contents (C26-604.2).	Corridors shall be kept free of combustible contents (27-369).	
	All exterior means of egress elements, including exterior corridors and stairs, shall be maintained free of ice and snow accumulation (C26-604.2, C26-604.9).	All exterior means of egress elements, including exterior corridors and stairs, shall be maintained free of ice and snow accumulation (27-369(f), 27-376).	
	Corridors may be used as supply or return air ducts or plenums if equipped with an approved smoke detector or thermostatic device to shutdown fans (C26-604.2(j), RS 13-1 Sec. 316(d).	Corridors may be used as supply or return air ducts or plenums only in a fully sprinklered office building (27-369(j); RS 13-1 Sec. 2-3.11.1).	Associated with requirement for sprinklers in office buildings adopted by Local Law 16-1984
	Stairways connecting two or more stories shall not be used as plenums (RS13-1 Sec. 316(e)).	Stairways connecting two or more stories shall not be used as plenums (RS 13-1 Sec. 2-3.11.2).	
Exits	Every floor area shall be provided with at least two approved independent exits (C26-603.2).	Every floor area shall be provided with at least two approved independent exits (27-366).	
	Public garages shall be provided with at least two exits from each tier of parking (C26-709.8).	Public garages shall be provided with at least two exits from each tier of parking (27-457).	

<table>
<tr><th></th><th>THEN CURRENT BCNYC</th><th>CURRENT BCNYC</th><th>SUMMARY OF SIGNIFICANT DIFFERENCES</th></tr>
<tr><td>Exits (continued)</td><td>A minimum of two exits or exit access doors shall be provided from every room or space in which the occupant load exceeds the following limits (C26-603.1):
<table><tr><th>Occupancy Group</th><th>Occupant Load</th></tr><tr><td>B (Storage)</td><td>50</td></tr><tr><td>C (Mercantile)</td><td>75</td></tr><tr><td>E (Business)</td><td>75</td></tr><tr><td>F (Assembly)</td><td>75</td></tr></table></td><td>A minimum of two exits or exit access doors shall be provided from every room or space in which the occupant load exceeds the following limits (27-365(a)):
<table><tr><th>Occupancy Group</th><th>Load</th></tr><tr><td>B (Storage)</td><td>50</td></tr><tr><td>C (Mercantile)</td><td>75</td></tr><tr><td>E (Business)</td><td>75</td></tr><tr><td>F (Assembly)</td><td>75</td></tr></table></td><td></td></tr>
<tr><td></td><td>All required exits shall be located such that they are clearly visible, accessible and unobstructed access at all times C26-602.1).</td><td>All required exits shall be located such that they are clearly visible, accessible and unobstructed access at all times (27-361).</td><td></td></tr>
<tr><td></td><td>In multi-tenant configurations, each tenant shall have access to the required numbers of exits without passing through other tenant spaces (C26-602.2).</td><td>In multi-tenant configurations, each tenant shall have access to the required numbers of exits without passing through other tenant spaces (27-362).</td><td></td></tr>
<tr><td></td><td>When more than one exit is required from a floor of a building, they shall be located as remote from each other as practicable (C26-602.3).</td><td>When more than one exit is required from a floor of a building, they shall be located as remote from each other as practicable (27-363).</td><td></td></tr>
<tr><td></td><td>Door openings to scissor stairs shall be at least 15 ft apart (C26-602.3).</td><td>Door openings to vertical exits shall be the greater of 30 ft or one-third the maximum travel distance of the floor (27-363).</td><td>Local Law 16/1984 amended section to change remote location of stairs from 15 ft to 30 ft (or one-third the maximum travel distance of the floor).</td></tr>
</table>

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Exits (continued)	All vertical exits shall extend in a continuous enclosure to discharge directly to an exterior space or at a yard, court, exit passageway or street floor lobby of the required width and size to provide all occupants with a safe access to an open exterior space (C26-602.4).	All vertical exits shall extend in a continuous enclosure to discharge directly to an exterior space or at a yard, court, exit passageway or street floor lobby of the required width and size to provide all occupants with a safe access to an open exterior space (27-364).	
	A maximum of 50 % of the required number of vertical exits is permitted to discharge through a single exit passageway (C26-604.3).	A maximum of 50 % of the required number of vertical exits is permitted to discharge through a single exit passageway (27-370).	
	100 % of the number of vertical exits may discharge through a street floor lobby if egress is provided in two different directions from discharge points to open exterior spaces remote from each other (C26-604.3(h)(1)).	100 % of the number of vertical exits may discharge through a street floor lobby if egress is provided in two different directions from discharge points to open exterior spaces remote from each other (27-370(h)(1)).	
	The clear width of an exit passageway serving two or more vertical exits shall be equal to 75 % of the width of all vertical exits it serves (C26-604.3(b)).	The clear width of an exit passageway serving two or more vertical exits shall be equal to 75 % of the width of all vertical exits it serves (27-370(b)).	
	The width of street floor lobbies serving as exit passageways shall be increased to accommodate the occupant load of all communicating spaces on the lobby floor that exit through them (C26-604.3(h)(2)).	The width of street floor lobbies serving as exit passageways shall be increased to accommodate the occupant load of all communicating spaces on the lobby floor that exit through them (27-370(h)(2)).	
	No openings other than exit doors are permitted in exit passageways (C26-604.3(f)), except:	No openings other than exit doors are permitted in exit passageways (27-370(f)), except:	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Exits (continued)	Openings between street floor lobbies serving as exit passageways and elevators or communicating spaces and show windows protected in accordance with Section C26-604.3(h)(3) are permitted (C26-	Openings between street floor lobbies serving as exit passageways and elevators or communicating spaces and show windows protected in accordance with Section 27-370(h)(3) are permitted.	
	Street floor lobbies serving as exit passageways may be occupied by newsstands, candy and tobacco stands, information booths or similar occupancies if constructed of noncombustible materials, occupying not more than 5 % of the net lobby floor area, and if not reducing the required clear width at any point (C26-604.3(h)(4)).	Street floor lobbies serving as exit passageways may be occupied by newsstands, candy and tobacco stands, information booths or similar occupancies if constructed of noncombustible materials, occupying not more than 5 % of the net lobby floor area, and if not reducing the required clear width at any point (27-370(h)(4)).	
	Horizontal and Supplemental Vertical Exits (C26-604.5 to C26-604.7):	Horizontal and Supplemental Vertical Exits (27-372, 27-373, 27-374):	
	The occupant load capacity for vertical exits may be reduced by 50 % when one area of refuge is provided and by 66 % when two or more areas of refuge are provided (C26-603.3).	The occupant load capacity for vertical exits may be reduced by 50 % when one area of refuge is provided and by 66 % when two or more areas of refuge are provided (27-367).	
	At least 3 ft^2 per person of clear public space, or space occupied by the same tenant or owner, shall be provided within the area of refuge for the occupant load received in addition to its own occupant load (C26-604.5(b)).	At least 3 ft^2 per person of clear public space, or space occupied by the same tenant or owner, shall be provided within the area of refuge for the occupant load received in addition to its own occupant load (27-372(b)).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Exits (continued)	Each area of refuge shall be provided with at least one vertical exit and when located above the 11th floor, the vertical exit shall be supplemented by at least one elevator (C26-604.5(c)).	Each area of refuge shall be provided with at least one vertical exit and when located above the 11th floor, the vertical exit shall be supplemented by at least one elevator (27-372(c)).	
	Access to an area of refuge, on the same floor, through a horizontal exit, may consist of doors, balconies, bridges and tunnels (C26-604.6).	Access to an area of refuge, on the same floor, through a horizontal exit, may consist of doors, balconies, bridges and tunnels (27-373).	
	Doors must swing in the direction of exit travel and be self-closing having a fire resistance rating of 1½ h. Where areas of refuge are provided on both sides of a horizontal exit, two door openings shall be provided, each swinging in opposite directions (C26-604.6(b)).	Doors must swing in the direction of exit travel and be self-closing having a fire resistance rating of 1½ h. Where areas of refuge are provided on both sides of a horizontal exit, two door openings shall be provided, each swinging in opposite directions (27-373(b)).	
	Balconies, bridges and tunnels serving as horizontal exits shall comply with Section C26-604.6(c).	Balconies, bridges and tunnels serving as horizontal exits shall comply with Section 27-373(c).	
	Access to an area of refuge on a floor nearer to the street, through a supplemental vertical exit, may consist of enclosed interior stairs, ramps, or escalators (C26-604.7).	Access to an area of refuge on a floor nearer to the street, through a supplemental vertical exit, may consist of enclosed interior stairs, ramps, or escalators (27-374).	
	Supplemental vertical exits shall comply with the requirements for interior stairs, and serve no other purpose than to connect a floor area with an area of refuge with no openings in the enclosure other than exit doors (C26-604.7).	Supplemental vertical exits shall comply with the requirements for interior stairs, and serve no other purpose than to connect a floor area with an area of refuge with no openings in the enclosure other than exit doors (27-374).	

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Exits (continued)	Every supplemental vertical exit shall have a sign at the entrance stating EXIT TO AREA OF REFUGE ON _____ FLOOR (C26-604.7).		Every supplemental vertical exit shall have a sign at the entrance stating EXIT TO AREA OF REFUGE ON _____ FLOOR (27-374).		
Egress Width and Capacity	Occupant load - calculate based on the net floor areas in square feet divided by the occupant load factor (ft^2/person) or the actual number of occupants from whom each occupied space is designed, whichever is greater (C26-601.2).		Occupant load - calculate based on the net floor areas in square feet divided by the occupant load factor (ft^2/person) or the actual number of occupants from whom each occupied space is designed, whichever is greater (27-358).		
	Occupancy	Factor	Occupancy	Factor	
	Business (offices)	100	Business (offices)	100	
	Conference rooms (Tables)	12	Conference rooms (Tables)	12	
	Conference rooms (movable chairs)	10	Conference rooms (movable chairs)	10	
	Dining spaces	12	Dining spaces	12	
	Mercantile – 1st floor / basement All other floors	 25 50	Mercantile – 1st floor / basement All other floors	 25 50	
	Assembly (fixed seats)	# of seats	Assembly (fixed seats)	# of seats	
	Waiting space (standing)	4	Waiting space (standing)	4	
	Garages / parking	250	Garages / parking	250	
	Storage rooms	200	Storage rooms	200	
	Mechanical rooms	200	Mechanical rooms	200	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Egress Width and Capacity (continued)	Nonsimultaneous Occupancy - The occupant load of toilets, locker rooms, meeting rooms, storage rooms, employee cafeterias, and similar rooms or spaces that are not occupied at the same time as other rooms or spaces on the same floor may be omitted from the occupant load calculation of the floor on which they are located (C26-601.2).	Nonsimultaneous Occupancy - The occupant load of toilets, locker rooms, meeting rooms, storage rooms, employee cafeterias, and similar rooms or spaces that are not occupied at the same time as other rooms or spaces on the same floor may be omitted from the occupant load calculation of the floor on which they are located (27-358).	
	The occupant load of any space shall include the occupant load of all spaces that discharge through it in order to gain access to an exit (C26-601.2).	The occupant load of any space shall include the occupant load of all spaces that discharge through it in order to gain access to an exit (27-358).	
	Where vertical exits serve more than one floor, only the occupant load of each floor considered individually is used in computing the required capacity of exits at that floor, except where one floor is used by another as a means of egress (C26-601.1).	Where vertical exits serve more than one floor, only the occupant load of each floor considered individually is used in computing the required capacity of exits at that floor, except where one floor is used by another as a means of egress (27-357).	
	Exit capacity (width) shall not decrease in the direction of exit travel (C26-604.8).	Exit capacity (width) shall not decrease in the direction of exit travel (27-375).	
	The width of each means of egress component shall be that computed using the appropriate egress unit factor but not less than the minimum width prescribed for the component (C26-601.1, C26-601.3).	The width of each means of egress component shall be that computed using the appropriate egress unit factor but not less than the minimum width prescribed for the component (37-357, 27-359).	
	Where computations give fractional results, the next larger integral number of egress units or integral number plus ½ shall be used (C26-601.3).	Where computations give fractional results, the next larger integral number of egress units or integral number plus ½ shall be used (27-359).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Egress Width and Capacity (continued)	A fraction less than ½ may be neglected when constituting less than 10 % of the total required number of egress units).	A fraction less than ½ may be neglected when constituting less than 10 % of the total required number of egress units).	
	Egress capacity factors - capacity per egress unit (C26-601.1, C26-601.3).	Egress capacity factors - capacity per egress unit (27-357, 27-359).	
	One unit of egress width is equal to 22 in. (C26-601.3).	One unit of egress width is equal to 22 in. (27-359).	
	Doors to outdoors at grade:	Doors to outdoors at grade:	
	Occupancy Group B (Storage) – 75 persons per unit.	Occupancy Group B (Storage) – 75 persons per unit.	
	Occupancy Groups C (Mercantile), E (Business), and F (Assembly) – 100	Occupancy Groups C (Mercantile), E (Business), and F (Assembly) – 100	
	Other exit and corridor doors:	Other exit and corridor doors:	
	Occupancy Group B (Storage) - 60	Occupancy Group B (Storage) - 60	
	Occupancy Group C (Mercantile), E (Business), and F (Assembly) - 80	Occupancy Group C (Mercantile), E (Business), and F (Assembly) - 80	
	Stairs and escalators:	Stairs and escalators:	
	Occupancy Group B (Storage) - 45	Occupancy Group B (Storage) - 45	
	Occupancy Groups C (Mercantile), E (Business), and F (Assembly) - 60	Occupancy Groups C (Mercantile), E (Business), and F (Assembly) - 60	
	Ramps, corridors, exit passageways, horizontal exits:	Ramps, corridors, exit passageways, horizontal exits:	
	Occupancy Group B (Storage) - 75	Occupancy Group B (Storage) - 75	
	Occupancy Groups C (Mercantile), E (Business), and F (Assembly) - 100	Occupancy Groups C (Mercantile), E (Business), and F (Assembly) - 100	
	When ramp slope exceeds 1 in 10, the capacity shall be reduced by 25 % (Table 6-1 note b).	When ramp slope exceeds 1 in 10, the capacity shall be reduced by 25 % (Table 6-1 note b).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Egress Width and Capacity (continued)	The capacity of horizontal exits shall be based on the width of doors swinging in the direction of exit travel (C26-604.6(a)).	The capacity of horizontal exits shall be based on the width of doors swinging in the direction of exit travel (27-373(a)).	
	Where a door is divided by mullions into two or more door openings each opening shall be measured separately in computing the number of egress units (Table 6-1 note m).	Where a door is divided by mullions into two or more door openings each opening shall be measured separately in computing the number of egress units (Table 6-1 note m).	
Doors	Minimum nominal width - 32 in. except for corridor and exit door openings which shall be 36 in. (C26-604.4(e)).	Minimum nominal width - 32 in. except for corridor and exit door openings which shall be 36 in. (27-371(e)).	
	Door jambs or stops and the door thickness when open shall not reduce the required width by more than 3 in. for each 22 in. of width (C26-604.4(e)).	Door jambs or stops and the door thickness when open shall not reduce the required width by more than 3 in. for each 22 in. of width (27-371(e)).	
	In all cases where a door opening is divided by mullions into two or more door openings, the minimum nominal width of each such opening shall be 32 in. (C26-604.4(c)).	In all cases where a door opening is divided by mullions into two or more door openings, the minimum nominal width of each such opening shall be 32 in. (27-371(c)).	
	Maximum width of leaf - 48 in. (C26-604.4(e)).	Maximum width of leaf - 48 in. (27-371(e)).	
	Minimum height - 6 ft, 8 in. (C26-604.4(f)).	Minimum height - 6 ft, 8 in. (27-371(f)).	
	Door jambs, stops, sills and closers shall not reduce the clear opening to less than 6 ft 6 in. (C26-604.4(f)).	Door jambs, stops, sills and closers shall not reduce the clear opening to less than 6 ft 6 in. (27-371(f)).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Doors (continued)	The floor on both sides of all exit and corridor doors shall be substantially level and have the same elevation for a distance at least equal to the width of the leaf (C26-604.4(h)).	The floor on both sides of all exit and corridor doors shall be substantially level and have the same elevation for a distance at least equal to the width of the leaf (27-371(h)).	
	Where doors lead out of a building, the floor level inside may be 7½ in. higher than the level outside (C26-604.4(h)).	Where doors lead out of a building, the floor level inside may be 7½ in. higher than the level outside (27-371(h)).	
	Exit doors, corridor doors serving high hazard occupancy Group A spaces, and corridor doors from rooms required to have more than one door shall swing in the direction of egress (C26-604.4(g)).	Exit doors, corridor doors serving high hazard occupancy Group A spaces, and corridor doors from rooms required to have more than one door shall swing in the direction of egress (27-371(g)).	
	Vertically sliding doors, rolling shutters, and folding doors shall not be used as exit doors or as corridor doors (C26-604.4(d)).	Vertically sliding doors, rolling shutters, and folding doors shall not be used as exit doors or as corridor doors (27-371(d)).	
	Revolving doors designed and constructed in accordance with Section C26-604.4(m) are permitted to be used as exits except that revolving doors shall not be used as interior exit access doors, at the foot of stairs, or at the head of basement stairs (C26-604.4(d)).	Revolving doors designed and constructed in accordance with Section 27-371(m) are permitted to be used as exits except that revolving doors shall not be used as interior exit access doors, at the foot of stairs, or at the head of basement stairs (27-371(d)).	
	Turnstiles designed and constructed in accordance with Section C26-604.4(n) may also be permitted.	Turnstiles designed and constructed in accordance with Section 27-371(n) may also be permitted.	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Doors (continued)	Power operated or power assisted manually operated doors may be used as exit or corridor doors provided they remain closed in case of power failure and are manually operable. To be credited as a required exit, power operated doors must swing in the direction of exit travel (C26-604.4(l)).	Power operated or power assisted manually operated doors may be used as exit or corridor doors provided they remain closed in case of power failure and are manually operable. To be credited as a required exit, power operated doors must swing in the direction of exit travel (27-371(l)).	
	Exit doors and corridor doors shall normally be kept in the closed position (C26-604.4(i)).	Exit doors and corridor doors shall normally be kept in the closed position (27-371(i)).	
	Latch bolts shall be provided on all exit doors and corridor doors to hold them in a closed position against the pressure of expanding gases (C26-604.4(j)(1)(c)).	Latch bolts shall be provided on all exit doors and corridor doors to hold them in a closed position against the pressure of expanding gases (27-371(j)(1)(c)).	
	Obstruction of means of egress during door opening.	Obstruction of means of egress during door opening.	
	Doors providing access to stairways or ramps shall not block stairs/ramps or stair landings or reduce the width of landings/stairs/ramps to less than 75 % of the required width or to less than the width of the door opening on them (C26-604.8(g), C26-604.10(c)(4)).	Doors providing access to stairways or ramps shall not block stairs/ramps or stair landings or reduce the width of landings/stairs/ramps to less than 75 % of the required width or to less than the width of the door opening on them (27-375(g), 27-377(c)(4)).	
	No door shall swing over the sloping portion of a ramp (C26-604.8(g)).	No door shall swing over the sloping portion of a ramp (27-377(c)(4)).	
	Exit and corridor doors and doors providing access to areas of refuge shall be readily openable at all times from the side from which egress is made without the use of a key (C26-604.4(j)(1)(a), C26-604.5(d)).	Exit and corridor doors and doors providing access to areas of refuge shall be readily openable at all times from the side from which egress is made without the use of a key (27-371(j)(1)(a), 27-372)d)).	

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Doors (continued)	Locks may be used in places where extra safeguards are required (banks, museums, etc.), subject to approval of the commissioner, provided the locks are equipped with electrical release devices for remote control in case of emergency (C26-604.4(j)(1)(a)(2)).		Locks may be used in places where extra safeguards are required (banks, museums, etc.), subject to approval of the commissioner, provided the locks are equipped with electrical release devices for remote control in case of emergency (27-371(j)(1)(a)(2)).		
	Doors opening into interior enclosed stairs shall not be locked from either side except that doors may be locked to prevent access to the stair from the outside at the street floor (C26-604.4(j)(1)(b).		Doors opening into interior enclosed stairs shall not be locked from either side except that doors may be locked to prevent access to the stair from the outside at the street floor (27-371(j)(1)(b)).		
Exit Access Corridors	Minimum clear width of corridors (C26-604.2(a), Table 6-1):		Minimum clear width of corridors (27-369(a), Table 6-1):		
	Occupancy Groups B (Storage), C (Mercantile) - 36 in.		Occupancy Groups B (Storage), C (Mercantile) - 36 in.		
	Occupancy Groups E (Business), F (Assembly) - 44 in.		Occupancy Groups E (Business), F (Assembly) - 44 in.		
	The maximum length of exit access travel shall not exceed the following limits, measured from the most remote point in an area, to the center of an exit door (C26-601.4, Table 6-1, C26-709.8, C26-801.9, Table 8-1)		The maximum length of exit access travel shall not exceed the following limits, measured from the most remote point in an area, to the center of an exit door (27-360, Table 6-1, 27-457(a), 27-533, Table 8-1).		
	Occupancy Group	Distance (Feet)	Occupancy Group	Distance (Feet)	
		Unsprink. /sprinkler		Unsprink. /sprinkler	
	B-1 (Storage)	100/150	B-1 (Storage)	100/150	
	B-2 (Storage)	125/175	B-2 (Storage)	125/175	
	B-2 (Parking Garage)	100/150	B-2 (Parking Garage)	100/150	

	THEN CURRENT BCNYC		CURRENT BCNYC		SUMMARY OF SIGNIFICANT DIFFERENCES
Exit Access Corridors (continued)	C (Mercantile)	150/200	C (Mercantile)	150/200	
	E (Business)	200/300	E (Business)	200/300	
	F (Assembly) <75 persons: >75 persons:	 150/200 varies	F (Assembly) < 75 persons: >75 persons:	 150/200 varies	
	Travel distance shall be measured along the natural and unobstructed path of travel. Where the path of travel is over an access stair, it shall be measured along an inclined straight line through the center of the outer edge of each tread (C26-601.4(c).		Travel distance shall be measured along the natural and unobstructed path of travel. Where the path of travel is over an access stair, it shall be measured along an inclined straight line through the center of the outer edge of each tread (27-360(c)).		
	The maximum dead-end distance shall not exceed the following limits (C26-604.2(d), Table 6-1):		The maximum dead-end distance shall not exceed the following limits (27-369(d), Table 6-1):		
	Occupancy Group	Distance (Feet)	Occupancy Group	Distance (Feet)	
	B-1 (Storage)	50	B-1 (Storage)	50	
	B-2 (Storage)	NR (no requirement)	B-2 (Storage)	NR	
	C (Mercantile)	50	C (Mercantile)	50	
	E (Business)	50	E (Business)	50	
	F (Assembly)	30	F (Assembly)	30	
	When a corridor is completely enclosed in 2 h fire resistance rated construction with 1½ h fire rated doors, the permissible length of dead ends may be increased by 100 % (C26-604.2(d)).		When a corridor is completely enclosed in 2 h fire resistance rated construction with 1½ h fire rated doors, the permissible length of dead ends may be increased by 100 % (27-369(d)).		

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Exit Access Corridors (continued)	Exterior corridors designed and constructed in accordance with Section C26-604.2(f) may be used as a means of egress.	Exterior corridors designed and constructed in accordance with Section 27-369(f) may be used as a means of egress.	
Stairways	Minimum clear width - 44 in. (C26-604.8(b)).	Minimum clear width – 44 in. (27-375(b))	
	The width of stairs shall be the clear width between walls, grilles, guard, or newel posts (C26-604.8(b)).	The width of stairs shall be the clear width between walls, grilles, guard, or newel posts (27-375(b)).	
	Stair stringer projections which do not exceed 2 in. on each side and handrail projections of 3½ in. are permitted (C26-604.8(b), C26-604.8(f)).	Stair stringer projections which do not exceed 2 in. on each side and handrail projections of 3½ in. are permitted (27-375(b), 27-375(f)).	
	Vertical exits in public garages may be 36 in. wide (C26-709.8).	Vertical exits in public garages may be 36 in. wide (27-457).	
	The minimum width of landings and platforms shall be at least the required width of the stairway (C26-604.8(d)(1)).	The minimum width of landings and platforms shall be at least the required width of the stairway (27-375(d)(1)).	
	On a straight run stair, landing and platform widths need not be more than 44 in.	On a straight run stair, landing and platform widths need not be more than 44 in.	
	Minimum headroom - 7 ft (C26-604.8(c).	Minimum headroom - 7 ft (27-375(c)).	
	Maximum vertical rise between landings - 12 ft (C26-604.8(d)(2)).	Maximum vertical rise between landings - 12 ft (27-375(d)(2)).	
	Treads and risers (C26-604.8(e), Table 6-4).	Treads and risers (27-375(e), Table 6-4).	
	Maximum riser height - 7¾ in.	Maximum riser height - 7¾ in.	
	Except - Occupancy Group F (Assembly) - 7½ in.	Except Occupancy Group F (Assembly) - 7½ in.	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Stairways (continued)	Minimum tread depth - 9½ in. plus nosing	Minimum tread depth - 9½ in. plus nosing	
	The sum of two risers plus one tread exclusive of the nosing shall not be less than 24 nor more than 25½ in. (C26-604.8(e)(1)).	The sum of two risers plus one tread exclusive of the nosing shall not be less than 24 nor more than 25½ in. (27-375(e)(1)).	
	Stair riser and tread dimensions shall be constant in any flight of stairs from story to story (C26-604.8(e)(2)).	Stair riser and tread dimensions shall be constant in any flight of stairs from story to story (27-375(e)(2)).	
	Curving or skewed stairs that conform to Section C26-604.8(e)(4) are permitted to be used as exits.	Curving or skewed stairs that conform to Section 27-375(e)(4) are permitted to be used as exits.	
	Where exit stairways serving floors above grade continue in the same enclosure to serve floors below grade, the above and below grade portions shall be separated by 1 h fire resistance rated construction with a ¾ h door (C26-602.4).	Where exit stairways serving floors above grade continue in the same enclosure to serve floors below grade, the above and below grade portions shall be separated by 1 h fire resistance rated construction with a ¾ h door (27-364).	
		Stair identification signs shall be posted on the occupancy side and stair side of the door indicating the letter designation of the stair (27-393).	Section C26-608.4 was added in 1973 by Local Law #5 and renumbered 27-393 in 1985.
	In buildings or in building sections more than three stories or 40 ft high with roofs having a slope of less than 20 degrees, access to the roof shall be provided by at least one interior stair (C26-604.8(k)).	In buildings or in building sections more than three stories or 40 ft high with roofs having a slope of less than 20 degrees, access to the roof shall be provided by at least one interior stair (27-375(k)).	
	Access to set back roof areas may be through a door or window opening to the roof(C26-604.8(k)).	Access to set back roof areas may be through a door or window opening to the roof (27-375(k)).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Stairways (continued)	No openings of any kind are permitted into stair enclosures other than windows, fire department access panels and exit doors (C26-604.8(j)).	No openings of any kind are permitted into stair enclosures other than windows, fire department access panels and exit doors (27-375(j)).	
	Exterior stairs designed and constructed in accordance with Section C26-604.9 may be used as exits in lieu of interior stairs (C26-604.9).	Exterior stairs designed and constructed in accordance with Section 27-376 may be used as exits in lieu of interior stairs (27-376).	
	No exterior stair shall exceed 75 ft or six stories in height (C26-604.9).	No exterior stair shall exceed 75 ft or six stories in height (27-376).	
	Escalators designed and constructed in accordance with Section C26-604.11 may be used as exits in lieu of interior stairs.	Escalators designed and constructed in accordance with Section 27-378 may be used as exits in lieu of interior stairs.	
Ramps	The minimum clear width of exit ramps is 44 in. (C26-604.10).	The minimum clear width of exit ramps is 44 in. (27-377).	
	Level platforms or landings at least as wide as the ramp shall be provided at the top and bottom of all ramps and at intermediate levels as necessary (C26-604.10(c)(3)).	Level platforms or landings at least as wide as the ramp shall be provided at the top and bottom of all ramps and at intermediate levels as necessary (27-377(c)(3)).	
	Level platforms shall be provided on each side of door openings into or from ramps. (C26-604.10.c.3).	Level platforms shall be provided on each side of door openings into or from ramps. (27-377(c)(3))	
	Platforms shall be at least as wide as the ramp with a minimum length in the direction of travel of 3 ft (5 ft when a door swings on the platform).	Platforms shall be at least as wide as the ramp with a minimum length in the direction of travel of 3 ft (5 ft when a door swings on the platform).	
	Minimum headroom - 6 ft 8 in. (C26-604.10).	Minimum headroom - 6 ft 8 in. (27-377).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Ramps (continued)	Ramps shall be straight. Changes in direction of travel shall be made only at landings or platforms (C26-604.10(c)(1).	Ramps shall be straight. Changes in direction of travel shall be made only at landings or platforms (27-377(c)(1)).	
	Except - Ramps with a slope not greater than 1 in 12 at any place may be curved.	Except - Ramps with a slope not greater than 1 in 12 at any place may be curved.	
	Ramps shall not have a slope steeper than 1 in 8 (C26-604.10(b)) and sloping portions shall be at least 3 ft but not more than 30 ft long between platforms or landings (C26-604.10(c)(2)).	Ramps shall not have a slope steeper than 1 in 8 (27-377(b)) and sloping portions shall be at least 3 ft but not more than 30 ft long between platforms or landings (27-377(c)(2)).	
	Level and ramped moving walkways designed and constructed in accordance with Section C26-604.12 may be used as exits.	Level and ramped moving walkways designed and constructed in accordance with Section 27-379 may be used as exits.	
Handrails and Guardrails	Continuous handrails are required on both sides of all stairs and all ramps with a slope exceeding 1 in 12 (C26-604.8(f), C26-604.10(c)(5))	Continuous handrails are required on both sides of all stairs and all ramps with a slope exceeding 1 in 12 (27-375(f), 27-377(c)(5)).	
	Stairs less than 44 in. wide may have a handrail on one side only (C26-604.8(f)).	Stairs less than 44 in. wide may have a handrail on one side only (27-375(f)).	
	Intermediate handrails shall be provided to divide stairs more than 88 in. wide into widths that maintain nominal multiples of 22 in. and widths not greater than 88 in. nor less than 44 in. (C26-604.8(f)(1)).	Intermediate handrails shall be provided to divide stairs more than 88 in. wide into widths that maintain nominal multiples of 22 in. and widths not greater than 88 in. nor less than 44 in. (27-375(f)(1)).	
	Handrail height shall be 30 to 34 in. measured vertically above the nosing of treads (C26-604.8(f)(2)).	Handrail height shall be 30 to 34 in. measured vertically above the nosing of treads (27-375(f)(2)).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Handrails and Guardrails (continued)	Handrail ends shall be returned to walls and posts when terminated (C26-604.8(f)(3).	Handrail ends shall be returned to walls and posts when terminated (27-375(f)(3)).	
	Handrails shall provide a finger clearance of 1½ in. and shall project not more than 3½ in. into the required stair width (C26-604.8(f)).	Handrails shall provide a finger clearance of 1½ in. and shall project not more than 3½ in. into the required stair width (27-375(f)).	
	Stair landings and platforms shall be enclosed on sides by walls, grilles, or guards at least 3 ft height (C26-604.8(d)(3)).	Stair landings and platforms shall be enclosed on sides by walls, grilles, or guards at least 3 ft height (27-375(d)(3)).	
Exit Signs and Lights	In all buildings, the location of every exit on every floor shall be clearly indicated by approved EXIT signs (C26-606.1).	In all buildings, the location of every exit on every floor shall be clearly indicated by approved EXIT signs (27-383).	
	EXIT signs shall be placed at an angle with the exit opening if such placement is required for the signs to serve their purpose (C26-606.1).	EXIT signs shall be placed at an angle with the exit opening if such placement is required for the signs to serve their purpose (27-383).	
	In areas where the location of the exit may not be readily visible or understood (including long corridors and open floor areas), directional signs shall be provided to serve as guides from all portions of the corridor or floor (C26-606.1).	In areas where the location of the exit may not be readily visible or understood (including long corridors and open floor areas), directional signs shall be provided to serve as guides from all portions of the corridor or floor (27-383).	
	The size, color and illumination of EXIT signs shall conform to Section C26-606.3. Directional signs shall conform to Section C26-606.4.	The size, color and illumination of EXIT signs shall conform to Section 27-385. Directional signs shall conform to Section 27-386.	
	All EXIT signs shall be illuminated at all times when the building is occupied (C26-606.3).	All EXIT signs shall be illuminated at all times when the building is occupied (27-385).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Exit Signs and Lights (continued)	Where a total of more than four signs (exit and/or directional) are required, all EXIT signs shall be connected to circuits that are separate from the general lighting and power circuits. These circuits shall be taken off ahead of the main switch or connected to an emergency lighting power source when such source is provided (C26-606.2).	Where a total of more than four signs (exit and/or directional) are required, all EXIT signs shall be connected to an emergency power source or to storage battery equipment. Existing buildings in Occupancy Group E were required to comply by April 1, 1987 (C26-606.2 amended by Local Law 16/1984 and renumbered 27-384 in 1985).	Current NYC Building Code requires emergency power source or storage battery equipment. Retroactive for existing high-rise buildings.
	Any door, passageway, stair, or other means of communication that is not an exit shall be so identified with a "NOT AN EXIT" sign, a sign indicating its use or purpose or a directional exit sign shall be provided (C26-606.5).	Any door, passageway, stair, or other means of communication that is not an exit shall be so identified with a "NOT AN EXIT" sign, a sign indicating its use or purpose or a directional exit sign shall be provided (27-387).	
Means of Egress Lighting	Corridors and exits shall be equipped with artificial lighting facilities to provide at least 5 foot candle intensity floor lighting continuously during occupancy (C26-605.1).	Corridors and exits shall be equipped with artificial lighting facilities to provide at least 5 foot candle intensity floor lighting continuously during occupancy (27-381).	
	Lighting shall be provided to illuminate changes in direction in and intersections of corridors, balconies, exit passageways, stairs, ramps, escalators, bridges, tunnels, landings and platforms.	Lighting shall be provided to illuminate changes in direction in and intersections of corridors, balconies, exit passageways, stairs, ramps, escalators, bridges, tunnels, landings and platforms.	
	Illumination shall be arranged so that failure of any one light does not leave any area in darkness.	Illumination shall be arranged so that failure of any one light does not leave any area in darkness.	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Means of Egress Lighting (continued)	Means of egress lighting in all buildings, where a total of more than four lights is required, shall be connected to circuits that are separate from the general lighting and power circuits. These circuits shall be taken off ahead of the main switch or connected to an emergency lighting power source when such source is provided (C26-605.2).	Means of egress lighting in all buildings, where a total of more than four lights is required, shall be connected to an emergency power source or to storage battery equipment. Existing buildings in Occupancy Group E were required to retroactively comply by April 1, 1987 (C26-605.2 amended by Local Law 16/1984 and renumbered 27-382 in 1985).	Current NYC Building Code requires emergency power source or storage battery equipment. Retroactive for existing high-rise buildings.
A.7 FIRE SUPPRESSION			
Automatic Sprinkler Protection	Automatic sprinkler protection shall be designed and installed in accordance with Section C26-1703.1 and RS 17-2 in the following areas: Spaces in Group B-2 > 5,000 ft^2; Spaces in Group C > 7,500 ft^2; Any story above grade and the 1st story below grade w/o required ventilation; All other stories below grade.	Automatic sprinkler protection shall be designed and installed in accordance with Section 27-954 and RS 17-2 in the following areas: Spaces in Group B-2 > 5,000 ft^2; Spaces in Group C > 7,500 ft^2; Any story above grade and the 1st story below grade w/o required ventilation; All other stories below grade; Buildings classified in Occupancy Group E, 75 ft or more in height and existing office buildings 100 ft or more in height; Buildings in Occupancy Group E with a total gross floor area of 100,000 ft^2 or more.	NYC Local Law 5/1973 requires sprinklers in new and existing buildings in Occupancy Group E, 100 ft or more in height (with HVAC systems that serve more than the floor located). NYC LL 16/1984 requires sprinklers in Occupancy Group E buildings over 75 ft in height or with a total gross floor area of 100,000 ft^2 or more.
	A wet-pipe sprinkler system shall be provided throughout all areas requiring automatic sprinkler protection (C26-1703.13).	A wet-pipe sprinkler system shall be provided throughout all areas requiring automatic sprinkler protection (27-966).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Automatic Sprinkler Protection (continued)	In areas subject to freezing the sprinkler system shall be protected (insulation, heat trace, antifreeze) or a dry-pipe system shall be provided (C26-1703.13).	In areas subject to freezing the sprinkler system shall be protected (insulation, heat trace, antifreeze) or a dry-pipe system shall be provided (27-966).	
	A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or section (C26-1703.4).	A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or section (27-957).	
Standpipes	Wet standpipes designed and installed in accordance with Section (C26-1702.1 and RS 17-1 shall be provided (C26-1702.1(a)(1)).	Wet standpipes designed and installed in accordance with Section 27-932 and RS 17-1 shall be provided (27-932(a)(1)).	
	The number and location of standpipes shall be such that every point of every floor can be reached by a 20 ft stream from a nozzle attached to not more than 125 ft of hose connected to a riser outlet valve (C26-1702.4).	The number and location of standpipes shall be such that every point of every floor can be reached by a 20 ft stream from a nozzle attached to not more than 125 ft of hose connected to a riser outlet valve (27-935).	
	Standpipe risers and 2½ in. hose valves shall be located within stairway enclosures (C26-1702.5(a)).	Standpipe risers and 2½ in. hose valves shall be located within stairway enclosures (27-936(a)).	
	When stairway enclosures are not available within the 125 plus 20 (145) ft distance, risers and valves shall be located as near to the enclosure as practicable (C26-1702.5(a)).	When stairway enclosures are not available within the 125 plus 20 (145) ft distance, risers and valves shall be located as near to the enclosure as practicable (27-936(a)).	
	The highest riser shall be extended above the roof with a 3-way manifold with 2½ in. hose valves (C26-1702.11(a)(2)).	The highest riser shall be extended above the roof with a 3-way manifold with 2½ in. hose valves (27-942(a)(2)).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Standpipes (continued)	A 2½ in. hose outlet shall be provided at each standpipe riser on each floor served, and on the entrance floor above the riser control valve, located between 5 ft and 6 ft above the landing or floor (C26-1702.11(a)(1)).	A 2½ in. hose outlet shall be provided at each standpipe riser on each floor served, and on the entrance floor above the riser control valve, located between 5 ft and 6 ft above the landing or floor (27-942(a)(1)).	
	Hose stations shall be located at the standpipe risers, either inside or adjacent to the entrance of stairway enclosures (C26-1702.11(b)).	Hose stations shall be located at the standpipe risers, either inside or adjacent to the entrance of stairway enclosures (27-942(b)).	
	Hose stations shall be located to satisfy the 125 plus 20 (145) ft requirement (C26-1702.11 (b)(1)).	Hose stations shall be located to satisfy the 125 plus 20 (145) ft requirement (27-942(b)(1)).	
	Hose shall be 1½ in. "flax-line" unlined linen hose in Groups C, E and F; 2½ in. (unlined) in Group B(C26-1702.11(c)).	Hose shall be 1½ in. "flax-line" unlined linen hose in Groups C, E and F; 2½ in. (unlined) in Group B (27-942(c)).	
	Auxiliary hose stations equipped with 1½ in. (unlined) hose are permitted in Groups C, E and F (C26-1702.11(c)(4), C26-1702.11 (d)).	Auxiliary hose stations equipped with 1½ in. (unlined) hose are permitted in Groups C, E and F (27-942(c)(4), 27-942(d)).	
	Standpipe systems that include more than one riser shall have all risers cross-connected at, or below, the street entrance floor level (C26-1702.10(a)).	Standpipe systems that include more than one riser shall have all risers cross-connected at, or below, the street entrance floor level (27-941(a)).	
	Standpipe systems having more than one zone shall be arranged such that the risers supplied from each zone are cross-connected below, or in, the story of the lowest hose outlets from the water source in each zone (C26-1702.10(b)).	Standpipe systems having more than one zone shall be arranged such that the risers supplied from each zone are cross-connected below, or in, the story of the lowest hose outlets from the water source in each zone (27-941(b)).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Standpipes (continued)	Standpipe risers shall be at least 4 in. in diameter where the riser height is 150 ft or less from the highest hose outlet to the level of the entrance floor, 6 in. in diameter where greater than 150 ft (C26-1702.7, Table 17-1).	Standpipe risers shall be at least 4 in. in diameter where the riser height is 150 ft or less from the highest hose outlet to the level of the entrance floor, 6 in. in diameter where greater than 150 ft (27-938, Table 17-1).	
Water Supply	Standpipe systems shall have a primary water supply available at all times to every hose outlet or made available automatically when the hose valve at any outlet is opened (C26-1702.14).	Standpipe systems shall have a primary water supply available at all times to every hose outlet or made available automatically when the hose valve at any outlet is opened (27-945).	
	Combinations of two or more of the following sources shall serve as the primary water supply, including siamese connections (C26-1702.14 (b)):	Combinations of two or more of the following sources shall serve as the primary water supply, including siamese connections (27-945(b)):	
	Direct connection to city water system	Direct connection to city water system	
	Direct connection to a private yard main	Direct connection to a private yard main	
		Gravity tank(s)	Gravity tanks added
	Pressure tank(s)	Pressure tank(s)	
	Automatic fire pump (C26-1702.14(b)(5)).	Automatic fire pump (27-945(b)(5)).	
	In buildings higher than 300 ft, the automatic fire pump shall be used only for the lower 300 ft. Zones above 300 ft shall be supplied by either a gravity or pressure tank.	In buildings higher than 300 ft, the automatic fire pump shall be used only for the lower 300 ft. Zones above 300 ft shall be supplied by either a gravity or pressure tank.	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Water Supply (continued)	An additional standpipe system water supply shall be provided for standpipes in buildings over 300 ft high (C26-1702.15(a)).	An additional standpipe system water supply shall be provided for standpipes in buildings over 300 ft high (27-946(a)).	
	The primary water supply to the standpipe system shall be supplemented by one or more manually operated fire pumps (C26-1702.15(a)).	The primary water supply to the standpipe system shall be supplemented by one or more manually operated fire pumps (27-946(a)).	
	At least one of the following automatic source of water supply shall be provided for sprinklers (C26-1703.8(a)):	At least one of the following automatic source of water supply shall be provided for sprinklers (27-961(a)):	
	Gravity tank(s)	Gravity tank(s)	
	Pressure tank(s)	Pressure tank(s)	
	Automatic fire pump	Automatic fire pump	
	Direct connection to public water system	Direct connection to public water system	
	Domestic water supply may be used to supply cooling tower sprinklers and sprinklers installed in buildings classified in Occupancy Group E (Business) in accordance with Section C26-1703.9(e) (C26-1703.9(c) and (d)).	Domestic water supply may be used to supply cooling tower sprinklers and sprinklers installed in buildings classified in Occupancy Group E (Business) in accordance with Section 27-962(e) (27-962(c) and (d)).	
	Auxiliary sources of water supply for sprinkler systems may include a manually actuated fire pump or siamese connection (C26-1703.8(b)	Auxiliary sources of water supply for sprinkler systems may include a manually actuated fire pump or siamese connection (27-961(b)).	
	Combined Water Supplies	Combined Water Supplies	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Water Supply (continued)	Fire pumps may simultaneously serve as the required auxiliary water supply for standpipe and sprinkler systems in accordance with Section C26-1702.15(d).	Fire pumps may simultaneously serve as the required auxiliary water supply for standpipe and sprinkler systems in accordance with Section 27-946(d).	
	Tanks used to provide the required primary water supply to a standpipe system may also be used as a supply for an automatic sprinkler system (C26-1703.8(c)).	Tanks used to provide the required primary water supply to a standpipe system may also be used as a supply for an automatic sprinkler system (27-961(c)).	
	One standpipe system and one sprinkler system siamese connection shall be provided for each 300 ft of exterior building wall or fraction thereof facing each street or public space (C26-1702.9(a), C26-171703.6(a)(1)).	One standpipe system and one sprinkler system siamese connection shall be provided for each 300 ft of exterior building wall or fraction thereof facing each street or public space (27-940(a), 27-959(a)(1)).	
	Modifications based on street frontage as permitted by Sections C26-1702.9(b)-(f).	Modifications based on street frontage as permitted by Sections 27-940(b)-(f).	
	Each siamese connection shall be connected to a riser or to a cross connection connecting other siamese connections or risers (C26-1702.10(f)).	Each siamese connection shall be connected to a riser or to a cross connection connecting other siamese connections or risers (27-941(f)).	
	In below grade sprinkler systems for garage occupancies, a sprinkler siamese connection shall be provided within 50 ft of every exit or entrance used by motor vehicles (C26-1703.6 (a)(2)).	In below grade sprinkler systems for garage occupancies, a sprinkler siamese connection shall be provided within 50 ft of every exit or entrance used by motor vehicles (27-959(a)(2)).	
	Siamese connections for partial sprinkler systems shall be in accordance with Section C26-1703.6(a)(3).	Siamese connections for partial sprinkler systems shall be in accordance with Section 27-959(a)(3).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Water Supply (continued)	No Requirement (NR)	Standpipe risers may be used to supply water to sprinklers in high rise buildings classified in Occupancy Group E, and existing office buildings, 100 ft or more in height. (Section added by Local Law 5/1973 as C26-1703.9(g) and subsequently relettered by Local Law 16/1984 as C26-1703.9(f) and renumbered 27-962(h)).	Section added by Local Law 5/1973.
A.8 INTERIOR FIRE ALARM, DETECTION, AND SIGNALING SYSTEMS			
Fire Alarm Systems	NR	New Buildings classified in Occupancy Group E, 75 ft or more in height and existing buildings in Occupancy Group E one hundred (100) or more feet in height are required to be provided with a Class E (or modified Class E) fire alarm and communication system including loud speakers, two-way voice, and a fire command station. (27-968(a)(9), 27-971(g)(h); 27-972(f)(g), 27-975):	NYC retroactive requirement added by Local Law 5/1973 Section subsequently amended by Local Law 16/1984. Class 'E' fire alarm and voice communication system in new buildings. Modified Class 'E' systems in existing office buildings, Mini-Class 'E' systems in buildings <100 ft, with more than 100 persons above the street floor.
	A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or section (C26-1703.4).	A sprinkler alarm system shall be provided when more than 36 heads are installed in any fire area or section (27-957).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Fire Alarm Systems (continued)	A local water flow alarm unit shall be provided (outdoor water motor or electric alarm gongs) where there is no watchman with watch service (RS 17-2, Sec. 3722).	A local water flow alarm unit shall be provided (outdoor water motor or electric alarm gongs) where there is no watchman with watch service (RS 17-2).	
	Central station water flow alarm service is desirable but does not waive the local alarm requirement (RS 17-2, Sec. 3721).	Central station water flow alarm service is desirable but does not waive the local alarm requirement (RS 17-2,).	
Smoke and Heat Detector Locations	HVAC Systems (C26-1300.7(a), RS 13-1).	HVAC Systems (27-777(a), RS 13-1).	
	In systems over 5,000 cfm capacity, thermostatic devices shall be provided for automatic fan shut-down as follows (RS 13-1, Sec. 1002):	In systems over 5,000 cfm capacity, thermostatic devices shall be provided for automatic fan shut-down as follows (RS 13-1):	
	125 ºF (max) devices located in the return air stream prior to exhaust or dilution by outside air (RS 13-1, Sec. 1002(a)).	125 ºF (max) devices located in the return air stream prior to exhaust or dilution by outside air (RS 13-1).	
	50 ºF (max) above maximum operating temperature devices located in the main supply duct down stream of the filters (RS 13-1, Sec. 1002(b)).	50 ºF (max) above maximum operating temperature devices located in the main supply duct down stream of the filters (RS 13-1).	
	Where thermostatic devices are installed in systems utilizing recirculated air on floors protected by sprinkler or fire alarm systems, fans shall automatically shut-down on alarm (RS 13-1, Sec. 1005).	Where thermostatic devices are installed in systems utilizing recirculated air on floors protected by sprinkler or fire alarm systems, fans shall automatically shut-down on alarm (RS 13-1).	
	In systems over 15,000 cfm capacity smoke detectors shall be provided for automatic fan shut-down as follows (RS 13-1, Sec. 1003):	In systems over 15,000 cfm capacity smoke detectors shall be provided for automatic fan shut-down as follows (RS 13-1):	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Smoke and Heat Detector Locations (continued)	Smoke detectors shall be located in the main supply duct downstream of the filters (RS 13-1, Sec. 1003.b).	Smoke detectors shall be located in the main supply duct downstream of the filters (RS 13-1).	
	Smoke detectors shall be arranged to provide audible and visual annunciation at a local supervisory control board in the building in accordance with RS 13-1, Sec. 1003.c.	Smoke detectors shall be arranged to provide audible and visual annunciation at a local supervisory control board in the building in accordance with RS 13-1)	
	In systems utilizing recirculated air, smoke detectors shall be provided for automatic fan shut-down when any of the following conditions exists (RS 13-1, Sec. 1003.a):	In systems utilizing recirculated air, smoke detectors shall be provided for automatic fan shut-down when any of the following conditions exists (RS 13-1):	
	System supplies an exit passageway, or a space leading from elevators to a street or to the exterior.	System supplies an exit passageway, or a space leading from elevators to a street or to the exterior.	
	System supplies spaces on more than one story or spaces in different fire areas in the same story.	System supplies spaces on more than one story or spaces in different fire areas in the same story.	
	Where the area of a building or space served is over 20,000 ft^2 in mercantile or indoor assembly occupancies.	Where the area of a building or space served is over 20,000 ft^2 in mercantile or indoor assembly occupancies.	
	Where there is a duct opening in a required 2 h fire resistance rated interior Fire Division.	Duct openings are required 2 h fire resistance rated interior Fire Divisions.	
	Where a duct passes through a firewall.	Duct openings through a firewall.	
	Where a corridor is used as a plenum.	Where a corridor is used as a plenum.	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Manuas Fire Asarm			

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Communication Systems (continued)	Gravity tank rooms	Gravity tank rooms	
	Each floor near main standpipe riser	Each floor near main standpipe riser	
	The system shall be a selective ringing, common talking system supplied by a 24 V direct current power source (C26-1704.7(b)).	The system shall be a selective ringing, common talking system supplied by a 24 V direct current power source (27-974(b)).	
	Permanent wall telephones shall be provided with 6 in. gongs except in the pump room where a loud speaking receiver shall be provided (C26-1704.7(c)).	Permanent wall telephones shall be provided with 6 in. gongs except in the pump room where a loud speaking receiver shall be provided (27-974(c)).	
	Where portable phones are used, jacks protected by break-glass boxes shall be provided (C26-1704.7(c)).	Where portable phones are used, jacks protected by break-glass boxes shall be provided (27-974(c)).	
	At least three portable phones shall be provided for each standpipe installation, kept in a dedicated, locked cabinet located in the main hall of the entrance floor (C26-1704.7(d)).	At least three portable phones shall be provided for each standpipe installation, kept in a dedicated, locked cabinet located in the main hall of the entrance floor (27-974(d)).	
	A pilot light shall be provided over the cabinet to indicate if the system is in use or a receiver is off the hook (C26-1704.7 e)).	A pilot light shall be provided over the cabinet to indicate if the system is in use or a receiver is off the hook (27-974(e)).	
	Standpipe Signaling Devices	Standpipe Signaling Devices	
	Manual, individually coded sending stations shall be located in the main corridor of the building arranged to transmit a signal to alarm sounding devices (C26-1704.7(f)(1)).	Manual, individually coded sending stations shall be located in the main corridor of the building arranged to transmit a signal to alarm sounding devices (27-974(f)(1)).	
	System shall be installed in accordance with RS 17-3 (C26-1704.7(f), C26-1704.8).	System shall be installed in accordance with RS 17-3 (27-974(f), 27-975).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Communication Systems (continued)	An 8 in. gong shall be provided in the pump rooms and in elevator shafts at intervals not exceeding 10 floors (C26-1704.7(f)(1)).	An 8 in. gong shall be provided in the pump rooms and in elevator shafts at intervals not exceeding 10 floors (27-974(f)(1)).	
	Adjacent to each telephone station and near the main standpipe riser, a closed circuit strap key connected in series with the box circuit of the signal sending station shall be provided (C26-1704.7(f)(2)).	Adjacent to each telephone station and near the main standpipe riser, a closed circuit strap key connected in series with the box circuit of the signal sending station shall be provided (27-974(f)(2)).	
	NR	In a Modified Class E fire alarm signal system, the standpipe fire line telephone and signaling system may be combined with the fire alarm system provided (27-974(g)).	Subdivision (g) added by Local Law 5/1973.
	NR	The alarms and two way voice communication with the fire command station include the pump and gravity tank rooms.	
	NR	A designated floor station of the Class E system is located at or near the main standpipe riser on every floor.	
	NR	A floor warden station shall be located between required stairways, vertical exits or other exits (RS 17-3B 7.b).	
	NR	System shall include a telephone type handset at the floor warden station with integral signaling to the fire command station.	
	NR	Warden station may be part the speaker system.	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
A.9 ELEVATORS AND ESCALATORS			
General	Elevators or escalators shall be provided in accordance with Section C26-1800.1 and RS 18-1 in all new buildings exceeding four stories in height (C26-604.1(a), C26-1800.6(d)).	Elevators or escalators shall be provided in accordance with Section 27-982 and RS 18-1 in all new buildings exceeding four stories in height (27-368(a), 27-987(d)).	
	When Areas of Refuge are provided above the 11th floor of a building, they shall be served by at least one elevator (C26-604.5(c).	When Areas of Refuge are provided above the 11th floor of a building, they shall be served by at least one elevator (27-372(c))	
	Escalators may be used as exits in lieu of interior stairs (C26-604.11 and C26-1800.6(g)).	Escalators may be used as exits in lieu of interior stairs (27-378 and 27-987(g)).	
	In every building exceeding 100 ft in height, at least one elevator shall be kept available for immediate use by the fire department during all hours (C26-1702.22, C26-1800.8).	In every building exceeding 100 ft in height, at least one elevator shall be kept available for immediate use by the fire department during all hours (27-953, 27-989).	
	In buildings exceeding 150 ft in height, there shall be an operator available at all times (C26-1800.8).	In buildings exceeding 150 ft in height, there shall be an operator available at all times (27-989).	
	Automatic passenger elevators shall be equipped with emergency controls for fire department use (RS 18-1 Rule 210.13).	Automatic passenger elevators shall be equipped with emergency controls for fire department use (RS 18-1, Rule 211.3a).	
	A two-position keyed switch shall be provided at a main floor of each elevator or group of elevators for recall to the main floor in accordance with RS 18-1, Rule 210.13.a.	A two-position keyed switch shall be provided at the designated level and at the sky lobby of each elevator or group of elevators for recall to the main floor in accordance with RS 18-1, Rule 211.3a).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
General (continued)	A keyed switch shall be provided in or adjacent to an operating panel of each elevator to initiate emergency service in accordance with RS 18-1, Rule 210.13.b.	A keyed switch shall be provided in or adjacent to an operating panel of each elevator to initiate emergency service in accordance with RS 18-1, Rule 211.3.c.	
A.10 EMERGENCY ELECTRICAL AND STANDBY POWER SYSTEMS			
Emergency Power Systems	NR	An emergency power system shall be provided in high rise buildings in Occupancy Group E and have capacity to operate equipment such as (27-396.4): Fire pumps; at least three elevators at one tie, with manual transfer to other elevators; alarm and communications systems, emergency lighting, ventilating systems used for smoke venting or control, and stair pressurization.	Section added by Local Law 16/1984.
A.11 SPECIAL FEATURES			
Public Garages	A public garage used exclusively for parking of vehicles having fuel storage tanks of 26 gal capacity or less is classified in storage Occupancy Group B-2 (C26-709.2(b)).	A public garage used exclusively for parking of vehicles having fuel storage tanks of 26 gal capacity or less is classified in storage Occupancy Group B-2 (27-451(b)).	
	All floors shall be concrete or equivalent noncombustible material and columns shall be protected from vehicle impact or designed to resist lateral forces in accordance with Section C26-902.4 (C26-709.3).	All floors shall be concrete or equivalent noncombustible material and columns shall be protected from vehicle impact or designed to resist lateral forces in accordance with Section 27-559 (27-452).	
	Public garages shall be ventilated in accordance with Section C26-709.7.	Public garages shall be ventilated in accordance with Section 27-456.	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Public Garages (continued)	Ramps serving as required exits shall be enclosed in 2 h fire resistance rated construction with vehicle openings at each parking tier protected by a 3 gpm/ft deluge type sprinkler water curtain (C26-709.9).	Ramps serving as required exits shall be enclosed in 2 h fire resistance rated construction with vehicle openings at each parking tier protected by a 3 gpm/ft deluge type sprinkler water curtain (27-458).	
Smoke and Heat Venting	NR	Unsprinklered buildings classified in Occupancy Group E, one hundred feet or more in height, having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located, shall be provided with at least one smoke shaft by means of which smoke and heat shall be mechanically vented to the outdoors as provided in Reference Standard 5-17. Existing unsprinklered office buildings 100 ft or more in height, having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located, shall be provided with at least one smoke shaft per RS 5-17 or in lieu of smoke shafts, all interior enclosed stairs other than a fire tower stair, may be provided with a system of pressurization for fire emergency use as provided in Reference Standard RS 5-18 (27-353(b) and (c)).	Local Law 5/1973 added new requirements for smoke and heat venting for new and existing office buildings (Occupancy Group E) 100 ft or more in height. Stair Pressurization option for existing buildings.
	Elevator and dumbwaiter shafts in accordance with RS 18-1.	Elevator and dumbwaiter shafts in accordance with ANSI A17.1.	
	Other closed shafts, including stairway enclosures:	Other closed shafts:	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Smoke and Heat Venting (continued)	All closed shafts having an area exceeding 4 ft^2 shall be provided with a smoke vent having an area of at least 3½ % of the maximum shaft area at any floor but not less than ½ ft^2 (C26-504.6(d)).	All closed shafts having an area exceeding 4 ft^2 shall be provided with a smoke vent having an area of at least 3½ % of the maximum shaft area at any floor but not less than ½ ft^2 (27-344(d)).	
	Smoke vents may be windows, louvers, skylights, vent ducts or similar devices.	Smoke vents may be windows, louvers, skylights, vent ducts or similar devices.	
	Vent ducts shall be enclosed by construction having the same fire resistance rating as required for the shaft and extend vertically, diagonally, or horizontally in accordance with Sections C26-504.6(d)(1) , C26-504.6(d)(2).	Vent ducts shall be enclosed by construction having the same fire resistance rating as required for the shaft and extend vertically, diagonally, or horizontally in accordance with Sections 27-344(d)(1), 27-344(d).(2).	
	Of the total required vent area for shafts, at least 1/3 shall be clear to the outdoors, either in the form of fixed louvers, ridge vents, or hooded or goosenecked openings (C26-504.6(e)).	Of the total required vent area for shafts at least 1/3 shall be clear to the outdoors either in the form of fixed louvers, ridge vents, or hooded or goosenecked openings (37-344(e)).	
	As an alternate, skylights or trap doors may be used arranged to open automatically by fusible link or other mechanical device when subjected to 160 ºF fixed temperature or 15 to 20 ºF per minute temperature rise (C26-504.6(e)).	As an alternate, skylights or trap doors may be used arranged to open automatically by fusible link or other mechanical device when subjected to 160 ºF fixed temperature or 15 to 20 ºF per minute temperature rise (27-344(e)).	
	Of the total required vent area for shafts up to 2/3 may be a window or skylight glazed with plain glass not more than 1/8 in. thick or slow burning plastic (27-344(e)).	Of the total required vent area for shafts up to 2/3 may be a window or skylight glazed with plain glass not more than 1/8 in. thick or slow burning plastic (27-344(e)).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Smoke and Heat Venting (continued)	Vents shall not be located in doors leading to machine rooms which communicate with the shaft (27-344(f)).	Vents shall not be located in doors leading to machine rooms which communicate with the shaft (27-344(f)).	
Atria and Floor Openings	NR	An atrium is classified in Occupancy Group F-3 Assembly (27-251.2).	Section added by Local Law 16/1984.
		Atria may be constructed only in buildings in noncombustible construction groups 1-A, 1-B, and 1-C (27-254.3(a)).	
		The atrium shall be fully enclosed except openings of any size are permitted in the lowest two levels when protected by 1½ h opening protectives or sprinklers spaced no more than 6 ft apart (27-251.3(b)).	
		Atrium enclosure walls shall be of at least two hour fire resistance rated construction or of wired, laminated, or tempered glass and is provided on the occupied side with sprinklers spaced no more than 6 ft apart (27-251.3(d)).	
		Smoke detectors are required in all spaces opening onto the atrium and a smoke detecting systems shall be installed in accordance with NFPA 72E - 1990 (27-251.4(a)).	
		A mechanical ventilation system capable of exhausting the volume of the atrium and all spaces open to the atrium at six air changes per hour (27-251.8(a)).	

	THEN CURRENT BCNYC	CURRENT BCNYC	SUMMARY OF SIGNIFICANT DIFFERENCES
Atria and Floor Openings (continued)		No vertical exits shall discharge into an atrium at any level (27-251.5(a)).	
		At least one standpipe outlet in addition to risers within required stairways shall be provided in the atrium (27-251.4(b)).	
		Every story or mezzanine within an atrium that overhangs another story or mezzanine within 50 ft shall be sprinklered (27-251.4(c)).	
		Atrium ceilings less than 50 ft but greater than 30 ft alternatively may be provided with central supervisory smoke detectors connected to a central station in lieu of sprinklering (27-251.4(c)).	
		Every room or space that opens on to the atrium shall be sprinklered (27-251(c)).	
		An interior fire alarm and communication system shall be installed in accordance with NFPA 72.	
		All atria shall be provided with an emergency power system (27-251.9).	

NIST NCSTAR 1-1G

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Rolf Jensen & Associates, Inc.

September 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

National Institute of Standards and Technology
William Jeffrey, Director

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In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

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ABSTRACT

This report was prepared to support the analysis of building and fire codes and practices of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation. This report supports the objective of documenting the requirements that governed the design and construction of WTC 1, 2, and 7.

The purpose of this report is to provide an evolution of the life safety provisions of the Building Code of the City of New York (BCNYC) since the design of WTC 1 and WTC 2, including retroactive provisions for existing high-rise office towers. It has been previously established that WTC 1 and WTC 2 were designed and constructed in accordance with the BCNYC as enacted by Local Law No. 76 for the year 1968, effective December 6, 1968.

The evolution of the BCNYC begins with a brief history of the Building Code prior to 1968 and reviews the various local laws that have amended fire protection and life safety provisions of the Code from 1968 until the collapse of the WTC towers on September 11, 2001.

Keywords: Administrative code, building code, compartmentation, elevators, emergency power, fire alarm, fire protection, fire safety, fire sprinklers, high-rise buildings, inspections, interior finish, life safety, means of egress, pressurization, venting, voice communication, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

ASTM	ASTM International
BSA	New York City Board of Standards and Appeals
BCNYC	Building Code of the City of New York (Local Law No. 76)
LL	Local Law to amend the Administrative Code of the City of New York
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
RS	Reference Standard to the Building Code of the City of New York
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

^{o}F	degrees Fahrenheit
cfm	cubic foot per minute
ft	foot
ft^2	square foot
h	hour
min	minute

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GLOSSARY

active fire protection – A means to help prevent the loss of life and property from fire by extinguishing, suppressing, or controlling a fire through functional systems. Sprinkler systems, fire alarm systems, and smoke control systems are examples of active fire protection.

area of refuge – A floor area to which egress is made through a horizontal exit or supplemental vertical exit.

combustible – A material that is not determined to be noncombustible.

damper – A device installed in heating, ventilating, and air conditioning ductwork used to prevent the spread of fire and/or smoke. Dampers are provided to maintain a fire resistance rating of the assembly being penetrated.

detector – An initiation device that automatically detects a change in state, such as presence of smoke, high temperature, or abnormal rate of temperature rise.

fire alarm system – A system, automatic or manual, arranged to give a signal indicating a fire emergency and initiate the appropriate response.

fire resistance rating – The time in hours that materials or their assemblies will withstand fire exposure as determined by a fire test.

fireproofing – Materials or assemblies used to provide a fire resistance rating to a building component.

firestop – A solid or compact, tight closure to retard the spread of flames or hot gases within concealed spaces.

initiation device – A system component that originates a change-in-state signal in the fire alarm system. An initiation device begins the life safety processes, such as evacuation; heating, ventilating, and air conditioning shut down; elevator recall; etc.

manual fire alarm box – A manually operated initiation device that originates a change-in-state signal in the fire alarm system.

means of egress – A continuous and unobstructed path of vertical and horizontal travel from any point in a building to a public way. The means of egress consists of the exit access, the exit, and the exit discharge.

noncombustible – A material that, in the form in which it is used in construction, will not ignite and burn when subjected to fire. However, any material which liberates flammable gas when heated to any temperature up to 1,380 ºF for 5 min shall not be considered noncombustible.

notification appliance – A fire alarm system component such as a bell, horn, speaker, or strobe that provides audible, tactile, or visible outputs, or any combination thereof.

passive fire protection – Fire protection features that are incorporated into the building construction or building materials that do not rely on active fire protection methods to limit fire ignition, fire growth, or material failure. Fire separations and divisions, sprayed-on fire proofing, and enclosing structural members with noncombustible materials are examples of passive fire protection.

smoke and heat venting – A process used to move products of combustion to the outdoor air.

PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

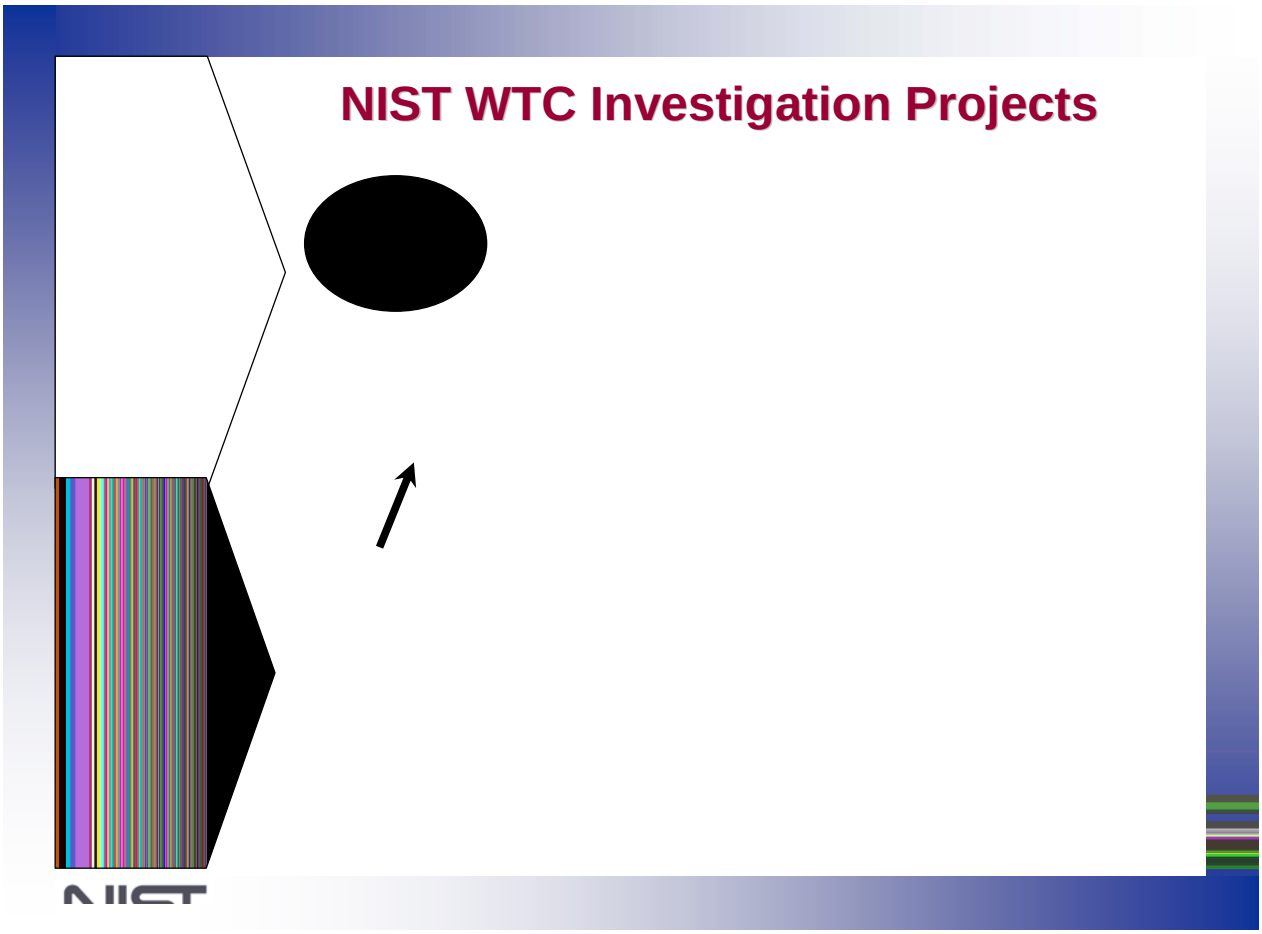
NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.


NIST WTC Investigation Projects

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

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EXECUTIVE SUMMARY

As part of the analysis of building and fire codes and practices of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation, this report supports the effort to document the changes in building code regulations that occurred after construction of WTC 1 and WTC 2.

WTC 1 and WTC 2 were to be designed and constructed in accordance with the Building Code of the City of New York (BCNYC) as enacted by Local Law No. 76 for the year 1968, effective December 6, 1968 (referred to as the "new code").

This report is not intended to give a complete history of the BCNYC. The purpose of this report is to provide an evolution of the life safety provisions of the BCNYC since the design of WTC 1 and WTC 2, including retroactive provisions for existing high-rise office towers. The evolution of the New York City code begins with a brief overview of the BCNYC prior to 1968 (referred to as the "old code") and reviews the various local laws that have amended fire protection and life safety provisions of the code from 1968 until the collapse of the WTC towers on September 11, 2001.

The BCNYC that became effective on January 1, 1938, had remained in effect and was edited and amended by local laws until 1968. Local Law 76 for the year 1968 repealed the 1938 BCNYC; however, buildings in existence prior to 1968 are still permitted to be altered in accordance with the 1938 BCNYC, provided the general safety and public welfare are not thereby endangered, in the opinion of the Authority Having Jurisdiction.

The BCNYC is a part of the Administrative Code of the City of New York. From 1968 until 1985, the BCNYC was part of Title 'C' of Chapter 26 of the Administrative Code. In 1985, the Administrative Code was reorganized and renumbered. The General Provisions of the Department of Buildings are currently organized under Chapter 1 of Title 26 – Housing and Buildings. The BCNYC is currently Chapter 1 of Title 27 – Construction and Maintenance. Due to the reorganization of the Administrative Code, BCNYC section numbers before 1985 are preceded with "C26-" and section numbers after 1985 are preceded by "27-."

To amend the Administrative Code of the City of New York, including the BCNYC, a bill (proposed legislation) must be introduced in the City Council. When the bill is approved by the City Council and signed by the Mayor, then it becomes a Local Law.

Through the years, serious incidents such as fires, and in most cases, fires that have resulted in the loss of innocent lives, have caused the need to change certain code requirements. In most cases, a Local Law added or modified requirements for new construction or major alterations. In other cases, the Local Law included retroactive provisions that were applicable to buildings existing on the effective date of such Local Law.

The applicable Local Laws that have amended the fire protection and life safety provisions of the BCNYC include, but are not limited to:

1. 1970 - Local Law No. 54, Local Laws of the City of New York for the Year 1970 (effective date immediately), November 17, 1970

2. 1973 - Local Law No. 5, Fire Safety Requirements and Controls (effective date immediately except as noted), January 18, 1973

3. 1975 – Local Law No. 26, Local Laws of the City of New York for the Year 1975 (effective date immediately), June 2, 1975

4. 1976 - Local Law No. 55, Local Laws of the City of New York for the Year 1976 (effective date immediately), November 1, 1976

5. 1978 - Local Law No. 33, Local Laws of the City of New York for the Year 1978 (effective date immediately), October 6, 1978

6. 1978 – Local Law No. 41, Local Laws of the City of New York for the Year 1978 (effective 30 days after enactment), December 13, 1978

7. 1979 - Local Law No. 84, Fire Safety Pressurization Requirements in Certain Office Buildings (effective date immediately), December 13, 1979

8. 1979 - Local Law No. 86, Dates for Compliance with the Local Laws Enacted for Fire Safety Requirements and Controls in Certain Buildings (effective date immediately), December 13, 1979

9. 1984 - Local Law No. 16, Local Laws of the City of New York for the Year 1984 (effective date immediately except as noted), March 27, 1984

10. 1987 – Local Law No. 16, Local Laws of the City of New York for the Year 1987 (effective date immediately), April 20, 1987

Since 1968, the BCNYC Reference Standards have been updated by various New York City procedures and authorities including Local Laws passed by the City Council, Building Code Rules approved by the New York City Board of Standards and Appeals until 1991, and by the authority of the Building Commissioner, after 1991. Included in this report is a summary of the applicable fire protection and life safety reference standards and the effective dates. Most Reference Standards are nationally recognized standards (ASTM International, National Fire Protection Association, etc.) that New York City references (often with New York City modifications). Other Reference Standards are developed by the New York City Department of Buildings (e.g., Standpipe Construction, Fire Alarm Systems).

Chapter 1
INTRODUCTION

The purpose of this report is to provide an evolution of the life safety provisions of the Building Code of the City of New York (BCNYC) since the design of World Trade Center (WTC) 1 and WTC 2, including retroactive provisions for existing high-rise office towers.

WTC 1 and WTC 2 were to be designed and constructed in accordance with the BCNYC as enacted by Local Law No. 76 for the year 1968, effective December 6, 1968 (referred to as the "new code").

The BCNYC is a part of the Administrative Code of the City of New York. The latest major overhaul of the BCNYC occurred in 1968. Since then, several Local Laws have been approved by the City Council and the Mayor of the City of New York to amend the BCNYC. Most Local Laws amend certain provisions of the BCNYC and pertain to new construction or new installations of equipment. However, some Local Laws have retroactive provisions that apply to existing buildings or structures.

The first Local Law that is signed by the Mayor for a particular year is Local Law No. 1 for that year. It is important to associate a Local Law number with the year it was passed. For example, Local Law No. 5 for the year 1973 is not the same as Local Law No. 5 for 1972 or Local Law No. 5 for 1974, etc.

This report is intended to summarize the Local Laws that have had an impact on fire protection and life safety related requirements and that may provide an understanding about the requirements that were applicable in the design, construction, and alterations of WTC 1, 2, and 7.

The most notable of the Local Laws that have amended the fire protection and life safety provisions of the BCNYC are Local Law No. 5 for the year 1973 and Local Law No. 16 for the year 1984. Local Law No. 5 and Local Law No. 16 contain several retroactive fire protection and life-safety-related requirements for existing buildings, including automatic sprinkler systems, compartmentation, stair pressurization, fire alarm and communication systems, emergency power systems and smoke control provisions.

Chapter 2 includes a list of the Local Laws containing fire protection and life safety provisions. Table 2–1 provides the effective dates of various Local Laws amending the BCNYC. The Local Laws containing fire protection and life safety provisions are presented in Chapter 4 in chronological order beginning with Local Law No. 54 for the year 1970.

In addition to the BCNYC, several amendments have been made to the Reference Standards of the Code. As the Code was updated and new technologies and industry standards became available, it was necessary to update the Reference Standards. Most Reference Standards are nationally recognized standards such as those published by the American National Standards Institute, ASTM International and the National Fire Protection Association. Other Reference Standards are promulgated by the New York City Department of Buildings, such as the reference standards for standpipe systems and the Reference Standards for fire alarm systems.

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Chapter 2
GENERAL

2.1 LOCAL LAWS CONTAINING FIRE PROTECTION/LIFE SAFETY PROVISIONS

1. 1970 - Local Law No. 54, Local Laws of the City of New York for the Year 1970 (effective date immediately), November 17, 1970

2. 1973 - Local Law No. 5, Fire Safety Requirements and Controls (effective date immediately except as noted), January 18, 1973

3. 1975 – Local Law No. 26, Local Laws of the City of New York for the Year 1975 (effective date immediately), June 2, 1975

4. 1976 - Local Law No. 55, Local Laws of the City of New York for the Year 1976 (effective date immediately), November 1, 1976

5. 1978 - Local Law No. 33, Local Laws of the City of New York for the Year 1978 (effective date immediately), October 6, 1978

6. 1978 – Local Law No. 41, Local Laws of the City of New York for the Year 1978 (effective 30 days after enactment), December 13, 1978

7. 1979 - Local Law No. 84, Fire Safety Pressurization Requirements in Certain Office Buildings (effective date immediately), December 13, 1979

8. 1979 - Local Law No. 86, Dates for Compliance with the Local Laws Enacted for Fire Safety Requirements and Controls in Certain Buildings (effective date immediately), December 13, 1979

9. 1984 - Local Law No. 16, Local Laws of the City of New York for the Year 1984 (effective date immediately except as noted), March 27, 1984

10. 1987 – Local Law No. 16, Local Laws of the City of New York for the Year 1987 (effective date immediately), April 20, 1987

2.2 EFFECTIVE DATES OF LOCAL LAWS AMENDING THE BUILDING CODE

Table 2–1. Effective dates of Local Laws.

Year	Local Law	Effective Date	Comments
1969	61	December 4, 1969	
1969	65	December 22, 1969	
1969	73	December 20, 1969	
1970	54	November 17, 1970	Fire protection/life safety amendments
1971	75	December 22, 1971	
1972	39	June 1, 1972	
1972	76	November 6, 1972	
1973	5	January 18, 1973	Fire protection/life safety amendments with retroactive requirements for office buildings
1973	50	September 21, 1973	
1973	58	October 15, 1973	
1973	80	December 28, 1973	
1973	85	December 28, 1973	
1974	7	May 16, 1974	
1975	13	March 31, 1975	
1975	26	June 2, 1975	
1976	55	November 1, 1976	
1976	63	December 10, 1976	
1977	67	September 30, 1977	
1977	69	September 30, 1977	
1978	41	January 1979	
1979	79	December 4, 1979	
1979	84	December 14, 1979	
1979	86	December 14, 1979	
1981	21	March 19, 1981	
1982	12	March 5, 1982	
1982	30	June 15, 1982	
1983	58	November 16, 1983	
1984	16	March 27, 1984	Fire protection/life safety amendments with retroactive requirements
1984	45	July 12, 1984	
1986	80	December 22, 1986	
1986	82	December 30, 1986	
1987	9	March 5, 1987	
1987	13	March 23, 1987	

Year	Local Law	Effective Date	Comments
1987	16	April 20, 1987	Amended Local Law 16/1984
1987	29	June 30, 1987	
1987	40	July 6, 1987	
1987	58	August 5, 1987	
1987	61	November 3, 1987	
1988	11	March 9, 1988	
1988	33	May 27, 1988	
1988	34	February 2, 1988	
1988	46	July 11, 1988	
1988	49	July 11, 1988	
1988	50	July 11, 1988	
1988	58	January 1, 1989	
1988	65	November 4, 1988	
1988	73	December 8, 1988	
1988	77	June 8, 1988	
1989	14	April 13, 1989	
1989	29	November 16, 1989	
1989	38	June 28, 1989	
1989	55	January 25, 1990	
1989	80	November 8, 1989	
1989	81	February 6, 1990	
1989	90	December 6, 1989	
1989	100	December 27, 1989	
1989	103	December 27, 1989	
1990	23	July 7, 1990	
1990	38	August 11, 1990	
1990	65	November 14, 1990	
1991	33	August 23, 1991	
1991	48	July 1, 1991	
1991	49	July 1, 1991	
1991	54	July 1, 1991	
1991	55	July 17, 1991	
1991	62	January 1, 1992	
1991	72	October 21, 1991	
1991	99	February 21, 1992	
1992	18	March 9, 1992	
1993	6	March 22, 1993	
1993	12	January 22, 1994	
1993	13	January 22, 1994	

Year	Local Law	Effective Date	Comments
1993	14	February 9, 1993	
1993	15	February 9, 1993	
1993	39	May 28, 1993	
1993	53	June 30, 1993	
1993	56	June 30, 1993	
1999	10	March 24, 1999	Residential sprinklers and fire safety plans
2002	26	August 15, 2002	Mercantile sprinklers

Source: Building Code of the City of New York.

Chapter 3
HISTORY OF THE NEW YORK CITY BUILDING CODE

Building regulations in New York City date back to 1625 when the Dutch West India Company established rules for the types and locations of houses that could be built by the colonists of New Amsterdam. Extensive laws governing construction and fire prevention were in place by 1674.

This chapter is not intended to give a complete history of the Building Code of the City of New York (BCNYC). The specific task of this report is to provide an understanding of the evolution of the BCNYC since the design of World Trade Center (WTC) 1 and WTC 2, which is understood to be circa 1968. Since the current BCNYC permits buildings in existence prior to December 6, 1968, to be altered in compliance with the applicable laws in existence prior to 1968, this chapter also includes a brief overview of the 1938 Building Code, often referred to as the "old code."

3.1 1938 BUILDING CODE (OLD CODE)

The BCNYC in existence prior to 1938 was repealed and replaced with a code that became effective on January 1, 1938. For 30 years, this version of the BCNYC was enforced throughout the five boroughs of New York City. It was edited and amended by Local Laws on December 6, 1968, when Local Law No. 76 for the year 1968 repealed the 1938 Code. Buildings in existence prior to 1968 are permitted to be altered in accordance with the 1938 BCNYC, provided the general safety and public welfare are not thereby endangered in the opinion of the Authorities Having Jurisdiction.

3.2 1968 BUILDING CODE (THEN CURRENT CODE)

On November 6, 1968, Local Law No. 76 of the City of New York was approved by the Mayor. Local Law No. 76 was "A Local Law to amend the New York City charter and the administrative code of the city of New York, in relation to revising the city's code and providing for powers and duties of the department of buildings and certain other city departments with respect to buildings and matters related thereto."

Titles A, B, and C of Chapter 26 of the Administrative Code of the City of New York (the 1938 BCNYC) were repealed and reenacted under sec. 1 of Local Law No. 76. Part II of Title C is known and may be cited as the "building code of the city of New York" (Sec. C26-100.1).

The Local Law became effective 30 days after it was enacted. Therefore, the effective date of Local Law No. 76 for the year 1968, including the Building Code, is December 6, 1968.

Among other requirements, occupancy and construction classifications changed from the 1938 BCNYC to the 1968 BCNYC. For example, an office building constructed in accordance with the 1938 BCNYC is classified as a commercial occupancy, whereas the same building in the 1968 BCNYC is classified as Occupancy Group E – Business. Under the 1938 BCNYC, a tall office building must be constructed in the construction classification of fireproof (4 h). The same building constructed under the

1968 BCNYC may be constructed in construction type IA (4 h) or IB (3 h). In 1973, Local Law No. 5 (1973) added another possible classification, IC (2 h), which required the installation of automatic sprinklers.

Chapter 4
EVOLUTION OF BUILDING CODE SINCE 1968

Through the years, serious incidents such as fires, and in most cases, fires that have resulted in the loss of innocent lives, have caused the need to change certain code requirements. In most cases, a Local Law added requirements for new construction or major alterations. In other cases, the Local Law included retroactive provisions that were applicable to buildings existing on the effective date of such Local Law.

This chapter identifies the Local Laws that have included substantial modifications to the fire protection and/or life safety provisions of Building Code of the City of New York (BCNYC). Highlights of each of the Local Laws are provided.

4.1 1970 – LOCAL LAW NO. 54, POWERS AND DUTIES OF THE DEPARTMENT OF BUILDINGS

Local Law No. 54 for the year 1970 (LL 54/1970) was approved "to amend the administrative code of the city of New York, in relation to further clarifying and correcting provisions relating to the powers and duties of the department of buildings."

Although the title of LL 54/1970 refers to powers and duties of the department of buildings, LL 54/1970 amended several sections of the Building Code, including the following fire protection/life safety provisions:

- C26-504.6 – Shafts (LL 54, sec. 4)
- C26-600.3 – Inadequate exits for existing structures (LL 54, sec. 5)
- C26-604.3(h)(3) – Street floor lobbies as exit passageways (LL 54, sec. 6)
- C26-604.4(j)(1)(b) – Locking of doors opening into interior enclosed stairs (LL 54, sec. 7)
- C26-604.8(b) – Width of interior enclosed stairs (LL 54, sec. 8)
- C26-604.8(i)(2) – Access stairs (LL 54, sec. 9)
- Table 6–1 – Exit and Access Requirements (LL 54, sec. 10)
- C26-1800.8 – Elevator in readiness (LL 54, sec. 16)
- C26-1804.1 – Elevator operators (LL 54, sec. 17)

The new and amended requirements in LL 54/1970 were applicable to new construction and alterations after the effective date, but were not retroactive for existing buildings.

LL 54/1970 was approved by the Mayor on November 17, 1970, and became effective immediately.

4.2 1973 – LOCAL LAW NO. 5, FIRE SAFETY REQUIREMENTS IN CERTAIN OFFICE BUILDINGS

After five fatalities that occurred in two high-rise buildings in New York City in 1970, a Mayor's Advisory Committee on Fire Safety in High-Rise Buildings was commissioned to "undertake an extraordinary effort to further improve the safety of our major working environment, the high-rise tower." The Report of Mayor's Advisory Committee on Fire Safety in High-Rise Buildings was released in November 1971.

As a result of the report, Local Law No. 5 for the year 1973 (LL 5/1973) was approved by Mayor John V. Lindsay on January 18, 1973, and was to take effect immediately. LL 5/1973 was described as a "Local Law to amend the administrative code of the city of New York, in relation to fire safety requirements and controls in certain office buildings."

LL 5/1973 consists of 44 sections and at that time it was "the most comprehensive set of fire safety improvements ever proposed in any jurisdiction."

Enacted in 1973 and further amended by Local Law No. 26/1975 (LL 26/1975), LL 5/1973 was the subject of a lengthy period of litigation and appeals. The Court of Appeals rendered a final decision on December 26, 1978, upholding Local Law No. 5 in its entirety.

Sections of the Fire Prevention Code and Building Code were amended by LL 5/1973. This local law provided requirements for new buildings in occupancy group E as well as retroactive provisions in existing office buildings.

The major highlights of LL 5/1973 are summarized in the following sections.

4.2.1 Fire Safety in Office Buildings

A new sec. C19-161.2 was added to the New York City Fire Prevention Code to provide for fire safety in office buildings. This new section requires new occupancy group E buildings and existing office buildings with an occupant load of more than 100 persons above or below the street level or more than 500 persons in the entire building to provide a fire safety plan for fire drill and evacuation procedures. As part of the Fire Safety Plan, Fire Safety Directors, Deputy Fire Safety Directors, Building Evacuation Supervisors, and Fire Brigades must be provided. In addition, stair and elevator signs must be posted and maintained in accordance with the requirements of the BCNYC (LL 5, sec. 1).

4.2.2 Compartmentation

Section C26-504.1(c) was added to require unsprinklered floor areas, more than 40 ft above curb level, in new buildings in occupancy group E and existing office buildings 100 ft or more in height "having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located," to be subdivided by 1 h fire separations into spaces or compartments not to exceed 7,500 ft^2. Floor areas may be increased up to 15,000 ft^2 if protected by 2 h fire-resistive construction and smoke detectors. Regardless of the floor area, compartmentation is not required when complete sprinkler protection is provided (LL 5, sec. 6).

4.2.3 Smoke and Heat Venting

Section C26-504-15 was added to require new buildings in occupancy group E, 100 ft or more in height, having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located, to be provided with at least one smoke shaft by means of which smoke and heat shall be mechanically vented to the outdoors as provided in Reference Standard (RS) 5-17.

Existing office buildings, 100 ft or more in height, having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located, have an option of providing the smoke shaft in accordance with RS 5-17 or in lieu of the smoke shafts, may provide a system of pressurization in all interior enclosed stairs other than a fire tower stair for emergency use only.

Buildings that are sprinklered throughout are exempt from the smoke shaft and stair pressurization requirements (LL 5, sec. 7).

4.2.4 Means of Egress

Several sections of Article 6 of the BCNYC were amended to provide for signs in new and existing office buildings regarding the use of elevators and stairs. Additional provisions permit all stair doors to be locked from the stair side in buildings less than 100 ft in height. In buildings over 100 ft in height, the stair doors on every fourth floor are required to be openable to provide for re-entry from the stair. However, all the doors may be locked if they are provided with safety features such as fail-safe system in the event of loss of power and interface with the fire alarm system and the phase I elevator recall system.

Section C26-600.1 was amended to clarify the scope of the regulation with respect to new, altered, changed in occupancy, existing, and special use buildings (LL 5, sec. 8).

Section C26-604.4 was amended to permit locking of certain doors from the stair side in buildings in occupancy group E (LL 5, sec. 9).

Section C26-607.1 was amended to address retroactive provisions of LL 5/1973 for signs and exit lighting (LL 5, sec. 10).

Sub-Article 608 (secs. C26-608.1 through C26-608.7) was added regarding Stair and Elevator Signs in Office Buildings (LL 5, sec. 11).

4.2.5 Sprinklers

Subdivision (i) of sec. C26-1703.1 was added and Table 17-2 was amended to require sprinklers in showroom spaces exceeding 7,500 ft^2 in area and located more than 40 ft above curb level in new buildings in occupancy group E and existing office buildings, 100 ft or more in height having air-conditioning and/or mechanical ventilation systems that serve more than the floor on which the equipment is located (LL 5, sec. 16).

Subdivision (d) was added to sec. C26-1702.14 and subdivision (g) was added to sec. C26-1703.9 to allow standpipe systems to be used to supply water to sprinklers in buildings classified in occupancy

group E, 100 ft or more in height, and in existing office buildings, 100 ft or more in height, in accordance with the applicable provisions of RS 17-1 and RS 17-2 (LL 5, sec. 14, 20).

4.2.6 Interior Fire Alarm Signal and Voice Communication Systems

Prior to 1973, a fire alarm system was not required for a building in occupancy group E (new code) or commercial office buildings (old code). Only a standpipe fireline telephone and signaling system was required in buildings over 300 ft in height for fire department use in operating the standpipe system.

A new paragraph (9) was added to sec. C26-1704.1(a) to require a fire alarm system in buildings classified in occupancy group E, 100 ft or more in height (LL 5, sec. 21).

Two new subdivisions (g) and (h) were added to sec. C26-1704.4 to provide requirements for class E and modified class E fire alarm signal systems, respectively (LL 5, sec. 23).

Two new subdivisions (f) and (g) were added to sec. C26-1704.5 for the requirements of fire alarm systems in new buildings in occupancy group E and existing office buildings 100 ft or more in height (LL 5, sec. 25).

Subdivision (h) was added to sec. C26-1704.5 for the requirements of two-way voice communication and fire alarm signal system for buildings in occupancy group E and existing office buildings, less than 100 ft in height, occupied for an occupant load of more than 100 persons above or below the street level or more than a total of 500 persons in the entire building (LL 5, sec. 25).

A new sec. C26-1704.8 was added regarding the requirements for communication systems and fire command station in buildings classified in occupancy group E 100 ft or more in height, and existing office buildings 100 ft or more in height (LL 5, sec. 30).

4.2.7 Elevators

Section C26-1800.8 was amended regarding an elevator in readiness in every building in occupancy group E, 100 ft or more in height and in existing office buildings 100 ft or more in height (LL 5, sec. 31).

4.2.8 Reference Standards

In addition to amending existing building code requirements or enacting new code requirements, LL 5/1973 also modified existing Reference Standards and added new Reference Standards as follows:

- RS 5-17, Standards for the Installation of Smoke Shafts (added LL 5, sec. 32).
- RS 5-18, Standards for the Pressurization of Stairs (added LL 5, sec. 33).
- RS 13-1, Standards for the Installation of Air Conditioning and Ventilating Systems, National Fire Protection Association (NFPA) No. 90-A, 1967, as modified, was amended to add a new sec. 1006 regarding manual controls and smoke detection requirements in buildings in occupancy group E, 100 ft or more in height, where a system serves more than the floor on which the equipment is located (amended LL 5, sec. 34).

- RS 16, Plumbing and Gas Piping (amended LL 5, sec. 35).
- RS 17-1, Standpipe System Construction (amended LL 5, sec. 36, 37).
- RS 17-2, Standard for the Installation of Sprinkler Systems, NFPA No. 13 – 1966, as modified (amended LL 5, sec. 38).
- RS 17-3A, Standards for the Installation of Class E Fire Alarm Signal Systems (new LL 5, sec. 39).
- RS 17-3B, Standards for the Installation of Modified Class E Fire Alarm Signal Systems (new LL 5, sec. 40).
- RS 18-1, USA Standard Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks, including Supplement A17-1a –1967, as modified (amended LL 5, sec. 41, 42).

4.3 1975 – LOCAL LAW NO. 26, FIRE SAFETY IN OFFICE BUILDINGS

LL 26/1975 was approved "to amend the administrative code of the city of New York, in relation to fire safety requirements and controls in certain office buildings."

LL 26/1975 revised the smoke and heat venting compliance dates previously established by LL 5/1973, as follows:

- C26-504.15(c) Smoke and heat venting – revised the completion date for compliance with the smoke and heat venting requirements to be within 4½ years after February 7, 1973. The completion date for existing buildings that were to be sprinklered throughout was established as February 7, 1979 (LL 26, sec. 1).

Note that the compliance dates revised by LL 26/1975 were further modified by Local Law No. 86 for the year 1979 (see Sec. 4.8 of this report).

LL 26/1975 was approved by the Mayor on June 2, 1975, and was effective immediately.

4.4 1976 – LOCAL LAW NO. 55, INSPECTION OF SPRAYED-ON FIRE PROTECTION OF STRUCTURAL MEMBERS

Local Law No. 55 for the year 1976 (LL 55/1976) was approved "to amend the administrative code of the city of New York, in relation to the fire protection of structural members."

A new subdivision (f) was added to sec. C26-502.2 mandating that the installation of all required sprayed-on fire protection of structural members except those encased in concrete shall be subject to the controlled inspection requirements of C26-106.3 (LL 55, sec. 1).

LL 55/1976 was approved by the Mayor on November 1, 1976, and was effective immediately for new installations, but was not retroactive for installations that were filed with the Department of Buildings prior to November 1, 1976.

4.5 1978 – LOCAL LAW NO. 33, FIRE WARDENS IN OFFICE BUILDINGS

Local Law No. 33 for the year 1978 (LL 33/1978) was approved "to amend the administrative code of the city of New York, in relation to tenant's employees as fire wardens in certain office buildings."

LL 33/1978 consists of two sections that amend a provision added to the Fire Prevention Code by LL 5/1973. The two sections pertain to fire safety plans and the designation and training of fire wardens and deputy fire wardens by the fire safety directors.

Section 1 adds a new paragraph 6 to sec. C19-161.2(a) requiring the tenant or tenants on each floor to provide responsible and dependable employees for designation and training by the fire safety director as fire wardens and deputy fire wardens to carry out their responsibilities as contained in the fire safety plan.

Section 2 amends C19-161.2(a)(2)(a) requiring the fire safety director to designate and train the fire wardens and deputy fire wardens provided by the tenants on each floor.

LL 33/1978 was signed by the Mayor on October 6, 1978, and was effective immediately. Since the LL 5/73 requirements for fire safety plans and fire safety directors were applicable to existing office buildings, the additional requirement for fire wardens and deputy fire wardens were also applicable to existing office buildings.

4.6 1978 – LOCAL LAW NO. 41, FIRE PROTECTION FOR PLACES OF ASSEMBLY

After the tragic fire in the Blue Angel nightclub in midtown Manhattan in December 18, 1975, Local Law No. 41 for the year 1978 (LL 41/1978) was approved "to amend the administrative code of the city of New York, in relation to fire protection for places of assembly."

A place of assembly is defined in the BCNYC as "an enclosed room or space in which seventy-five or more persons gather for religious, recreational, educational, political or social purposes, or for the consumption of food or drink, or for similar group activities…" At the World Trade Center (WTC) complex, several cafeterias throughout the buildings and restaurants such as the Windows on the World on the 107th floor of WTC 1 are classified as occupancy group F-4 places of assembly.

Sections of the Fire Prevention Code and Building Code were amended by LL 41/1978 to require emergency lighting, sprinklers, and fire alarm signal systems in certain areas of places of assembly. LL 41/1978 included requirements for new places of assembly as well as retroactive provisions for existing places of assembly. The following code requirements are applicable for all new places of assembly and include retroactive provisions for such existing places of assembly:

- C26-801.18, Emergency lighting – All new and existing assembly spaces are required to be provided with emergency lighting facilities sufficient to provide at least 5 foot candles of illumination at the floor level. Such lighting shall be on circuits that are separate from the general lighting and power circuits, either taken off ahead of the main switch or connected to a separate emergency power source, and be arranged to operate automatically in the event of failure of the normal lighting system. Compliance in existing buildings was to be completed within a one year time period (amended LL 41, sec. 11).

- C26-802.0(b)(7)(g) – Automatic sprinklers for stage areas in new and existing occupancy group F-1a places of assembly within 1 year of the effective date (added LL 41, sec. 12).

- C26-802.3(b)(2) – Automatic sprinklers and fire alarm protection for stages, dressing rooms and property rooms in new and existing occupancy group F-1b places of assembly providing live entertainment within 1 year of effective date (added LL 41, sec. 13).

- C26-804.1(a)(3) and C26-804.1(b) – Automatic sprinklers and fire alarm protection in new and existing occupancy group F-4 places of assembly used as a cabaret[1] within 1 year of effective date (added LL 41, secs. 14 and 15).

- C26-1703.1(j) – Automatic sprinkler systems in dressing rooms and property rooms used in conjunction with all new and existing places of assembly providing entertainment (amended LL 41, sec. 19).

- C26-1703.1(s) – Automatic sprinkler systems in new and existing

  – (1) occupancy group F-4 places of assembly used as cabarets.

  – (2) stages within F-1a, F-1b, F-3 or F-4 occupancies providing live entertainment (added LL 41, sec. 20).

- C26-1704.1(a)(10) – Interior fire alarm and signal systems in new and existing

  – (a) Stages, dressing rooms and property rooms used in conjunction with all places of assembly used as cabarets.

  – (b) Places of assembly used as a cabaret (added LL 41, sec. 21).

LL 41/1978 was approved by the Mayor on December 13, 1978, and took effect 30 days after its enactment into law (January 12, 1979).

4.7 1979 – LOCAL LAW NO. 84, FIRE SAFETY PRESSURIZATION IN OFFICE BUILDINGS

Local Law No. 84 for the year 1979 (LL 84/1979) was approved "to amend the administrative code of the city of New York, in relation to fire safety pressurization requirements in certain office buildings."

To accommodate the requirement for stair pressurization as added by LL 5/1973, the opening paragraph for shafts (C26-504.6) and the requirement for openings in stair enclosures (C26-604.8(j)) was editorially revised (LL 86, secs. 1 and 2).

[1] Cabaret – The term cabaret shall mean any room, place, or space in which any musical entertainment, singing, dancing or other similar amusement is permitted in connection with an eating and drinking establishment.

Section 3 of LL 84/1979 amends RS 5-18, Standards for the Installation of Pressurization of Stairs.

LL 84/1979 was approved by the Mayor on December 13, 1979, and became effective immediately.

4.8 1979 – LOCAL LAW NO. 86, REVISED COMPLIANCE DATES FOR LOCAL LAW NO. 5/1973

Local Law No. 86 for the year 1979 (LL 86/1979) was approved "to amend the administrative code of the city of New York, in relation to the dates for compliance with the local law enacted for fire safety requirements and controls in certain office buildings."

Various provisions of Local Law No. 5 for the year 1973 (i.e., compartmentation, pressurization, interior fire alarm and communication, elevator in readiness) have been amended by LL 86/1979 to provide for new dates for compliance as follows:

- C26-504.1(c)(6) – Compartmentation – Existing office buildings 100 ft or more in height shall comply as follows (amended LL 86, sec. 1):
  - At least one-third of the total floor area of the building within 2 years of the effective date of LL 86/1979 (on or before December 13, 1981)
  - At least two-thirds of the total floor area of the building on or before August 7, 1984
  - Full compliance on or before February 7, 1988
- C26-504.15(c) – Smoke and heat venting – Existing office buildings 100 ft or more in height that are required to provide smoke vents or stair pressurization shall complete installation within 2 years and 9 months of the effective date of this local law (by September 13, 1982), or
- C26-504.15(c) – Sprinklers in lieu of smoke and heat venting – Existing buildings that are sprinklered throughout shall be exempt from the compartmentation and the smoke vent or stair pressurization requirements under the following conditions (amended LL 86, sec. 2):
  - At least one-third of the total floor area of the building, including but not limited to the entrance lobby, corridors and elevator landing areas, is sprinklered within 2 years of the effective date of LL 86/1979 (on or before December 13, 1981),
  - At least two-thirds of the total floor area of the building is sprinklered within 3 years (on or before December 13, 1982),
  - The building is sprinklered throughout within 4 years (on or before December 13, 1983).
- C26-1704.5(f)(12) – Class E fire alarm signal system – Existing office buildings 100 ft or more in height shall install a class E fire alarm signal system within 1 year and 9 months of the effective date of LL 86/1979 (on or before September 13, 1981), (amended LL 86, sec. 3), or

- C26-1704.5(g)(10) – Modified Class E fire alarm system permitted in lieu of Class E fire alarm system – Existing office buildings 100 ft or more in height shall comply within 1 year and 9 months of the effective date of LL 86/1979 (on or before September 13, 1981), (amended LL 86, sec. 4),

- C26-1704.8(c) – Communication system and fire command station – Existing office buildings 100 ft or more in height were required to install a one-way and two-way voice communication system and fire command station within 1 year and 9 months of the effective date of LL 86/1979 (on or before September 13, 1981), (amended LL 86, sec. 5),

- C26-1800.8(c) – Elevator in readiness – Existing office buildings 100 ft or more in height were required to provide elevators for immediate use by the fire department within 1 year and 9 months of the effective date of LL 86/1979 (on or before September 13, 1981), (amended LL 86, sec. 6).

LL 86/1979 was approved by the Mayor on December 13, 1979, and became effective immediately.

4.9 1984 – LOCAL LAW NO. 16, FIRE SAFETY REQUIREMENTS IN CERTAIN BUILDINGS

Local Law No. 16 for the year 1984 (LL 16/1984) was approved "To amend the administrative code of the city of New York, in relation to fire safety requirements in certain buildings and repealing certain provisions thereof relating thereto." Not since Local Law No. 5/1973 was there as extensive a local law amending fire protection and life safety provisions of the BCNYC. LL 16/1984 consists of 40 pages with 100 sections of code amended.

Sections of the Fire Prevention Code and the Building Code were amended by LL 16/1984. This local law provided additional fire protection and life safety requirements for new buildings in most occupancy groups and retroactive provisions for existing buildings in most occupancy groups, but primarily buildings in occupancy group J-1 (hotels).

The major highlights of LL 16/1984 are summarized in the following sections.

4.9.1 Fire Safety Requirements

Section C19-161.3 of the New York City Fire Prevention Code was added requiring all new and existing buildings, when required by the BCNYC, to be provided with sprinklers, exit lighting, exit signs, stair and elevator signs, signs in sleeping rooms, fire alarms, communication systems, and fire command stations (LL 16/1984, sec. 3).

4.9.2 Alterations to Existing Buildings

Section C26-103.0 of the BCNYC was amended regarding alterations of existing buildings. Three new subdivisions were added requiring the following provisions to apply to alterations of existing buildings, regardless of magnitude or cost (LL 16/1984, sec. 8):

1. Interior finish work, as provided in sec. C26-504.10
2. Finish flooring and floor covering, as provided in C26-504.13
3. The installation or replacement of elevators, as provided in article 18

4.9.3 Fire Protection Plan

A new sub-article 124.0 (secs. C26-124.1 through C26-124.4) was added requiring a fire protection plan[2] for certain new buildings, including all high-rise buildings. The requirement for fire protection plans was also applicable retroactively to the construction of buildings in progress and not yet completed on the effective date (March 27, 1984) and to alterations to an existing building or building section if the cost of the alteration exceeded one million dollars or involved a change of use. Section C26-124.2 outlines the scope of items to be included in the fire protection plan (LL 16/1984, sec. 12).

4.9.4 Special Filing Requirements

A new sub-article 125.0 (sec. C26-125.1) was added requiring the owners of all existing buildings, which are required to comply with certain provisions of LL 16/1984 to file a report with the New York City Department of Buildings on or before April 1, 1987, certifying the installation of the required fire

- C26-1800.8(c)(2) – Elevators in readiness
- C26-1801.4 – Locks on elevator hoistway doors
- C26-1801.5 – Firemen’s service operation for 226 Ls

4.9.5 Definitions

4.9.15 Automatic Sprinklers

Several sections were amended by LL 16/1984 requiring automatic sprinklers in various occupancy groups. New requirements for sprinklers were added for new high-rise buildings and spaces in occupancy groups E, F, G, and J-1 and certain low rise buildings in occupancy groups E and J-1. Sprinklers are also required in certain existing buildings and spaces in occupancy groups C, F, and J-1.

The requirements for buildings in occupancy group E are as follows:

- Section C26-1703.1(z) was added to require automatic sprinklers in new high-rise buildings classified in occupancy group E and low-rise buildings classified in occupancy group E with a total gross floor area of 100,000 ft^2 or more.

- Section C26-1703.9(h) was amended to permit standpipe risers to be used to supply water to sprinklers in high-rise buildings classified in occupancy groups E, G, H, and J and in existing office buildings, 100 ft or more in height.

4.9.16 Fire Alarm and Communication Systems

Section C26-1704.5 was amended by adding two new subdivisions (i) and (j) requiring fire alarm and communication systems and command stations for new high-rise buildings in occupancy groups C (mercantile), new and existing high-rise buildings in occupancy group J-1 (hotels) and new and existing low rise buildings in occupancy group J-1 with 30 or more sleeping rooms (LL 16/1984, sec. 75).

Section C26-1704.6(a)(2) was amended to require all fire alarm manual stations installed or relocated after April 1, 1984, to be installed so that the handle is approximately 4 ft from the floor (LL 16/1984, sec. 76).

Section C26-1704.8 as added by LL 5/1973 was amended to modify the requirement for communication systems and fire command stations in buildings in occupancy group E. Local Law 5/1973 initially required such systems in new and existing buildings in occupancy group E (offices), 100 ft or more in height. Local Law 16/1984 amended this section to require communication systems and fire command stations in new buildings in occupancy group E, 75 ft or more in height, or if less than 75 ft in height, buildings with a total gross area of 200,000 ft^2 or more. The requirement for existing office buildings remained as 100 ft or more in height (LL 16/1984, sec. 77).

Section C26-1705.2 as added by LL 62/1981 was amended by adding a new subdivision (b) requiring approved and operational smoke detecting devices to be installed in mechanical rooms, electrical switch gear rooms and electric and telephone closets over 75 ft^2 in gross floor area in all buildings in all occupancy groups (LL 16/1984, sec. 78).

4.9.17 Elevators

Section C26-1800.8, as amended by LL 5/1973 and LL 86/1979, was amended to reduce the height of new buildings required to comply with the requirements of elevator in readiness from 100 ft to 75 ft, consistent with the new definition of high-rise buildings. This section was also amended to expand on the types of buildings required to comply with this section to include: high-rise buildings classified in

occupancy groups A, B, C, D, E, F, G, and H, buildings classified in occupancy group E with a gross area of 200,000 ft^2 or more, buildings classified in occupancy groups J-1 and J-2, existing high-rise buildings classified in occupancy groups C, F, G, and H, existing buildings classified in occupancy group J-1 and existing office buildings 100 ft or more in height (LL 16/1984, sec. 79).

Section C26-1801.4 was added requiring owners of existing high-rise buildings to remove any switch, lock or other device on any elevator car or elevator hoistway door that prevents the opening of such doors by anyone not having a key. Existing high-rise buildings were required to comply with this section on or before April 1, 1987 (LL 16/1984, sec. 80).

Section C26-1801.5 was added to require firemen service operation (as defined in ASME A17.1) in existing elevators in high-rise buildings in occupancy group C and all buildings classified in occupancy group F, G, H, or J-1 on or before April 1, 1987 (LL 16/1984, sec. 80).

4.9.18 Reference Standards

In addition to amending existing building code requirements or enacting new code requirements, LL 16/1984 also modified existing Reference Standards and added new Reference Standards as follows:

- RS 5-19, Standard Method of Fire Tests of Through-Penetration Fire Stops, ASTM International (ASTM) E 814 – 1981 (added LL 16/1984, sec. 85).
- RS 5-20, Standard for the Flammability of Carpets (added LL 16/1984, sec. 85).
  - Methane Pill Test, DOC FF1-1970
  - Standard Test Method for Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Source, ASTM E 648-1978
  - Standard Test Method for Specific Optical Density of Smoke Generated by Solid Materials, ASTM E 662-1979
- RS 13-1, Standard for the Installation of Air Conditioning and Ventilating Systems, NFPA 90A – 1981, as modified (repealed and re-enacted by LL 16/1984, sec. 87).
- RS 17-3, Standards for the Installation of Fire, Sprinkler, Standpipe, Smoke Detection…and other Alarm and Extinguishing Systems (amended LL 16/1984, secs. 88 through 92).
- RS 17-3A, Standards for the Installation of Class E Fire Alarm Signal Systems (amended LL 16/1984, secs. 93 through 96).
- RS 17-3C, Standard for the Installation of Fire Alarm Signal Systems and Communication Systems for High-Rise Buildings in Occupancy Group C – Mercantile, and J-1 – Residential (Transient), and Buildings in Occupancy Group J-1 – Residential Containing 30 or More Sleeping Rooms (added LL 16/1984, sec. 97).

- RS 17-3D, Standard for the Installation of Fire Alarm Signal Systems and Communication Systems for Existing Buildings in Either Group J-1 – Residential (Transient) 75 ft or More in Height or with 30 or More Sleeping Rooms (added LL 16/1984, sec. 97).

- RS 18-1, Rule 211.3a (1)(b) (repealed and re-enacted LL 16/1984, sec. 98).

LL 16/1984 was approved by the Mayor on March 27, 1984, and took effect immediately, except as otherwise specifically provided. Note that some of the provisions of LL 16/1984 were further amended by Local Law No. 16 for the year 1987 (LL 16/1987).

4.10 1985 – LAWS OF NEW YORK STATE, RENUMBERING OF NEW YORK CITY ADMINISTRATIVE CODE

The New York City Administrative Code was renumbered and changed by chapter 907 of the New York State Laws of 1985 and chapter 839 of the New York State Laws of 1986, effective September 1, 1986. The renumbering of the Administrative Code included the Building Code and the Fire Prevention Code of the City of New York.

The Building Code was originally part of Title 'C' of Chapter 26 (C26-) of the Administrative Code. After 1985, the General Provisions of the Department of Buildings were organized under Chapter 1 of Title 26 – Housing and Buildings and the Building Code is Chapter 1 of Title 27 – Construction and Maintenance. The format of the Department of Buildings provisions and the Building Code under the renumbered Administrative Code is as follows:

- Title 26 – Housing and Buildings
  - Chapter 1 – Department of Buildings
  - Subchapter 1 – General Provisions
  - Subchapter 2 – Licenses
  - Subchapter 3 – Building Construction
- Title 27 – Construction and Maintenance
  - Chapter 1 – Building Code
  - Subchapters 1 through 19
  - Appendix – Building Code Reference Standards

Subsequent publications of the BCNYC include the new section number with the former Building Code sections enclosed by parentheses. Conversion or Distribution Tables are also provided in the BCNYC for convenience of converting from former code sections to new code sections and vice-versa.

The Fire Prevention Code was originally part of Chapter 19 (C19-) of the Administrative Code. After 1985, the Fire Prevention Code was organized under Chapter 4 of Title 27 of the Administrative Code as follows:

- Title 27 – Construction and Maintenance
  - Chapter 4 – Fire Prevention Code
  - Subchapters 1 through 29

4.11 1987 – LOCAL LAW NO. 16, FIRE ALARM SYSTEMS AND REFERENCE STANDARDS

Local Law No. 16 for the year 1987 (LL 16/1987) was approved "To amend the administrative code of the city of New York, in relation to fire alarm systems and to repeal reference standards RS 17-3C and RS 17-3D of the appendix thereto." LL 16/1987 made several modifications to the fire alarm and signal system requirements that were added to the BCNYC by LL 5/1973 and LL 16/1984.

The following is a summary of the sections amended or added by LL 16/1987:

- 27-929 (formerly C26-1700.7) Retroactive Requirements – amended by adding a new subdivision (b) to revise the dates for compliance with the retroactive provisions of LL 16/1984 for the installation of a fire alarm and signal system in occupancy group J-1 (hotels). The date for completed installation was extended from April 1, 1987 to December 31, 1987 (LL 16/1987, sec. 1).

- 27-971(g) (formerly C26-1704.4(g)) Class E system and 27-971(h) (formerly C26-1704.4(h)) Modified Class E system – amended to include the provision of sec. 27-973(a)(2) requiring fire alarm stations installed or relocated after April 1, 1984, to be installed so that the handle is approximately 4 ft from the floor (LL 16/1987, sec. 2).

- 27-971 (formerly C26-1704) was amended by adding four new subdivisions i, j, k, and l as follows (LL 16/1987, sec. 3):
  - (i) Class C fire alarm and communication system – for new mercantile (retail) buildings in occupancy group C, 75 ft or more in height.
  - (j) Class J fire alarm and communication system – for new buildings in occupancy group J-1 (hotels), 75 ft or more in height or containing 30 or more sleeping rooms.
  - (k) Modified class J fire alarm and communication system – for existing buildings in occupancy group J-1 (hotels) 75 ft or more in height.
  - (l) Modified class J-1 fire alarm and communication system – for existing buildings in occupancy group J-1 (hotels) less than 75 ft in height or containing 30 or more sleeping rooms.

- 27-972(i) (formerly C26-1704.5(i) as added by LL 16/1984) was amended to separate the requirements for high-rise buildings classified in occupancy group C from the requirements for buildings classified in occupancy group J-1 by proving two separate paragraphs (1) and (2) respectively and provide the following modifications (LL 16/1987, sec. 4):

  – Paragraph (1) – the Reference Standard for Class C fire alarm systems was changed to RS 17-3A (from RS 17-3C).

  – Paragraph (2) – the Reference Standard for Class J-1 fire alarm systems was changed to RS 17-3A (from RS 17-3C). Also, new alternative methods for two-way voice communication systems in lieu of fire warden stations were added.

- 27-972(j) (formerly C26-1704.5(i) as added by LL 16/1984) for existing buildings classified in occupancy group J-1, was amended to include two new paragraphs as follows (LL 16/1987, sec. 4):

  – Paragraph (1) for existing buildings in occupancy group J-1, 75 ft or more in height provides an exception for "residential hotels" as defined in the Building Department Rules of the City of New York. The Reference Standard for modified Class J fire alarm systems was changed to RS 17-3B (from RS 17-3D). Also, two new alternative methods for two-way voice communication systems in lieu of fire warden stations were added.

  – Paragraph (2) was added to provide a new fire alarm system classification, a modified Class J-1 fire alarm and communication system, for existing buildings in occupancy group J-1, less than 75 ft in height and containing thirty or more sleeping rooms. The requirements for a fire command station, public address system and central station monitoring of the fire alarm system are also provided.

- 27-972(k) (formerly C26-1704.5(k)) was added requiring buildings classified in occupancy group C (mercantile), 75 ft or more in height to be provided with a Class C fire alarm and communications system, including the applicable criteria (LL 16/1987, sec. 5).

- 27-972(l) (formerly C26-1704.5(l)) was added requiring buildings in occupancy group J-1 (hotels), 75 ft or more in height or containing 30 or more sleeping rooms, to be provided with a Class J fire alarm and communication system, including the applicable criteria (LL 16/1987, sec. 5).

- 27-972(m) (formerly C26-1704.5(m)) was added requiring existing buildings in occupancy group J-1 (hotels), 75 ft or more in height or containing 30 or more sleeping rooms, to be provided with a modified Class J fire alarm and communication system, including the applicable criteria (LL 16/1987, sec. 5).

- RS 17-3A (as added by LL 5/1973) – the title was amended to read "Standards for the Installation of Class E, Class C and Class J Fire Alarm Signal Systems" (LL 16/1987, sec. 6).

- RS 17-3B (as added by LL 5/1973) – the title was amended to read "Standards for the Installation of Modified Class E, and Modified Class J Fire Alarm Signal Systems" (LL 16/1987, sec. 7).

- RS 17-3C (as added by LL 16/1984) was repealed. The installation standards for fire alarm signal systems and communication systems in high-rise buildings in occupancy group C – Mercantile, and J-1 – Residential (transient), and buildings in occupancy group J-1 – Residential containing 30 or more sleeping rooms is now RS 17-3A (LL 16/1987, sec. 8).

- RS 17-3D (as added by LL 16/1984) was repealed. The installation standard for the installation of fire alarm signal systems and communication systems for existing buildings in either occupancy group J-1 – Residential (transient) 75 ft or more in height or with 30 or more sleeping rooms is now RS 17-3B (LL 16/1987, sec. 8).

LL 16/1987 was approved by the Mayor on April 20, 1987, and was effective immediately.

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Chapter 5
BUILDING CODE REFERENCE STANDARDS

Since 1968, the Reference Standards (RS) of the Building Code of the City of New York have been updated by Local Laws passed by the City Council, Building Code Rules approved by the New York City Board of Standards and Appeals (BSA) until 1991, and by the authority of the Building Commissioner, after 1991. A New York City Reference Standard may adopt a standard developed and published by an outside standards developer (such as the National Fire Protection Association [NFPA]) in whole or in part, and may choose to modify parts to meet local conditions or practices. When such modifications are adopted, the New York City Reference Standard differs from the published standard. The following is a summary of the applicable fire protection or life safety reference standards and effective dates.

5.1 RS 5-2, ASTM E 119

RS 5-2, Standard Methods of Fire Tests of Building Construction Materials, ASTM International (ASTM) E 119 - 1961

- Added by Local Law No. 76/1968 (LL 76/1968), effective December 6, 1968
- Amended by BSA 217-72-BCR, effective April 25, 1972
- Amended by BSA 1343-88-BCR, effective December 20, 1988

5.2 RS 5-5, ASTM E 84

RS 5-5, Standard Method of Test for Surface Burning Characteristics of Building Materials, ASTM E 84 - 1961

- Added by LL 76/1968, effective December 6, 1968
- Amended by BSA 218-72-BCR, effective April 25, 1972
- Amended by BSA 308-81-BCR, effective June 16, 1981
- Amended by BSA 1343-88-BCR, effective December 20, 1988

5.3 RS 5-8, NFPA 80

RS 5-8, Installation of Fire Doors and Windows, NFPA 80 – 1967

- Added by LL 76/1968, effective December 6, 1968
- Amended BSA 71-79-BCR, effective February 20, 1979

- Amended by BSA 308-81-BCR, effective June 16, 1981
- Amended by BSA 1343-88-BCR, effective December 20, 1988

5.4 RS 13-1, NFPA 90A

RS 13-1, Standard for the Installation of Air Conditioning and Ventilating Systems, NFPA 90A – 1967, as modified

- Added by LL 76/1968, effective December 6, 1968
- Amended by LL 16/1984, effective March 27, 1984
- Amended by BSA 17-87-BCR, effective February 10, 1987
- Repealed and added by Building Department, effective May 4, 2002

5.5 RS 17-1, STANDPIPE CONSTRUCTION

RS 17-1, Standpipe Construction

- Added by LL 76/1968, effective December 6, 1968
- Amended by BSA 177-72-BCR, effective April 18, 1972
- Amended by LL 5/1973, effective January 18, 1973
- Amended by BSA 1014-0-BCR, effective November 25, 1980
- Amended by BSA 384-82-BCR
- Amended by BSA 310-90-BCR, effective January 22, 1991
- Amended by Building Department, effective July 24, 1996

5.6 RS 17-2, NFPA 13

RS 17-2, Standard for the Installation of Sprinkler Systems NFPA 13 - 1966, as modified

- Added by LL 76/1968, effective December 6, 1968
- Amended by BSA 633-83-BCR, effective September 13, 1983
- Amended by BSA 310-90-BCR, effective January 22, 1991
- Amended by Building Department, effective April 3, 2003

5.7 RS 17-3, FIRE ALARM AND EXTINGUISHING SYSTEMS

RS 17-3, Standards for the Installation of Fire, Sprinkler, Standpipe, Smoke Detection…and other Alarm and Extinguishing Systems

- Added by LL 76/1968, effective December 6, 1968
- Amended by BSA 149-75-BCR, effective May 6, 1975
- Amended by BSA 515-75-BCR, effective December 2, 1975
- Amended by LL 16/1984, effective March 27, 1984
- Amended by Building Department, effective April 3, 2003

5.8 RS 17-3A, CLASS E FIRE ALARM SYSTEMS

RS 17-3A, Standards for the Installation of Class E, Class C, and Class J Fire Alarm Signal Systems

- Added by LL 5/1973, effective January 18, 1973
- Amended by LL 16/1984, effective March 27, 1984
- Amended by Building Department, effective April 3, 2003

5.9 RS 17-3B, MODIFIED CLASS E FIRE ALARM SYSTEMS

RS 17-3B, Standards for the Installation of Modified Class E, and Modified Class J, Fire Alarm Signal Systems

- Added by LL 5/1973
- Amended by BSA 49-74-BCR, effective March 12, 1974
- Amended by LL 16/1984, effective March 27, 1984
- Amended by LL 16/1987, effective April 20, 1987
- Amended by Building Department, effective April 3, 2003

5.10 RS 17-5, NFPA 72

RS 17-5, Proprietary and Auxiliary Protective Signaling Systems, NFPA 72 – 1967

- Added by LL 76/1968, effective December 6, 1968
- Amended by BSA 310-90-BCR, effective January 22, 1991
- Repealed and added by Building Department, effective January 9, 2002

5.11 RS 18-1, AMERICAN NATIONAL STANDARDS INSTITUTE A17.1

RS 18-1, USA Standard Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks, USASI 17.1 – 1965, including Supplement A17.1a-1967, as modified

- Added by LL 76/1968, effective December 6, 1968
- Amended by BSA 385-82-BCR, effective August 10, 1982
- Amended by LL 16/1984, effective March 27, 1984
- Amended by BSA 678-85-BCR, effective October 1, 1985
- Amended by BSA 11-91-BCR, effective March 12, 1991
- Amended by Building Department

Chapter 6
REFERENCES

City Publishing Center Department of General Services. 1968. *The City of New York Building Code.* New York, NY, December 6.

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NIST NCSTAR 1-1H

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Post-Construction Modifications to Fire Protection and Life Safety Systems of the World Trade Center Towers

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NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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September 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
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National Institute of Standards and Technology
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In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

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ABSTRACT

This report was prepared to support the analysis of building and fire codes and standards of the National Institute of Standards and Technology World Trade Center (WTC) Investigation. The purpose of this report is to document the Port Authority of New York and New Jersey guidelines for inspection, repair, and modifications to fire protection and egress systems in WTC 1, 2, and 7. This includes guidelines governing the inspection and upgrading of fire alarm and fire suppression systems; the reapplication of fireproofing; and the upgrading of elevators, hoistways, and elevator lobbies.

This report also documents repairs and modifications made to the fire protection and life safety systems on the affected floors of WTC 1 and WTC 2.

Keywords: Compartmentation, elevators, emergency power, fire alarm, fire protection, fire safety, fire sprinklers, high-rise buildings, inspections, interior finish, means of egress, pressurization, venting, voice communication, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

ADA	Americans with Disabilities Act
ASTM	American Society for Testing and Materials
BCNYC	Building Code of the City of New York (Local Law 76)
BFP	Bureau of Fire Prevention
FDNY	New York City Fire Department
HVAC	heating, ventilating, and air conditioning
LERA	Leslie E. Robertson Associates
MER	Mechanical Equipment Room
MOU	Memorandum of Understanding
MPC	Maintenance Procedure Card
NFPA	National Fire Protection Association
NYCDB	New York City Department of Buildings
NIST	National Institute of Standards and Technology
PANYNJ	Port Authority of New York and New Jersey
R&D	research and development
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

°F	degrees Fahrenheit
cfm	cubic foot per minute
ft	foot
ft^2	square foot
in.	inch
lb	pound
V	volt

W	watt
yd^2	square yard

GLOSSARY

active fire protection – A means to help prevent the loss of life and property from fire by extinguishing, suppressing or controlling a fire through functional systems. Sprinkler systems, fire alarm systems, and smoke control systems are examples of active fire protection.

area of refuge – A floor area to which egress is made through a horizontal exit or supplemental vertical exit.

combustible – A material that is not determined to be noncombustible.

damper – A device installed in heating, ventilating, and air conditioning ductwork used to prevent the spread of fire and/or smoke. Dampers are provided to maintain a fire resistance rating of the assembly being penetrated.

detector – An initiation device that automatically detects a change in state, such as presence of smoke, high temperature or abnormal rate of temperature rise.

fire alarm system – A system, automatic or manual, arranged to give a signal indicating a fire emergency and initiate the appropriate response.

fire resistance rating – The time in hours that materials or their assemblies will withstand fire exposure as determined by a fire test.

fireproofing – Materials or assemblies used to provide a fire resistance rating to a building component.

firestop – A solid or compact, tight closure to retard the spread of flames or hot gases within concealed spaces.

initiation device – A system component that originates a change in state signal in the fire alarm system. An initiation device begins the life safety processes, such as evacuation, heating, ventilating, and air conditioning shut down, elevator recall; etc.

manual fire alarm box – A manually operated initiation device that originates a change-in-state signal in the fire alarm system.

means of egress – A continuous and unobstructed path of vertical and horizontal travel from any point in a building to a public way. The means of egress consists of the exit access, the exit, and the exit discharge.

noncombustible – A material that, in the form in which it is used in construction, will not ignite and burn when subjected to fire. However, any material which liberates flammable gas when heated to any temperature up to 1,380 °F for 5 min shall not be considered noncombustible.

notification appliance – A fire alarm system component such as a bell, horn, speaker, or strobe that provides audible, tactile, or visible outputs, or any combination thereof.

passive fire protection – Fire protection features that are incorporated into the building construction or building materials that do not rely on active fire protection methods to limit fire ignition, fire growth or material failure. Fire separations and divisions, sprayed-on fire proofing and enclosing structural members with noncombustible materials are examples of passive fire protection.

smoke and heat venting – A process used to move products of combustion to the outdoor air.

PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

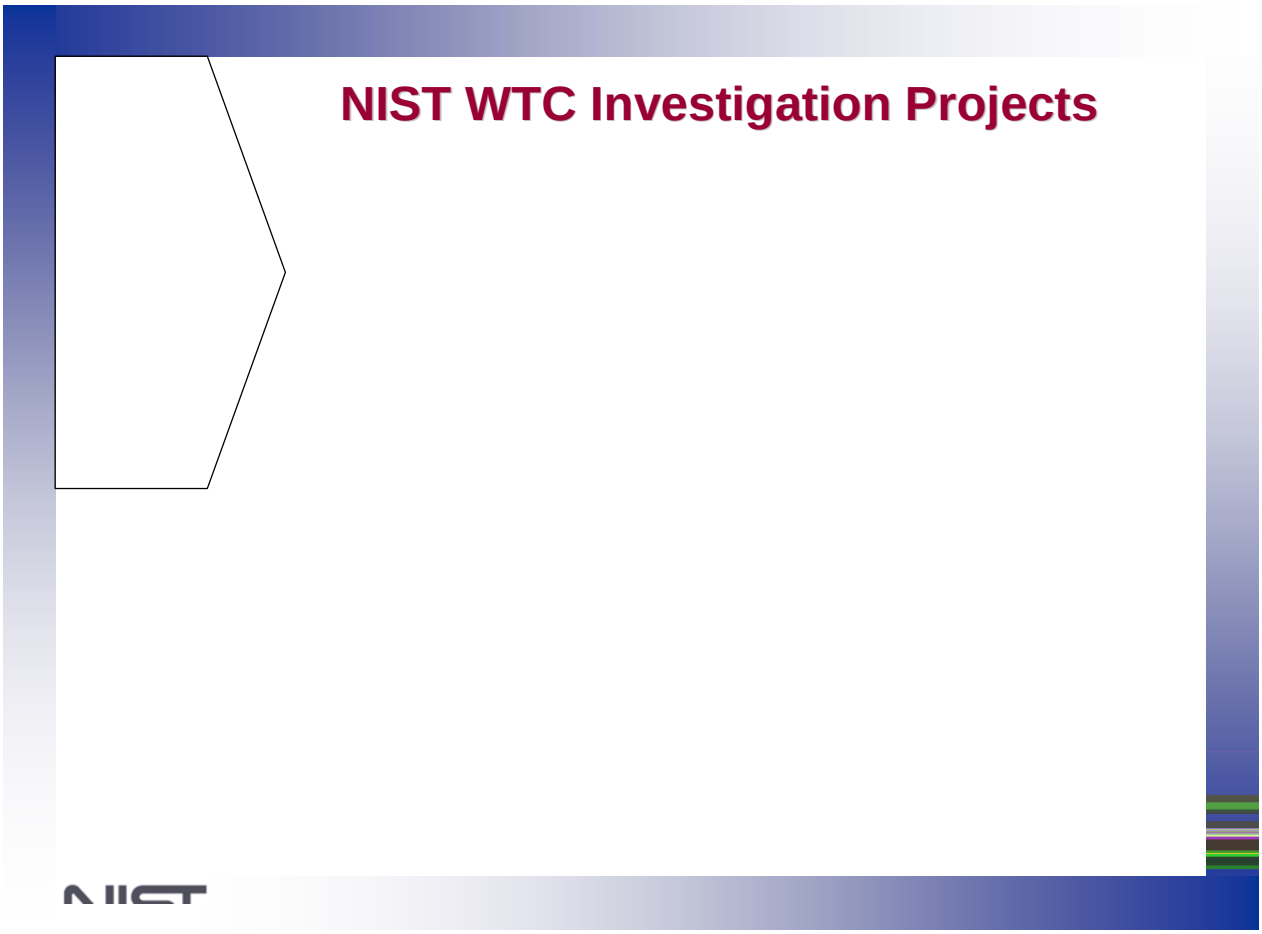
NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.


NIST WTC Investigation Projects

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

NIST (National Institute of Standards and Technology). 2008. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of World Trade Center 7.* NIST NCSTAR 1A. Gaithersburg, MD, November.

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Section I

PANYNJ Guidelines for Inspection, Repair, and Modifications to Fire Protection Systems

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EXECUTIVE SUMMARY

As part of the analysis of building and fire codes and standards of the National Institute of Standards and Technology World Trade Center (WTC) Investigation, this report supports the effort to document the Port Authority of New York and New Jersey (PANYNJ) guidelines for inspection, repair, and modifications to the fire protection systems in the WTC. Over the life of the buildings, in particular WTC 1, 2, and 7, repairs and modifications were made. These changes, depending on the magnitude of the enhancement, may have affected the overall building performance. The purpose of this report is to document the PANYNJ guidelines for inspection, repair, and modifications to fire protection and egress systems in WTC 1, 2, and 7. These include guidelines governing the inspection and upgrading of fire alarm and fire suppression systems, the reapplication of fireproofing, and the upgrading of elevators, hoistways, and elevator lobbies.

As part of the document search for this report, manuals, program standards, surveys, and correspondence of many parties were reviewed and analyzed. The following sections provide a summary of the documents that include guidelines and procedures for maintaining and modifying the fire protection and egress systems of the WTC.

Memorandums of Understanding

The PANYNJ, not being technically subject to the local building code of New York City, created a Memorandum of Understanding (MOU) with the New York City Department of Buildings (NYCDB) in 1993 to establish procedures and avoid construction conflicts. The MOU ensured that any construction project performed by the PANYNJ or any tenant within a PANYNJ building in New York City would conform to the Building Code of the City of New York (BCNYC). The MOU gave the PANYNJ the right to approve building plans. Any variance to the BCNYC, permitted by the PANYNJ, would be sent to the NYCDB for review.

In June of 1995, a supplement to the PANYNJ/NYCDB MOU was added. The MOU supplement permitted PANYNJ tenants to use New York State licensed engineers/architects to self certify construction plans and certify that the installation was in accordance to the certified plans, provided the engineers/architects meets the qualifications established by PANYNJ. The person approving the construction plans could not be the same person certifying that the installation was in accordance with the approved plans until September of 1995, when another supplement was added. The September 1995 supplement permitted a single New York State licensed engineer/architect to certify the construction plans and the installation.

In 1993, a MOU with the PANYNJ and the New York City Fire Department (FDNY) was established. The MOU permitted the FDNY to conduct fire safety inspections at the PANYNJ facilities in New York City. Upon inspection, the findings and recommendations were sent to PANYNJ for review and corrective action if necessary. In 1995, an amendment to the MOU was adopted requiring written notice to the FDNY of any additions or modifications to existing fire safety systems. The amendment also required the design and review of the addition or modification to be performed by a New York State

licensed engineer or architect. Additionally, the amendment required the design and review of such design to be performed by separate individuals.

Tenant Construction Review Manuals

The *Tenant Construction Review Manuals* were created by the Engineering Department, Quality Assurance Division of PANYNJ. The manuals were created to establish technical criteria to be followed by the tenants and their architectural and engineering consultants. Manuals were available from 1971 to 1997. The manuals indicated the applicable codes, standards and PANYNJ criteria that would be used to determine compliance of each modification or addition.

Design Guidelines

Various design guidelines were created by PANYNJ. Design guidelines were created for all the major construction disciplines. The design guidelines included minimum specifications and standard details for use in the alteration projects throughout the WTC complex. Details pertaining to standpipe systems, fire sprinkler systems, fire alarm systems, fireproofing and egress requirements were included.

Operation and Maintenance Manuals

The Engineering Department of PANYNJ established *Operation and Maintenance Manuals* (34 total) for the various systems throughout the WTC. Each manual contains Maintenance Procedure Cards describing in detail the inspection and maintenance procedures for the work to be done, including the frequency of each test or maintenance. Manuals #13, #18, and #23 describe the details for the fire sprinkler, standpipe and special hazard systems. Manual #23 and #12 provides the procedures for the inspection and maintenance of the fire detection systems.

Port Authority Facility Condition Survey Program

A facility condition survey program was established to continually monitor the condition of the WTC buildings. Engineering firms were contracted by PANYNJ to perform detailed inspections of the building conditions. Various building components, including architectural and structural, were inspected, photos were taken, and reports were generated with recommendations and guidelines for repair or replacement as necessary. There are at least two reports that detail the inspection and testing of fireproofing materials.

Structural Integrity Testing and Inspection Program

The *Structural Integrity Testing and Inspection Program* was established by the PANYNJ Engineering Department and Leslie E. Robertson Associates to monitor the structural integrity of WTC 1 and WTC 2. Although the complete details of this program are not summarized in this report, important procedures for the repair of fire proofing material are discussed. It was recommended to repair fire proofing material with the same brand and type initially used, where practical. Additional procedures were given based on the size of area being repaired and brand of material identified.

Tenants Manual

In 1984, the *World Trade Center Tenants Manual* was developed to provide WTC tenants information regarding the functions of the Operations Division of WTC. By following building standard requirements, the Operations Division could be contracted by a tenant to make alterations without having to hire an outside contractor or go through the review process with the WTC Planning Department.

Other Documents

As part of each tenant modification, specifications were created to establish minimum requirements as required by codes. There were literally hundreds of tenant alterations performed in WTC 1, 2, and 7. Summaries of the alterations on the affected floors of WTC 1 and WTC 2 and all of the alterations in WTC 7 are contained in a separate report. However, a specification to replace fireproofing material on the exposed columns and beams within the elevator shaft of WTC 1 identified additional procedures used at the WTC. This is discussed in Chapter 9 of this report. This specification listed the performance criteria, testing, and inspection requirements for fire proofing material.

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Chapter 1
INTRODUCTION

Over the course of years, the World Trade Center (WTC) complex and surrounding buildings were altered for numerous reasons, including tenant alterations, inspections, building repairs, enhancement, and maintenance. As changes occurred, the need to maintain safety standards arose. The Port Authority of New York and New Jersey (PANYNJ) adopted policies that set forth procedures to maintain and enhance safety standards at PANYNJ facilities. The purpose of this report is to document the PANYNJ guidelines for inspection, repair, and modifications to fire protection and egress systems in WTC 1, 2, and 7. These include guidelines governed the inspection and upgrading of fire alarm and fire suppression systems, the reapplication of fireproofing, and the upgrading of elevators, hoistways, and elevator lobbies.

The guidelines and policies are found in many PANYNJ documents and involved many parties. Manuals, program standards, surveys, and correspondence have been reviewed and analyzed in an effort to summarize the modification guidelines. Documents containing important information used in the process of performing building modifications are summarized in the following sections.

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Chapter 2
MEMORANDUMS OF UNDERSTANDING

The facilities of the Port Authority of New York and New Jersey (PANYNJ or Port Authority), an interstate compact under the U.S. Constitution, are not technically subject to the requirements of the local building codes, although PANYNJ intended to voluntarily follow the New York City codes where applicable. In order to minimize conflicts between PANYNJ and the New York City requirements for the World Trade Center (WTC), Memorandums of Understanding (MOUs) were executed. One MOU was executed between PANYNJ and the New York City Department of Buildings (NYCDB) in 1993 (PANYNJ 1993a). Another MOU was executed between PANYNJ and the New York City Fire Department (FDNY) also in 1993 (PANYNJ 1993b).

In November 1993, an agreement between PANYNJ and NYCDB was executed to establish procedures and ensure that any construction project of the PANYNJ or any of its tenants at buildings owned or operated by PANYNJ located in New York City conform to the Building Code of the City of New York (BCNYC).

Under the agreement to ensure conformance with the standards set forth in the Code at the time of design, the parties agreed that the design and review of such systems be performed by New York State licensed architects and engineers. Also, the New York State licensed architect and/or engineer approving the plans for any addition or modification for the Port Authority may not have assisted in the preparation of such plans. The Port Authority agreed to have each tenant obtain a certification from a New York State licensed architect or engineer that such system was constructed in accordance with the approved plans and specifications. For systems effectuated by the Port Authority, the Chief Engineer or his successor in duties was to certify that the system was constructed in accordance with the approved plans and specifications. The Port Authority was to maintain a file for each project, which would contain the most current documents, including certifications, necessary to justify code conformance. NYCDB was permitted, to at any time, request the Port Authority to provide NYCDB with a copy of any fire safety file. Any variance with the codes approved by the Chief Engineer of PANYNJ was to be sent to NYCDB. If NYCDB disagreed with the variance, NYCDB was to advise PANYNJ. Any matters of code conformance not resolved were subject to further review of PANYNJ Board of Commissioners. The MOU also indicates that PANYNJ would continue to conduct or cause to be conducted all building inspections, during both construction and post-construction periods. PANYNJ is to continue to perform structural integrity inspections on a cyclical basis for all of its structures located in New York City.

In June 1995, a supplement was added to the PANYNJ/NYCDB MOU. NYCDB had instituted an optional plan review system since the execution of the original MOU. The supplement requires WTC tenants to utilize New York State licensed architects or engineers meeting qualifications established by PANYNJ to certify and review projects, in lieu of any review by the Port Authority. It also states that the person who reviews and certifies the construction plans for code conformance cannot be the same person that certifies that construction has been performed in accordance with the approved plans.

In September 1995, a change to the supplement of the PANYNJ/NYCDB MOU was executed in connection with the PANYNJ's Tenant Self-Certification Program at the WTC. The change allows a single New York State licensed architect or engineer to certify both the construction plans and that construction is in conformance with the approved plans with the following exception if the alteration changes the character of the occupancy group under paragraph 27-237 of the BCNYC that would have been applicable had such space been located in a privately owned building.

In December 1993, procedures were set forth to implement the existing policy established in April 1993 between PANYNJ and FDNY. The Port Authority agreed to permit FDNY, acting through its Bureau of Fire Prevention (BFP), to conduct fire safety inspections at any PANYNJ facility in New York City. Upon inspection, BFP was to issue a report of fire safety findings and recommendations for corrective action with respect to any deficiencies to the Port Authority's General Manager of Risk Management operations. The Port Authority would undertake the implementation of such findings and corrective actions and notify BFP of the actions taken. BFP also had the right to conduct follow-up inspections with respect to any recommendations to PANYNJ.

In 1995, an Amendment to the PANYNJ/FDNY MOU was executed with respect to additions and/or modifications to existing fire safety systems. The Port Authority was to notify BFP in writing prior to the introduction of any additions or modifications to existing fire safety systems in a PANYNJ facility in the City of New York. BFP agreed to permit PANYNJ to review additions and/or modifications to existing fire safety systems. To ensure conformance with the standards set forth in local codes and regulations, the design and review of such systems were required to be performed by New York State licensed architects and engineers. Also, the New York State licensed, architect and/or engineer approving the plans for any addition or modification was not to have assisted in the actual preparation of such plans. This provision was later modified (September 1995) to permit the same New York State licensed architect or engineer to prepare and certify that plans met current code requirements.

The Port Authority agreed to require each tenant to obtain a certification from a New York State licensed architect or engineer that modifications were constructed in accordance with the approved plans and specifications. For systems effectuated by PANYNJ, the Port Authority Office of Risk Management would certify that the system was constructed in accordance with the approved plans and specifications. PANYNJ would maintain a file for each new or modified system, which would contain the most current documents, including certifications, necessary to justify code conformance. BFP could at any time request PANYNJ to provide BFP with a copy of any fire safety file. BFP could also audit any new or modified fire safety system to ensure conformance with the standards set forth in local codes and regulations. However, when circumstances or conditions were unusual, the Port Authority could petition the BFP for a variance.

Whenever work was done in the WTC buildings, a project number was assigned by the Port Authority under which all contracts, drawings, and correspondence was filed. These numbers are typically of the format W(yy)-1234 (where yy is the year initiated and 1234 is a four-digit number). This report includes these numbers as references to individual projects, and files retained by the Port Authority are identified by these numbers.

Chapter 3
TENANT CONSTRUCTION REVIEW MANUALS

The *Tenant Construction Review Manual* (the Manual) was prepared by the Engineering Department, Quality Assurance Division of the Port Authority of New York and New Jersey (PANYNJ or Port Authority). Manuals were available between 1971 and March 1997. The Manual presents technical criteria to be followed by tenants and their architectural and engineering consultants at all Port Authority facilities, including the World Trade Center (WTC) complex. The following guidelines for inspection, repair, and modifications to fire protection and egress systems are from the March 1997 (latest) edition of the Manual.

3.1 GENERAL

Each chapter or section of the Manual refers to compliance with the applicable codes, standards, and Port Authority design criteria listed in the particular section. The codes and regulations referenced for use in New York City include the following:

1. New York City Building Code and its Reference Standards
2. New York City Fire Prevention Code and Directives
3. New York City Local Laws
4. Rules of the Board of Standards and Appeals
5. New York State Labor Law
6. New York State Multiple Dwelling Law (Hotels)
7. New York State Energy Conservation Construction Code
8. Directives and Memoranda of the Department of Buildings
9. Rules of the City of New York, Title 1, Department of Buildings
10. New York City Electrical Code
11. National Electrical Code

Additionally, tenant modifications at all Port Authority facilities were required to comply with the Americans with Disabilities Act and applicable Flood Controls.

In addition to the Reference Standards referenced in the Building Code of the City of New York (BCNYC), the following standards are specifically referenced:

1. National Fire Protection Association (NFPA) 75, Computer Rooms
2. NFPA 20, Centrifugal Fire Pumps
3. NFPA 30, Flammable and Combustible Liquids Code
4. NFPA 54, National Fuel Gas Code
5. NFPA Standards in areas not covered by codes

In addition to the Port Authority design criteria, Section 14 of the Manual outlines the requirements for acceptance (approval) of materials, assemblies, forms, methods of construction, and the intended use of equipment, as well as the requirements for inspection of materials, assemblies, and construction. The requirements for the approval/acceptance of materials and equipment and the requirements for controlled inspections are abstracted from the BCNYC.

3.2 FIRE SUPPRESSION

The guidelines for the installation and alteration of sprinkler and fire suppression systems are included in:

- Section 10 – Mechanical
- Section 11 – Plumbing
- Section 12 – Fire Protection

Section 10 – Mechanical covers fire suppression systems and controls. For the WTC, the Port Authority Design Criteria refers to the published WTC guidelines for heating, ventilating, and air conditioning and Fire Safety systems (see Design Guidelines below).

Section 11 – Plumbing covers fire sprinklers and standpipes. At the WTC, the Port Authority Design Criteria for plumbing and fire protection work was required to conform to the Tenant Plumbing/Fire Protection Design Guidelines (see Design Guidelines below). Details of the representative fire protection items reviewed by the PANYNJ include:

- Fire standpipe systems: floor plans, riser diagrams and available water pressure.
- Sprinkler/fire protection systems: water supplies, mains, risers, valves, siamese connections, etc., principal construction features of the building, electrical or automatic devices, and hydraulic calculations as required by NFPA 13.
- Other fire suppression systems: plans for chemical or gaseous fire suppression piping systems were required to contain: the type of extinguishing agent and number and size of agent containers, size, length and type of all piping used, number and location of all fusible links or detectors and the temperature setting.

Section 12 – Fire Protection covers the design of various fire detection, alarm and suppression systems. Details of representative fire protection items reviewed by the PANYNJ include:

- Sprinkler and other systems using dry chemicals, foams, gaseous, and other extinguishing agents shall be shown on drawings, signed and sealed by the Architect or Engineer of record, or if prepared by a specialized consultant, signed and sealed by such licensed consultant. Said consultants must be licensed to practice in the state in which the work will be performed.

- Sprinkler plans shall indicate or list the appropriate information and data specified in NFPA 13 regarding available water sources, supply pressure, number and type of sprinklers, fire department connections, hazard classification, alarm devices, and supervisory connections. Hydraulic computations shall be submitted when used.

3.3 FIRE ALARM

Section 12 – Fire Protection covers the design of various fire detection, alarm and suppression systems. For the WTC complex, the Port Authority Design Criteria includes specific requirements for:

- Wiring: including general, initiating device circuits (smoke and heat detectors, system interfaces and manual pull stations), notification appliance circuits, control circuits and power supply.

- System: All components connected to the WTC Base Building Fire Alarm System were required to be fully compatible with the Base System. Underwriters Laboratories, Inc./Materials and Equipment Acceptance listings, cross listings and manufacturers' approvals were required. Additional requirements include: field circuits, relay control circuits and conventional inputs (waterflow, tamper, alarm and trouble from tenant panels).

Details of the representative fire protection items reviewed by the PANYNJ include a complete fire alarm riser diagram showing locations of all manual pull stations, visible and audible alerting devices, control panels and wiring where required to be provided.

3.4 FIREPROOFING

No specific design criteria is specified in Section 5 – Architectural, however, the Details of Architectural Review include fire protection of building components and finishes (including documentation verifying that all materials and equipment used are of an approved type).

Section 14 – Materials, Operations and Equipment Approval and Inspection includes the requirements for acceptance (approval) of materials, assemblies, etc. and the requirement for controlled inspections of materials, assemblies and construction.

Spray-on fireproofing, in accordance with BCNYC Sec. 27-345(h), is specifically listed as an item subject to controlled inspection. Such inspection is required to be made and witnessed by or under the direct supervision of a registered architect or professional engineer.

3.5 EGRESS

Section 5 – Architectural covers the scope of the architectural review consisting of compliance with the applicable codes, standards and PANYNJ design criteria. Other than the referenced codes and regulations, no specific means of egress design criteria is stated.

The Details of Architectural Review in Section 5 include egress, establishing occupant load and existing capacity, including door and hardware requirements.

In addition, Section 10 – Mechanical includes requirements for smoke detectors and fire/smoke dampers at ducts entering "safe areas," exit passageways and lobbies.

Chapter 4
DESIGN GUIDELINES

The Port Authority of New York and New Jersey (PANYNJ or Port Authority) prepared several Design Guidelines, Specifications and Standard Details for use in construction and alterations at the World Trade Center (WTC) complex. The following guidelines were reviewed for criteria pertaining to the maintenance and modifications of fire protection and egress systems:

- Architectural and Structural Design Guidelines, Specifications and Standard Details – February 27, 1998.
- Design Guidelines, Specifications and Standard Details Program for heating, ventilating, and air conditioning (HVAC), Fire Protection and Plumbing – Revised May 11, 1998.
- Electrical Design Guidelines, Specifications and Standard Details for Electrical, Communications and Fire Alarm – November 25, 1997.
- Mandated Fire Alarm Guidelines for the WTC Base Building Fire Alarm System Design, Construction, Maintenance and Technical Support Services – March 1999.

The following sections outline the inspection, repair, and modification criteria established for the fire protection and egress systems.

4.1 GENERAL

The Design Guidelines were intended to provide design requirements and criteria for tenant alterations at WTC. The design specifications were intended to provide the tenant's consultant engineer with WTC requirements for each of the respective trades. The substance of the specifications was required to be included in the construction documents.

The scope of the architectural and engineering reviews was to ensure compliance with the applicable codes, standards and WTC Design Criteria.

Although the scope of this report does not address compliance with the Americans with Disabilities Act (ADA), several references are made to ADA regarding egress requirements, such as door hardware and access/corridor dimensions and visual warning devises (strobes) connected to the fire alarm system.

4.2 FIRE SUPPRESSION

The Design Guidelines, Specifications and Standard Details Program for HVAC, Fire Protection and Plumbing outline the criteria for wet-pipe sprinkler systems, preaction systems, fire standpipe systems, clean agent extinguishing systems, halon fire extinguishing systems and portable fire extinguishers as follows:

Wet-Pipe Sprinkler Systems

All tenant spaces were required to be sprinklered. At the time the Design Guidelines were published, most tenant floors in the WTC were provided with wet-pipe sprinkler systems. New tenants normally required a new sprinkler system. For renovations of existing spaces, modifications to the existing system would normally need to comply with any new partition configuration.

Sprinkler work was required to be designed to comply with the requirements of the Building Code of the City of New York (BCNYC), National Fire Protection Association (NFPA) 13 and the PANYNJ design guides. In areas requiring specialized sprinkler systems, additional applicable standards as referenced in NFPA 13 were required to be used for design, including but not limited to the following NFPA 15, 16, 231, and 231C.

Sprinkler systems were required to be hydraulically designed. A pipe schedule design was only permitted for minor renovations that did not change the number of heads, and where only a few existing sprinkler heads required relocation.

Preaction Systems

Only a single zone detecting system was required to be used. Actuation of the fire detection system was required to open the preaction valve permitting water to flow into the sprinkler system piping. Sprinkler pipe sizing was required to be hydraulically calculated.

Preaction systems may have been required when wet-pipe sprinkler systems were not provided in computer rooms to protect the areas above the raised floor. As an alternative, a total flooding, clean agent fire extinguishing system was permitted. Areas under raised floors, where wiring was installed in raceways and combustibles are limited, only required smoke detector protection. If the amount of combustibles was extensive, and/or the cabling was not in raceways, these areas were required to be protected by a carbon dioxide system or an approved total flooding, clean agent system.

Fire Standpipe Systems

In WTC 1 and WTC 2, three fire standpipe risers supplied water to the hose stations on Floors 1 through 110. Risers FS-F1, FS-F2 and FS-F3 were located in Stairway B (Stairway 3), C (Stairway 2), and A (Stairway 1), respectively. Riser FS-F1 supplied water to all hose racks in Stairway B and also to all auxiliary hose cabinets in the corridors and tenant areas.

In WTC 1 and WTC 2, tenant auxiliary standpipe systems were only permitted to be connected to the existing capped outlets provided at fire standpipe riser FS-F1 located in Stairway B.

Clean Agent Fire Extinguishing Systems

New installations of gas-fired extinguishing systems were permitted in the WTC where the systems were approved by New York City.

Inspection, testing and maintenance of automatic gas systems was required to be performed by competent contractors. Recorded results were required to be submitted to the WTC Fire Safety Coordinator.

Inspection, testing and maintenance was required to conform to the recommended routines outlined in NFPA 2001, the BCNYC, the New York City Fire Department (FDNY) Directive reference and the manufacturer's maintenance and service manuals.

A separate duct purge system (minimum of 6 air changes per hour of exhaust rate) was required to exhaust the discharging gas to the outdoors. The exhaust duct was required to be arranged so no gas was allowed to infiltrate into other spaces.

Complete contract drawings, specifications and testing procedures were required to be submitted to the Port Authority for review with the Tenant Alteration Application.

Halon Fire Extinguishing Systems

New halon fire extinguishing systems were not permitted to be installed in the WTC.

When an existing halon system was to be abandoned, the halon storage containers were to be carefully removed so that halon would not be discharged. Containers were required to be returned for recycling, or recovery of the agent when no longer needed, to comply with NFPA 12A, Sec. 2-1.4.2 (1992 Edition).

If a tenant decided to keep an existing halon fire protection system, the following tasks were required to be performed:

1. Inspection, testing and maintenance of automatic halon systems were required to be performed by competent contractors. Recorded results were required to be submitted to the WTC Fire Safety Coordinator.

2. Inspection, testing and maintenance was required to conform to the recommended routine outlined in NFPA 12A, FDNY Directives (dated October 22, 1990) and the manufacturer's maintenance and service manuals.

3. A complete testing specification was required to be submitted to the Port Authority for review.

Portable Fire Extinguishers

Portable fire extinguishers were required to be provided for all spaces in accordance with the FDNY Directive, Rules for Portable Fire Appliances (dated September 17, 1980) and Section 27-4009 of the New York City Fire Prevention Code (dated July 1, 1988).

4.3 FIRE ALARM

Requirements for fire alarm systems appear in the Electrical Design Guidelines, Specifications and Standard Details for Electrical, Communications and Fire Alarm and in the Mandated Fire Alarm Guidelines for the WTC Base Building Fire Alarm System Design, Construction, Maintenance and Technical Support Services.

The Electrical Design Guidelines provided limited criteria for HVAC systems and the requirements for smoke detection systems.

The Mandated Fire Alarm Guidelines (issued subsequent to the Electrical Design Guidelines) were intended as a resource to the fire alarm design engineer tasked with interfacing to the WTC Base Building Fire Alarm System. The Fire Alarm System Design Guideline was applicable to the WTC Class E Base Building Fire Alarm Systems installed in WTC 1 and WTC 2 after the 1993 bombing.

The Fire Alarm System Design Guideline describes the backbone system architecture, distribution of terminal strip cabinets, ALD terminal cabinets, riser/one-line diagrams, fire detection and interface devices, visual notification appliances (strobes), audible notification appliances (speakers), wiring and acceptance test procedures.

4.4 FIREPROOFING

The only reference in the Architectural and Structural Design Guidelines for fireproofing is an item under the heading Light Weight Ceiling Support System for Floors w/Double Truss. The item states: "Removal of fireproofing shall be kept to a minimum and shall be replaced by the contractor as directed by the Port Authority."

4.5 EGRESS

The Architectural and Structural Design Guidelines required an egress analysis to be a part of all submissions in which the proposed work affects the movement of people through the space. The analysis was required to include the following minimum information:

- Construction Classification/Occupancy Classification
  - Generally office space and related spaces shall be designed to meet the requirements of Occupancy Group E classification and Construction Class I-B, in accordance with the latest edition of the BCNYC.
- Entrance and Egress
  - All exit doors and their sizes to be used to exit any space must be indicated on the drawing, as well as the allowed occupant load per exit width in accordance with the BCNYC.
- Travel Distances
  - Travel distances to primary and secondary exits must be indicated following the path of travel through each space.
- Occupant Load
  - The office floors have been designed to sustain a live load, including partitions, which shall not be exceeded. In areas where there is a concentration of files, storage, or heavy

equipment, verification of the structural integrity of the floor system in these areas is required.

4.6 ELEVATORS AND HOISTWAYS

The Architectural and Structural Design Guidelines required all core walls to have a 2 h fire rating as required by the BCNYC. Since the elevators and hoistways were located in the core areas of WTC 1 and WTC 2, the requirement for 2 h fire ratings would have applied to the elevators and hoistways.

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Chapter 5
OPERATION AND MAINTENANCE MANUALS

The Maintenance Methods section of the Maintenance Engineering Design Division, Engineering Department of Port Authority of New York and New Jersey (PANYNJ or Port Authority), established Operation and Maintenance Manuals for various systems throughout the World Trade Center (WTC). The instructions and recommendations of the manuals were created to aid and guide WTC personnel who operated and maintained the various systems in the WTC. There are 34 manuals each with a different publication date most of which were finalized in the 1980s. Because not all of the manuals are applicable to the purpose of this report, only those portions of the manuals associated with the fire protection and fire alarm systems will be summarized.

The inspection and maintenance procedures of the various building systems were outlined on Maintenance Procedure Cards (MPCs). The work to be done and the associated intervals are outlined in the following sections.

5.1 FIRE SUPPRESSION

Instruction Manuals #13 (1981), #18 (1987), and #23 (1986) establish, among other things, inspection and maintenance procedures for the multiple fire sprinkler, standpipe, and special hazard systems located throughout the WTC. The fire sprinkler inspection and maintenance procedures are outlined on MPC numbers F-2H, M-86, M-137 and E-8. The procedures are as follows:

MPC F-2H

Work to be Done: Inspect and test sprinkler flow alarm system.

Frequency: 5 times per year. (Drain valves and inspector's test valves only)

Annually. (Main control valves)

Description:

1. A visual inspection should be made to determine that:
    a. Sprinklers are not painted, corroded, or physically damaged.
    b. High temperature sprinklers are used where excess ceiling temperatures exist. (Be alert to newly installed heat producing devices.)
    c. A supply of extra sprinklers is available. (Note special type used in refrigerated spaces.)
    d. There is no obstruction to sprinkler water distribution by high-piled material or partitions. (At least 18 in. of clearance is required; 36 in. if sprinklers are the spray type and stored material consists of large, closely packed piles of cases, bales, or cartons.)

2. If applicable, operate main sprinkler control valves and ensure reception of tamper switch alarm operation at the Police Security Desk. (Annually.)

3. Return control valves to open position and test all sprinkler flow alarms with actual flow by operating the drain valve or the inspector's test valve.

4. Ensure reception of a flow alarm at the Police Security Desk and local annunciator panel (if applicable) within specified time limit.

5. Ensure reception of main supply flow alarm on the annunciator panel in the control room on Level B4.

6. Check for proper shutdown of all interconnected fans.

7. Return system and interlocked fans to operating conditions.

8. Report unusual conditions to appropriate authority verbally and in writing.

9. Record inspection and testing of system in log.

MPC M-86

Work to be Done: Check for proper operation of the high and low water alarms on fire reserve tanks.

Frequency: Annually.

Description:

1. Make arrangements to have test witnessed by the Risk Management Division and the insurance carriers.

2. Coordinate test with the Electrical section's cleaning, inspecting, and testing.

3. Inform the WTC police of the test.

4. Install the sprinkler pump test manifold on the 6" sprinkler pump test connection located on the West Street wall of the Customs House. Note: When testing the pump on the 108th floor, open the test line to the sprinkler reserve tank on the 110th floor.

5. Secure the sprinkler pump on the other tower.

6. Start the pump and take the following readings with a closed discharge at rated capacity and at 150 percent capacity:

    a. Flow rate

    b. Discharge pressure

c. Suction pressure

d. Pump speed

7. Record all readings and findings in the maintenance history log.

8. Report all deficiencies verbally to the foreman and in writing on the routine work order.

MPC M-137

Work to be Done: Check high and low water alarms on fire reserve tanks.

Frequency: 5 times per year.

Description:

1. Fill tank until high water alarm is activated. Tanks should need only a few inches of additional water for alarm activation.

2. Drain tank until low water alarm is activated.

3. Refill tank to normal level.

MPC E-8

Work to be Done: Clean, inspect and test pump motor and associated controls.

Frequency: Annually.

Description:

1. Coordinate the cleaning, inspecting, and testing of the pump motor with the fire pump capacity test to be performed by the mechanical section.

2. Inform the WTC police of the pump shutdown.

3. De-energize motor and place an “Out of Service” tag on the motor starter.

4. Lockout and ground all feeders and equipment.

5. Clean housing and interior of control panel.

6. Replace defective contacts, if any, in pairs and return discarded contacts to the shop.

7. Tighten all electrical connections.

8. If possible, blow out or vacuum clean motor starter and rotor windings.

9. Report any evidence of corrosion and dampness to the foreman.

10. Reenergize motor.

11. Test run and take amprobe readings required by the mechanical test and compare them to the motor nameplate rating. Ratings should not be more than 90 percent of nameplate rating.

12. Check for unusual noise or vibration.

13. Inspect motor controller for overheating and check for defective contacts.

14. Check all aluminum current carrying connections with the infrared heat gun and note all temperatures above 120 °F.

15. Record all readings and findings in the maintenance history log.

16. Replace all defective indicator lamps.

17. Report all deficiencies verbally to the foreman and in writing on the routine work order.

Halon Systems

The inspection, maintenance and testing of the halon systems were performed by two outside contractors. One was responsible for the fire detection, warning and activation subsystems and the other was responsible for the halon extinguishing subsystem. The annual and semi-annual inspection procedures conformed to the recommended service routines required in National Fire Protection Association 12A and the listed manufacturer's maintenance and service manuals. The procedures were as follows:

Fire Detection, Warning and Activation Subsystems

The semiannual inspection of the fire detection, warning and activation subsystems include the following:

1. A visual inspection of the 88 ionization detector heads, and the removal of loose dust accumulation by gently tapping the detector head.

2. Activation of one detector in each of the 11 protected areas, resetting the system after each alarm, and checking for all required alarm signals.

3. Repetition of Step #2 on at least one detector with only battery power applied to the system.

4. A check of the supervisory circuit and associated signals by placing the system in a Trouble condition.

5. The taking of voltage reading, the checking of water levels, and the cleaning of cases of all system batteries.

6. A check of all system components for obvious physical damage.

7. The replacement of all burned out system lamps.

5.2 FIRE ALARM

Instruction Manual #23 establishes, among other things, inspection and maintenance procedures for the fire detection systems located throughout the WTC. The fire alarm inspection and maintenance procedures are outlined on MPC numbers E-10A, E-10B, E-23, E-24, E-25, E-26, E-32, E-36 and E-37. Instruction manual #12 also provides inspection and maintenance procedures for the Smoke Detection System on the Observation Deck of Tower B. The procedures are as follows:

MPC E-10A

Work to be Done: Clean, inspect, and test the ventilation smoke alarm system and controls.

Frequency: Annually.

Description:

1. Consult manufacturers' specifications for particular equipment requirements before performing any maintenance work.
2. Prior to testing, notify the Police Security Desk of the test and maintenance.
3. Shut power to control panel.
4. Clean and inspect control panel. Tighten connections. Check for unusual conditions.
5. Reenergize control panel.
6. Check supervisory AC circuit, supervisory DC circuit, and supervision of detector circuit.
7. Disconnect automatic extinguishing devices connected to the system (e.g., halon and carbon dioxide extinguishers).
8. Utilizing a sensitivity test set, test each detector and check for proper response at the control panel and computer center. Log readings.
9. Check that all detector identification labels are proper.
10. Check detector head screen for dust accumulation. If necessary, remove screen and brush clean.
11. The air holes in the air sampling tubes of the air duct detector should be cleaned as required to insure that the unit receives a proper air sample.
12. Test detector in both the static and dynamic conditions. Under dynamic test, check for proper operation of fan shutdown controls.

13. After completing the alarm tests, reconnect all automatic extinguishing equipment and notify proper authorities.

14. Report any deficiencies to the foreman verbally, and in writing on the routine work order.

MPC E-10B

Work to be Done: Clean, inspect and test interior return air and elevator lobby smoke alarm systems.

Frequency: Annually.

Description:

1. Notify the Police Security Desk of the test and maintenance.

2. Locate the smoke detector head and activate it using sensitivity tester. Record reading in log book and check for proper alarm indication at the computer terminal.

3. Remove detector head and check for proper indication at computer terminal.

4. Dust and wash detector head.

5. Replace detector head.

6. Using sensitivity tester, reactivate detector.

7. Reset the controls on panel box and make final check with computer terminal.

8. Report any deficiencies to foreman verbally and in writing on the routine work order.

MPC E-23

Work to be Done: Service public address system and fire station and intercom console (Executone).

Frequency: Annually.

Description:

1. Prior to testing, notify Police Security Desk and the New York City Fire Department (FDNY).

2. Remove module and replace with spare.

3. Clean contacts with chemicals and burnishing tools.

4. Adjust contact leaf pressure as required.

5. In odd-numbered years only, group relamp indicator lamps.

6. Replace spare module with service module. Restore to service and test.

7. Report any deficiencies to foreman verbally and in writing on the routine work order.

MPC E-24

Work to be Done: Service public address system amplifiers (Executone).

Frequency: Monthly.

Description:

1. Remove and clean the air intake filters.

2. Wipe and vacuum clean front blower enclosure.

3. Add 2 drops of non-detergent oil in each of the 2 oil cups per blower.

4. Remove panels in rear of enclosure. Disconnect blower unit. Wipe clean and vacuum rear of blower unit. Pay particular attention to the area of the air flow switch.

5. Wipe clean and vacuum amplifiers and housing.

6. Spot relamp defective indicator lamps on face of enclosure. Once each year, on the first pay period, group relamp.

7. Report any deficiencies to foreman verbally and in writing on the routine work order.

MPC E-25

Work to be Done: Test public address system amplifiers (Executone).

Frequency: Quarterly.

Description:

1. Test amplifiers with oscilloscope for proper wave shape and output level.

2. Make proper adjustments.

3. Report any deficiencies to foreman verbally and in writing on the routine work order.

MPC E-26

Work to be Done: Clean, inspect, and test the fire alarm signal boxes.

Frequency: Monthly.

Description:

1. Prior to testing, notify the Police Security Office.
2. Deactivate appropriate zone pull box.
3. Clean and lubricate as necessary.
4. Perform operational test. Trip electrically and check for proper operation and indication on fire station system console.

MPC E-32

Work to be Done: Test fire call boxes.

Frequency: Annually.

Description:

1. Prior to testing, notify the Police Security Office.
2. One man remains at the console while the other tests the local boxes.
3. The roving man should take extra break glass rods with him.
4. Turn the time to maximum on the zone you are working on, and pull the 110 V AC clock plug in back of the module. This will keep the rest of the system in auto mode while disabling the one module to be worked on. Note: If an alarm comes in from another box in the zone being tested, notify police to send an alarm to the FDNY.
5. At the fire call box, pay particular attention to the door latch for proper functioning. Lubricate if necessary.
6. Ensure smooth door swing.
7. Remove the break glass and check for the fire call at the console.
8. Check both channels A and B for clear voice communication from station to console.
9. Check for smooth plunger action on the microswitch and lubricate if needed.
10. Log location, date, and results of each test in equipment log.
11. Notify the Police Security Office when the test is completed. Note: Be sure to reinstall the clock plug and reset the timer before leaving.
12. Notify the system foreman of any problems.

MPC E-36

Work to be Done: Service facility recording unit.

Frequency: Semiannually.

Description:

1. Notify the Police Security Desk that you are removing recording unit from console.
2. Disconnect all connections to recorder.
3. Remove recorder from console.
4. Maintenance on unit:
    a. Clean out dust and dirt.
    b. Lubricate moving parts.
    c. Make adjustments to linkages if needed.
    d. Clean and demagnetize recording heads.
    e. Check operation of motors and solenoids.
    f. Check condition of drive belts, replace if necessary.
5. Replace recorder in console.
6. Restore all wiring and test for proper operation.

MPC E-37

Work to be Done: Perform operational check on duct speaker amplifiers.

Frequency: Annually.

Description:

1. Disconnect 70 V input signal from building base amplifiers (TB-2-2A and 3).
2. Remove amplifier power plug from 110 V outlet.
3. Connect 70 V input from test unit to TB-2-2A and 3.
4. Disconnect plug assembly for duct speakers from P-3013 amplifier (TB-1).
5. Install test load plug to amplifier (TB-1). (20 V transformers (4), 100 OHM resistor.)
6. Hook up jumper leads to existing 24 V line (TB-1). Positive to #7, negative to #7A.

7. Replace 110 V plug in outlet.

8. Using multimeter, adjust signal generator for 1 V, 1000 cycles into 200 W test amplifier. This will provide 70 V input for P-3013 amplifier.

9. Turn on test amp.

10. Leave all potentiometer settings in initial position. Make test to determine standing output voltages for amplifiers and speaker input. Record this data.

11. Attach mulitmeter to #1 amplifier output.

    a. Adjust #1 sensitivity control to 1.5 V.
    b. Adjust #1 volume control until approximately 20 V are attained.
    c. Follow above procedure for remaining amplifier output adjustments.
    d. Recheck all outputs, 1 through 4. Readjust where necessary to achieve 20 V.
    e. Attach test speaker for audio output from each speaker transformer.

12. Remove test equipment, restore to operation.

13. Check communications console for proper supervision.

Smoke Detection System for Observation Deck

The smoke detection system for the observation deck of WTC 2 is to be annually inspected, as a whole, in the following manner:

Fire Damper and Fire Door Bypass

Before carrying out any servicing and testing, perform the following:

1. Bypass the fire dampers by placing the Fire Damper Bypass Switch in the ON position.

2. Bypass the rollup fire doors by placing the Rollup Fire Door Bypass Switch in the ON position.

Control Panels

Service the control panels annually as described below:

1. Disconnect power to the control panels.

2. Clean and inspect the control panels. Tighten connections. Check for unusual conditions.

3. Reenergize the control panels.

Supervisory Circuits

1. Check the supervisory circuit of the AC power supply to the control panels as follows:

   a. Disconnect power supply to the panels.

   b. Check for proper trouble alarm indication at the Computer-Multiplex Console in the Security Room.

2. Check the supervisory circuit of the DC power supply to the smoke detectors and alarm and trouble bells by disconnecting the power supply to the smoke detectors and smoke alarm and trouble bells.

3. Check for trouble alarm indication at the Computer-Multiplex Console in the Security Room.

Manual Fire Alarm Stations

Check the electrical and mechanical functioning of each station as follows:

1. Operate the station.

   Note: If the station cannot be operated, there is a mechanical problem and it should be corrected.

2. Check for proper alarm indication at the Smoke Detection Control Panel on floor 107. Note: If the station is mechanically sound, the electrical circuit is healthy, and there is no proper alarm indication at the Smoke Detection Control Panel on floor 107, there is a problem with the electrical contact in the manual station and it should be corrected.

3. Check for proper smoke alarm indication at the Computer-Multiplex Console in the Security Room.

Ceiling Smoke Detectors

For each Ceiling Smoke Detector, perform the following tests annually and record results.

1. Locate the smoke detector and remove the detector head. Check for proper alarm indication at the Computer-Multiplex Console after the head is removed. Replace the detector head.

2. Activate the detector using a sensitivity tester[1] and record the reading in the log book. Check for proper alarm indication at the Computer-Multiplex Console in the Security Room.

3. Remove the detector head and clean it if necessary. Check for proper alarm indication at the Computer-Multiplex Console. Replace the detector head.

[1] The sensitivity tester referenced is Model NKT-24, Products of Combustion Detector Tester. The instruction manual is provided in Appendix D of Manual #12

4. Activate the detector using a sensitivity tester and record the second reading in the log book.

5. Check for the proper alarm indication at the Computer-Multiplex Console in the Security Room.

Duct Smoke Detectors

For each duct smoke detector, perform the following tests annually:

1. Clean the air sampling tubes of the detector, to insure that the unit receives a proper air sample.

2. Activate the detector using a sensitivity tester when the fan is not running (Static Condition) and record the reading in the log book. Check for proper alarm indication at the Computer-Multiplex Console.

3. Activate the detector using a sensitivity tester when the fan is running (Dynamic Condition) and record the reading in the log book. Measure the air velocity across the air sampling tubes and record it in the log book. Check for proper operation of the fan shutdown controls when the fan is running. Check for proper alarm indication at the Computer-Multiplex Console.

After completing the servicing and testing, perform the following:

1. Place the Fire Damper Bypass Switch in the OFF position. Now the fire dampers are in the Smoke Detection System.

2. Place the Rollup Fire Door Bypass Switch in the OFF position. Now the fire doors are in the Smoke Detection System.

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Chapter 6
PORT AUTHORITY FACILITY CONDITION SURVEY PROGRAM

Various reports from the 1990s for the Port Authority Facility Condition Survey Program have been located. The precise guidelines for these programs are unknown; however, extracting from the introductions and executive summaries of the available reports reveals some of the procedures for inspecting building features. The program focuses more toward architectural and structural aspects, although fire protection features are mentioned.

6.1 GENERAL

The Port Authority of New York and New Jersey contracted engineering firms to perform detailed inspections of building conditions. Inspection procedures varied by task. Visual inspections, material sampling, reviewing maintenance records, and walk-through inspections were performed. Photographs were taken and reports were generated with recommendations and, at times, guidelines for repair/replacement.

6.2 FIREPROOFING

The World Trade Center (WTC) Tower "B" report (PANYNJ 1990) includes inspection procedures relating to the fireproofing removal. Inspections were performed by removing the fireproofing from the steel floor framing and examining it for delamination and underlying corrosion. The fireproofing was replaced at the conclusion of the inspection by the WTC Department's structural contractor. Roughly 4 percent of the floor framing trusses and 3 percent of the exterior column spandrel plate splices were inspected on designated office area floors determined before the inspection (30 floors total). All four two-story Mechanical Equipment Rooms and selected core columns and elevator shafts were also inspected. The fireproofing was replaced after the inspections. No guidelines for repair were given.

The WTC Tower A report (PANYNJ 1991) followed very similar procedures as Tower B.

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Chapter 7
STRUCTURAL INTEGRITY TESTING AND INSPECTION PROGRAM

In March 1986, the Infrastructure Engineering Design Division, Engineering Department of the Port Authority of New York and New Jersey (PANYNJ or Port Authority) produced *Standards for Structural Integrity Inspection of the World Trade Center Towers A and B*. These standards, created by Leslie E. Roberson Associates (LERA), were designed to assist PANYNJ in the evaluation of the on-going structural integrity of World Trade Center (WTC) 1 and WTC 2. The bulk of this program will be addressed in other structural reports of Project 1. However, there is some information that is valuable to the purpose of this section.

As LERA performed Structural Integrity Inspections, reports were generated with recommendations and procedures for enhancing and repairing damaged materials. Included in some reports were procedures for repairing fireproofing. The following section summarizes the fireproofing repair procedures.

7.1 FIREPROOFING

Appendix D of Structural Integrity Inspection reports PII33903 and PII73902 established procedures for repairing spray- and trowel-applied fireproofing as follows:

Where practical, identify brand and type of fireproofing initially used (largely CAFCO BLAZE-SHIELD by Isolatek and Grace Monokote in WTC 1 and WTC 2).

As recommended by Underwriters Laboratories, Inc. (UL), repair "in kind."

- Where Isolatek fireproofing products are identified:
  - If area is less than 3 ft^2, prepare surfaces and trowel on CAFCO FIBER-PATCH (by Isolatek) or equivalent per manufacturer's specification.
  - For areas greater than 3 ft^2, one of the following procedures may be used:
    a. Prepare surfaces and spray on new BLAZE-SHIELD (by Isolatek) or equivalent per manufacturer's specifications; or
    b. Patch with CAFCO FIBER-PATCH (Type P) according to the following: "When the area to be patched is within 1 in. of the flange tip of the steel section, additional material would have to be removed prior to the application of the patching material to insure a proper key. The material to be removed would incorporate the material on the inner face of the flange up to the interface of the material on the web, the flange tips, and at least ½ the width of the outer flange face."[1]

[1] UL letter dated January 20, 1997.

- Where Grace fireproofing products are identified:
  - If area is less than 1 ft^2, prepare surfaces and trowel patch fireproofing with Monokote Z-106 or Monokote Z-146 (by Grace) or equivalent per manufacturer's specifications.
  - For areas greater than 1 ft^2, one of the following procedures may be used:
    a. Prepare surfaces and spray applied fireproofing with Monokote Z-106 or Monokote Z-146 (by Grace) or equivalent per manufacturer's specifications; or
    b. Prepare surfaces, "the Type Z-106 spray applied fire resistive material shall be mixed and sprayed to the appropriate density into a suitable container, then troweled at the required thickness to beams and columns, which have been wrapped following the contour with minimum 1.7 lb/yd^2 expanded metal lath. It should be understood that the thickness shall be measured to the face of the lath."[2] Key new material into the material surrounding the repair in accordance with manufacturer's recommendations. The integrity of the surrounding material is not to be impaired.

The thickness of repair material shall provide the same fire rating as material initially used.

[2] UL letter dated July 24, 1997.

Chapter 8
TENANTS MANUAL

The *World Trade Center Tenants Manual* was developed in 1984 to provide useful information to World Trade Center (WTC) tenants including, among other things, functions of the Operations Division, tenant alteration procedures, fire safety information, and rules and regulations.

8.1 GENERAL

The Operations Division was capable of providing an array of services to the tenants of WTC through the Structural, Tenant Services, Operations, Mechanical, and Electrical sections. Tenants desiring to make alterations could hire the Operations Division to perform alterations without having to receive approval from the WTC Planning Division or hire an outside contractor and go through the review process of the WTC Planning Division.

A Design Guide within the WTC Tenant Manual contains basic information for the tenant's architect/engineer that would be designing the tenant space. Within the Design Guide, the Port Authority of New York and New Jersey (Port Authority) committed to provide the tenant's architect/engineer with the necessary WTC drawings and building standard information in the possession of the Port Authority. If the alteration involved other than building standard requirements, the tenant was directed to work with one or more of the WTC consultant engineering firms listed in Table 8–1 below. If the required information could not be provided from the consultants, additional information would be supplied from the WTC Planning Representative. Also, if the need arose to alter fire protection features, the fire protection drawings had to be reviewed and approved by the Port Authority and Employers Group of Insurance Companies.

Table 8–1. WTC consultants, as of 1984.

Mechanical	Jaros, Baum & Bolles
Electrical and Structural	Joseph R. Loring & Associates
Structural	Skilling, Helle, Christiansen, & Robertson

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Chapter 9
OTHER DOCUMENTS

There are many other documents that contain procedures for modifying fire protection systems. As part of each tenant alteration, specifications were created to establish minimum requirements as required by codes. There were literally hundreds of tenant alterations performed in World Trade Center (WTC) 1, 2, and 7. Summaries of the alterations on the affected floors of WTC 1 and WTC 2 and all of the alterations in WTC 7 are summarized in a separate section and will not be discussed here. However, an important specification regarding the installation of the fireproofing material is summarized below. These specifications were not directly established as part of the Port Authority of New York and New Jersey (PANYNJ) guidelines, but were used in the upgrading/enhancement of the WTC buildings.

9.1 FIREPROOFING

As part of an effort to replace fireproofing for column and beam surfaces exposed within the elevator shafts of WTC 1, specifications for this work were created under Division 7 – Fireproofing. The specification is separated into two sections: 7A – Spray-on Replacement Fireproofing, and 7B – Testing and Inspection of Spray-on Fireproofing (PANYNJ 1993c, 1993d). Highlights of the specification include:

Submittals

The manufacturer's instructions for proper application were required to be submitted. Independent laboratory test results with the indicated performance criteria were also required to be submitted.

Performance Criteria

The fireproofing thickness was intended to provide for a minimum fire resistance rating of 2 h for beams (restrained) and 3 h for columns. The specified product was W.R. Grace and Co. Type 106. Other products could be used if approved by the Engineer.

- Bond strength per ASTM International (ASTM) E736 – Standard Test Method for Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural members.
- Compressive strength per ASTM E761 – Standard Test Method for Compressive Strength of Sprayed Fire-Resistive Materials Applied to Structural Members.
- Air erosion per ASTM E859 – Standard Test Method for Air Erosion of Sprayed Fire-Resistive Materials Applied to Structural Members.
- Corrosion resistance per ASTM E937 – Standard Test Method for Corrosion of Sprayed Fire-Resistive Materials Applied to Structural Members

- Minimum density per ASTM E605 – Standard Test Methods for Thickness and Density of Sprayed Fire-Resistive Materials Applied to Structural Members.

Testing and Inspection

All of the tests and inspections were performed by the PANYNJ Materials Division, but the responsibility of the approval was left with the Engineer. The tests and inspections were outlined as follows:

1. Inspect conditions of substrate daily, before application, for proper preparation of steel. Steel shall be free of dirt, grease, release agents, loose scale, extensive rust and loose paint (primer) which will prevent adhesion. Report areas not in compliance immediately for remedial action.

2. Test replacement fireproofing for density and thickness in accordance with ASTM E736.

3. Inspect and note whether or not corrective measures, including patching, have been properly carried out in all areas in need of re-spraying and patching, including areas where sprayed-on fire protection has been deliberately removed for testing, or has been damaged in any way.

4. Inspect replacement fireproofing for cracks. Replacement material shall not show any visual sign of cracking upon drying and curing.

5. All testing shall be based upon random samples and shall be the responsibility of the PANYNJ Materials Division.

Chapter 10
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Section II

Post-Construction Fire Protection and Life Safety Modifications to the World Trade Center Towers

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EXECUTIVE SUMMARY

As part of the analysis of building and fire codes and standards of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation, this report supports the effort to document and analyze the performance of the fire protection and life safety systems of WTC 1 and WTC 2. The performance of the fire protection and life safety systems is ultimately affected by the changes made to the systems. The purpose of this section is to identify the repairs and/or modifications made to the fire protection and life safety systems on the affected floors of WTC 1 and WTC 2. Various programs were established to accomplish the modifications to the fire protection and life safety systems. The Port Authority of New York and New Jersey (PANYNJ) installed the backbones of the systems and required devices in the public spaces. The building tenants would then modify/extend the systems into the leased spaces. The following is a list of programs in progress or completed as of September 11, 2001:

- *Corridor and tenant wall extension*. This program was intended to extend the walls to the underside of the floor slab above giving the tenant the option of compartmentalizing or sprinklering the leased space to meet code requirements.

- *Sprinkler and standpipe installation*. This program was initiated in the 1980s and was near completion in 2001. This program was initiated in response to Local Law 5.

- *Fire alarm system installation*. The fire alarm system was undergoing a major renovation at the time of the attacks. Soon after the 1993 bombing of the WTC, plans were initiated to install a new fire alarm system. Standpipe telephone jacks, smoke detectors, manual fire alarm pull boxes, loud speakers with voice communication capabilities, fire command stations, fire warden stations and strobes were installed throughout. For a more detailed description of the fire alarm system upgrade, refer to the NIST Investigation Project 4 reports.

- *Re-fireproofing*. This program was intended to provide the appropriate thickness of fireproofing materials to achieve a 2 h fire rating on the floors and 3 h on columns throughout the buildings.

- *Passenger elevator modernization*. This program was initiated because the equipment became obsolete. As part of the modernization project, firemen's recall functions were installed.

- *Freight elevator signage installation*. Appropriate signage was provided throughout the buildings as part of this program.

- *Emergency lighting and exit sign enhancement*. Emergency lights with battery packs were provided in stairs and elevators. The emergency lights were also connected to emergency circuits. Exit signs were upgraded with modern LED illuminated signs.

Other programs that were being developed but not yet implemented included:

- Correction of mechanical rooms exiting into the fire stairs.
- Identifying floors that have inadequate fire hose reach.
- Replacement of lobby carpeting not meeting the test requirements of the Building Code of the City of New York (BCNYC).
- Installation of fire stopping at duct/pipe penetrations.
- Installation of smoke dampers on the discharge side of all air-conditioning systems over 15,000 cfm.

Tenant alteration projects continuously modified the fire protection and life safety systems. As tenants moved in and out, new conditions (such as wall layouts and occupancy use) warranted a need for change. These changes within the tenant spaces mandated the need to modify the sprinkler system, fire alarm system, heating ventilating, and air conditioning system, emergency lighting and exit signs to fulfill PANYNJ and the BCNYC requirements. Tables 3–1 and 3–2 in Chapter 3 of this report list the tenant alterations performed on the affected floors of WTC 1 and WTC 2.

Chapter 11
INTRODUCTION

Over the life of the World Trade Center (WTC) 1 and WTC 2, enhancements to the fire protection and life safety systems were made. Tenant alterations, fires, revised building code provisions, and new technology all contributed to the reasons for enhancing the systems. Changes made to the fire protection and life safety systems ultimately affected the building performance. Thus, in order to analyze the performance of the buildings in response to the September 11, 2001, attacks, it is crucial to have the most up-to-date knowledge of the systems installed. The purpose of this section is to identify the repairs and/or modifications made to the fire protection and life safety systems on the affected floors of WTC 1 and WTC 2. The affected floors, for the purpose of this report, are the 94th through the 98th floors for WTC 1 and the 78th through the 84th floors for WTC 2.

As the building code provisions were updated, new tenants moved in and out, and technology advanced, the fire protection and life safety systems were modified. Modifications were accomplished through many short-term and long-term projects of varying magnitudes and objectives. Some modifications were the direct responsibility of the Port Authority of New York and New Jersey (PANYNJ) while other modifications were the responsibility of the tenant. The PANYNJ modified the common areas within the building (e.g., public corridors, stairways, utility closets, etc.) and installed the backbones of the fire protection and life safety systems. The building tenants, in turn, updated the leased spaces by modifying/extending the fire protection and life safety systems to accommodate the building code and mission continuity requirements within the tenant space. The base building modifications to the affected floors are summarized in Chapter 2, with tenant modifications of WTC 1 and WTC 2 summarized in Chapter 3.

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Chapter 12
BASE BUILDING MODIFICATIONS TO AFFECTED FLOORS

The Port Authority of New York and New Jersey (PANYNJ) and various consultants continuously evaluated the condition of the multiple fire protection and life safety systems throughout the World Trade Center (WTC) complex. Improvement programs were established to provide a basis for the preservation, repair and retrofit of the various systems. This chapter summarizes the base building fire protection and life safety programs developed for WTC 1 and WTC 2. Programs that were well under way or completed at the time of the September 11, 2001, attacks are listed in Sec. 2.1. Programs that were being developed or still in the design process are listed in Sec. 2.2.

12.1 MODIFICATION PROGRAMS IN PROGRESS OR COMPLETED AS OF SEPTEMBER 11, 2001

A corridor wall and tenant separation program was in place to extend the walls to the underside of the floor slab above to minimize smoke spread, meet code requirements and give tenants the choice of compartmentalizing or sprinklering the tenant space. The wall extension project was a long-term program that was incorporated in new tenant alterations. Tenants were reimbursed by the PANYNJ as the work was performed (PANYNJ 1999). The necessity to complete the wall extension program was in question because of the sprinklerization program that was later developed (Merritt and Harris 2000a, 2000b).

In the 1980s and in order to comply with Local Law 5, the complete sprinklerization of WTC 1 and WTC 2 was initiated. Exact details on how this retrofit process was accomplished have not been completely identified. Documentation indicates that the core area mail and storage rooms, the fire standpipe and drain risers were initially installed to provide future extension of the sprinkler system as tenants moved in and out (Appendix A). In 2000, it was reported that the office floors of WTC 1 and WTC 2 were fully sprinklered with the exception of the electrical and telephone closets, most toilet rooms, the main lobby and the B-6 Level Mechanical Equipment Room (MER). A standpipe riser with a fire hose rack on each floor was installed in each stairway (Merritt and Harris 2000). Various fire pumps and water tanks were installed throughout the buildings to supply the appropriate water demand. Further tenant modifications to the sprinkler system are listed in Chapters 3 and 4 of this report.

The base building fire alarm system was modified numerous times affecting various components of the system; see Table 12–1 for a listing of PANYNJ contracts. Permanent standpipe telephone jacks were installed and activated on each floor of all fire stairways (PANYNJ 1999). A program to install return air smoke detectors and return air smoke detector annunciation requirements was in place and scheduled to be completed by the end of 2000 (PANYNJ 1999). Upon completion of the return air smoke detector program, a program to comply with elevator lobby smoke detector requirements was to be initiated (PANYNJ 1999). Further reports indicate that elevator lobbies were installed with smoke detectors. Manual fire alarm boxes were installed on all floors so that travel distance to a fire alarm box was less than 200 ft (PANYNJ 1999). Loud speakers were installed in public corridors (PANYNJ 1999). The voice communication system was extended from the core corridors to the office areas. Fire command stations were installed in the lobbies of WTC 1 and WTC 2 (PANYNJ 1999). Soon after the 1993

bombing, plans were made to install a new Style 7 fire alarm system throughout the WTC complex. The new system was designed to completely replace the existing system using a three-phase process.

Table 12–1. Contracts involved with the fire alarm upgrades.

Contract	Description
WTC-499.18	Tower MER Sprinkler Installation and Modification to Smoke Detection System
WTC-857.090	WTC - Towers 1 and 2 Skylobbies Sprinklerization and Fire Alarm Upgrade
WTC-861.077	Fire Alarm System Device Upgrade Phase III
WTC-861.082	Fire Alarm System Phase III XL3 Conversion
WTC-861.089	Fire Command Center
WTC-861.101	Fire Alarm System Phase 3 Device Upgrade 1 and 2 WTC MER
WTC-861.171	Fire Alarm System Phase 3 4 WTC MER's, EMR's and Substations
WTC-861.174	Fire Alarm System Device Upgrade Phase III 2 WTC Contract #1
WTC-861.175	Fire Alarm System Device Upgrade Phase III 1 WTC Contract #2
WTC-861.176	Fire Alarm System Device Upgrade Phase III 1 WTC Contract #3
WTC-861.176 (SA#1)	Fire Alarm System Phase III Device Upgrade
WTC-861.177	Fire Alarm System Device Upgrade Phase III 1 WTC Contract #4
WTC-861.270	Fire Alarm System Device Upgrade Phase III 2 WTC Contract #1
WTC-861.271	Fire Alarm System Device Upgrade Phase III 2 WTC Contract #2
WTC-861.272	Fire Alarm System Device Upgrade Phase III 2 WTC Contract #3
WTC-861.273	Fire Alarm System Device Upgrade Phase III 2 WTC Contract #4
WTC-861.274	Fire Alarm System Device Upgrade Phase III 2 WTC Contract #5
WTC-861.474B	Fire Alarm System Subgrade Levels Backbone Modification
WTC-W2-987.107	Smoke Detection System Emergency Generator Room

Key: EMR, ???.

The program started in 1993 and was still being worked on in 2001 with phases one and two complete. By September 11, 2001, WTC 1 was approximately 85 percent complete and WTC 2 was approximately 80 percent complete, with an overall project completion of approximately 75 percent. The upgrade of the fire alarm system was estimated to cost $69 million dollars. It was estimated that 25 percent of the original fire alarm system was still in service at the time of the attack (PACO 2002). In addition to the base building fire alarm system, tenants installed or extended the fire alarm system within the tenant spaces as necessary. Further tenant modifications of the fire alarm system are given in Chapters 3 and 4 of this report. More specific details of the upgrade and final system capabilities are identified in reports for Project 4, Active Fire Alarm Systems, of the National Institute of Standards and Technology Investigation. A general list of system upgrades are as follows:

- The existing American Multiplex system was replaced with a decentralized system that included six independent fire alarm sub-systems. Each of the six sub-systems was linked to a Network Command Center located in the Fire Command Station at the lobby of each of four WTC buildings (WTC1, WTC 2, WTC 4, WTC 5) with backup centers throughout the WTC.

- Wall mounted strobes and ceiling mounted speakers were installed in all corridors, bathrooms, common areas and all occupied tenant spaces.

- Addressable area smoke detectors were installed in all base building electrical and telephone closets, mechanical rooms, elevator machine rooms and in elevator lobbies for elevator recall. Duct mounted smoke detectors and area detectors were installed in front of the return/supply air grills for fan shut down.

- Manual fire alarm boxes were installed next to each stairway and in the main exits in the main lobbies.

- All existing sprinkler tamper and flow switches were connected via interface modules.

- All tenant proprietary fire alarm panels were connected to the fire alarm system via interface modules to transmit an alarm or trouble.

- A floor warden station was installed on every floor to establish two-way communication between each floor and the Fire Command Station. A stairway standpipe fireline telephone jack was installed for the Fire Department.

An ongoing re-fireproofing program was under way to install an appropriate thickness to achieve a 2 h rating on floors as tenants vacated a space (PANYNJ 1999; DPV 2002; Merritt and Harris 2000a, 2000b). As of 2000, approximately 30 floors of WTC 1 and WTC 2 were completed (Merritt and Harris 2000a, 2000b).

In 2000, a program to modernize all passenger elevator cabs with new interior finishes, overlay controllers, the Americans with Disabilities Act features and firemen's recall was completed. Phase two of the modernization program included retrofitting door operators and installing new door re-opening devices. The project was initiated because equipment became obsolete. As of 2000, 126 elevators were completed, 8 in progress and 104 not yet modernized (Merritt and Harris 2000a, 2000b). Additionally, the Merritt and Harris reports indicate venting of the elevator shafts in WTC 1 and WTC 2 was accomplished through the elevator machine rooms due to the configuration of the elevators in the central core. This arrangement is not permitted by American Society for Mechanical Engineers A17.1 but was accepted by PANYNJ as the only viable solution (Merritt and Harris 2000a, 2000b).

In 1999, freight elevator signage was installed throughout WTC 1 and WTC 2. The enhancement was performed under the PANYNJ job number WPM-6424.

The emergency lighting and exit signs were upgraded subsequent to the 1993 bombing. The emergency lighting system was modified by providing fixtures with battery packs in the stairs and connecting the lights to emergency circuits. All elevators were provided with emergency lighting with 2 h battery packs with selected fixtures connected to emergency circuits. The initial exit signs, which were illuminated with fluorescent lamps, were replaced with modern LED illuminated exit signs. The program was accomplished from 1997 to 2000 (PACO 2002; Merritt and Harris 2000a, 2000b).

12.2 MODIFICATION PROGRAMS IN DEVELOPMENT

In addition to the modification programs mentioned in Sec. 2.1 above, many other modification programs were planned. The following is a list of programs that were in the process of implementation as of September 11, 2001:

- Correct the configuration that has mechanical rooms exiting into fire stairs (PANYNJ 1999).
- Identify floors that have inadequate fire hose reach (PANYNJ 1999).
- Replacement of the carpeting in lobbies which do not meet the test requirements of the Building Code of the City of New York (PANYNJ 1999).
- Installation of fire stopping at duct/pipe penetrations (PANYNJ 1999).
- Installation of smoke dampers in the discharge of all air-conditioning systems over 15,000 cfm (PANYNJ 1999).

Chapter 13
TENANT MODIFICATIONS TO AFFECTED FLOORS

Tenant alteration projects also modified the fire protection and life safety systems within World Trade Center (WTC) 1 and WTC 2. Tenant spaces were modified to accommodate new floor layouts as tenants moved in and out. New wall layouts, changed occupancy use, and mission continuity objectives in tenant spaces introduced different code requirements.

Generally speaking, the tenant alterations performed in WTC 1 and WTC 2 included typical business occupancy modifications to the primary fire protection and life safety systems. A typical office alteration included rearranging walls to accommodate the desired layout of the tenant while maintaining proper fire separations and divisions from other tenants within the building. Fire and/or smoke dampers were installed in the heating, ventilating, and air conditioning systems at penetrations of fire rated walls. The base building wet pipe sprinkler system was modified by the addition of sprinkler heads and branchlines in the tenant space, which was required by National Fire Protection Association (NFPA) 13 and the Building Code of the City of New York (BCNYC). Hydraulic calculations were performed to justify the pipe sizes of the branchlines as necessary. Documentation indicates that calculations were conducted back to the floor control valve assembly of each floor where system pressures were previously known. Fire alarm and voice communication systems were installed within each tenant space as required by NFPA 72 and the BCNYC. Each tenant fire alarm and voice communication system was designed to be connected to the base building system where signals could be reported at the Fire Command Station of each building. Providing exit and emergency lighting within the tenant space, which is required by the BCNYC, was also included in the tenant alteration project. All of the system modifications were submitted to the Port Authority of New York and New Jersey (PANYNJ) for approval or were approved using the self-certification process established by the PANYNJ. PANYNJ Tenant Construction Review Manuals were used for establishing minimum design criteria and design details.

Tables 13–1 and 13–2 list the tenant alterations that were performed on the affected floors of WTC 1 and WTC 2. Any variances from the typical office modification are noted.

13.1 WTC 1 TENANT ALTERATIONS ON AFFECTED FLOORS (78-84)

Table 13–1. Summary of WTC 1 tenant modifications within affected floors.

TAA#	Floor(s)	Location on floor	Year	Tenant	Systems Modified
W98-1199	94	North	1998	Guy Carpenter	Typical
W98-1197	94	South	1998	Marsh and McLennan	Typical
W-91093	94	Core	1991	Deloitte and Touche	Add sprinkler in electrical closet
W-4146	95	Southeast	1988	Sumitomo Bank, Ltd.	Typical
W-4183	95	Northwest	1988	Sumitomo Bank, Ltd.	Typical
W00-1135	95	North	2000	Marsh and McLennan	Typical, new pre-action sprinkler system
W98-1151	95–98	Entire floor	1998	PANYNJ	Demolition of floor, fire alarm system to remain operable, sprinklers to be removed
W98-1197	95–98	Entire floor	1998	Marsh and McLennan	Typical, new pre-action sprinkler systems and additional stairs
W-4112	97	North	1988	Deloitte Haskins and Sells	Typical
W-4412	97	Entire	1989	Deloitte Haskins and Sells	Demolition of floor, sprinkler and fire alarm system to remain operable
W-4417	97	Entire	1990	Deloitte Haskins and Sells	Typical

Key: TAA, Tenant Alteration Application.

13.2 WTC 2 TENANT ALTERATIONS ON AFFECTED FLOORS (94-98)

Table 13–2. Summary of WTC 2 tenant modifications within affected floors.

TAA#	Floor(s)	Location on floor	Year	Tenant	Systems Modified
W-4415	78	Unknown	1989	Fuji Bank	Typical
W97-2208	78	North	1997	Sky Markets	Egress analysis
W96-2192	78	Unknown	1997	First Commercial Bank	Typical
WX-0137	78	Core, Southwest	1998	PANYNJ	Typical
WC98-2133	78	Southeast	1998	Georgeson and Co., Inc.	Typical, including escalator to 77th floor
WPM-6417	78	Core	1999	Fuji Bank	Typical
W99-2146	78	Southeast	1999	Baseline	Typical
W01-1139	78	North	2001	Sky Markets	Partial demolition of floor, sprinklers to be removed
W99-2125	80	East	1999	Fuji Bank	Typical
W01-2149	80	Unknown	2001	Fuji Bank	Typical
W-4623	80, 81	Northeast, Southwest	1990, 1990	Fuji Bank	Typical
W97-2175	82	Southeast	1997	Fuji Bank	Typical
W97-2112	83	Unknown	1997	AON	Unknown
W99-2197	83	West	1999	IQ Financial Systems	Typical
W99-2185	83	Southeast	1999	The Chuo Trust and Banking Co.	Typical
W94-2117	84	West	1994	Euro Brokers	Typical

Key: TAA, Tenant Alteration Application.

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Chapter 14
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Appendix A
REPRODUCTION OF REPORT ON FIRE SAFETY OF THE WORLD TRADE CENTER

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building systems and access. In 1970, the Port Authority further cooperated with the Fire Department by making the 30 Church Street building available, immediately prior to its demolition, for the Fire Department and its consultant to conduct controlled fire tests and evaluate the principle of stair pressurization to provide safe egress from a fire floor. Partially, as a result of these actual fire test conditions of stair pressurization, requirements for such a pressurization system were included in one of the options of Local Law 5.

After the World Trade Center fire last spring, Dr. Ronan appointed a Commissioners' Fire Committee headed by Commissioner George Berlinger, and including Commissioners Axtell, Gilbert and Hellmuth. This committee directed Port Authority staff to thoroughly review all aspects of the World Trade Center fire and the life safety provisions of the structures, including the conforming of the complex to the provisions of Local Law 5. The latter provides for the selection of either a compartmentation option or a sprinkler option. The committee further retained an independent consultant to review the World Trade Center life safety provisions.

The consultant concluded that the existing structural fire retardants of the building are sufficient to make the probability of serious structural damage extremely remote and that the degree of vertical compartmentation provided sufficiently limits the spread of fire in the structures, but that the spread of smoke requires attention from a life safety standpoint.

The consultant further concluded that...

> "The results of these comparative analyses indicated that, in our opinion, either of the two fire protection

options provided for under Local Law 5 would provide a good level of occupant life safety within the World Trade Center complex, provided that whichever is selected is supplemented by certain additional measures."

The additional provisions recommended by the consultant over and above the compartmentation option are summarized as follows:

1) Sprinklering of all rooms in the central corridor area which could contribute excessive quantities of smoke to the corridor systems;
2) Doors which are normally kept open to the corridor system should be equipped with electro-magnetic "hold-open" devices which would be activated to close the doors;
3) Provide fail-safe automatic door closers, arranged to close upon activation by smoke detectors for the overhead rolling fire doors separating the below grade truck dock from the elevator lobby;
4) Perform an investigation to determine the optimum mode of operation of the building air-conditioning system to remove smoke from the central core compartments without contaminating adjacent areas.

The additional provisions recommended by the consultant over and above the sprinkler option are items 2, 3 and 4 above and the following.

Provide automatic smoke detection in immediate vicinity of elevators at each floor level.

In a separate report, prepared by the New York Board of

[redacted]

"In the overall, these towers may be considered as

[redacted]

following steps in compliance with Local Law 5 and the additional items over and above Local Law 5 requirements as listed below:

A) Compartmentation option of Local Law 5 which includes the following major steps:

1) Expansion of fire alarm and communication system.

2) The installation of smoke detectors in elevator lobbies and additional smoke detectors at air return inlets.

3) Compartmentation of spaces into 7500 square foot areas.

4) Proceed with stair pressurization design and prototype pressurization testing in the structure for World Trade Center Towers.

- E -

B) Additional items over and above Local Law 5:

1) The implementation of all the recommendations from the consultant and staff.

2) Sprinkler all janitor closets, mail rooms, file rooms, storage rooms, etc. in the central core of each floor of each tower and make provisions for extension of sprinkler system to any areas of such usage requiring same as occupancy may change.

PART I

Report on Fire of February 13, 1975

Introduction

After the World Trade Center fire last spring, Dr. Ronan appointed a Commissioners' Fire Committee which consisted of Commissioners Berlinger, Axtell, Gilbert and Hellmuth. Commissioner Berlinger was appointed chairman of the committee. This committee directed Port Authority staff to thoroughly investigate and review the extent of the fire and smoke damage, the origin of the fire, the functioning of the building systems for prevention, detection and fighting of fires, and safety procedures. The Port Authority staff members appointed to carry out this assignment were Messrs. R. M. Monti, Chief Engineer; R. F. Abrahams, Chief Contract Division, Law; J. DeMarinis, Manager, Risk Management Division. The Commissioners' Fire Committee also retained the services of an independent consultant to review all safety aspects of World Trade Center operations regarding fire protection.

Development of the Fire

The fire started in the office of R. J. Saunders, Inc., Suite no. 1119. It extended north to two smaller adjacent offices, where it was stopped in that direction and extended to the southwest corner of the Saunders office, where it was stopped in that direction. A telephone closet containing vertical telephone cables, and other equipment is located adjacent to the Saunders mail area. The closet had a door with ventilation

Cause of Fire - Suspected Arson

In July 1975 a Temco Maintenance Company employee was charged in an indictment with setting the February 13, 1975 fire as well as five subsequent World Trade Center fires.

Extent of Fire Damage

The fire damage occurred mainly on the 11th floor, in the southeast quadrant. Whatever fire damage occurred on other floors was generally limited to the telephone closet in the southeast quadrant of floors 9 through 14 and a small portion of spaces immediately adjacent to the telephone closets.

Smoke damage occurred in varying degrees in the adjoining sections of the 11th floor; elsewhere, the significant smoke damage occurred on the 10th, 12th, 13th and 14th floors. Smoke damage on floors 15 through 23 was generally limited to the area of the telephone closet in the southeast quadrant and a small portion of the tenant spaces immediately adjacent, in decreasing degrees.

Existing Building System Evaluation -
World Trade Center Building System - Building Code

For further information there follows a description of the World Trade Center building systems for fire protection and extinguishment, together with an account of the Port Authority's conformance to the standards established by the New York City Building Code, including the amendments known as Local Law 5/73, even though the State and its agencies, such as the Port Authority, are not subject to City building codes.

References are made in various places to the 1968 building code, since that code would have applied to construction generally at the time the World Trade Center was built. A separate discussion addresses itself to the amendments of 1973, i.e. Local Law No. 5. Following is a description of the existing systems at the World Trade Center:

Air Distribution Systems

The Trade Center air distribution systems, in addition to conforming to all the 1968 NYC Building Code requirements, also possess an additional mode of operation which can be utilized to assist in controlling smoke from a fire. In this mode the return air shaft and fan systems are used to exhaust from the office spaces to the exterior of the building. The core system is also operated to provide outside air to the corridors.*

Fire Standpipe System

The standpipe system consists of manually activated fire pumps rated at 750 GPM each located at the Service Level, 7th Floor, 41st Floor and 75th Floor. In addition, there

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* There are four mechanical equipment rooms serving each tower. These equipment rooms, which contain the air handling systems, are located

are 5,000 gal. water storage tanks located on the 20th Floor, 41st Floor, 75th Floor and roof. There are also a minimum of three fire hose racks on each floor capable of reaching every part of that floor. The standpipe system conforms to the 1968 Building Code. Initially, during the fighting of the fire, Tower A pump experienced some difficulty with the speed control panel. Tower B pump, which was designed to be operable also for Tower A, was then used. The Tower A pump was returned to use during the fire fighting, without difficulty. The standpipe system functioned to the complete satisfaction of the Fire Department throughout.

Smoke Detectors

Smoke detectors were installed in each return air fan discharge duct and each supply unit. Upon actuation any one of these detectors will shut down all the ventilation fans within the respective quadrant of the mechanical room and initiate a print-out and visual and audible alarms in the central control station. This installation is in conformance with the 1968 Building Code.

In addition to the smoke detectors previously noted, under a contract prepared prior to enactment of Local Law 5, detectors with supervised circuits have been installed at 4 locations on each floor of the Tower Buildings. These detectors are located above the hung ceiling directly in front of a return air duct intake and indicate an alarm condition, by floor, at the Port Authority Police Desk. In the building zone in which the fire occurred, detectors were installed and operational on Floors 9 through 19. These detectors initiated a print-out at the police desk.

Elevator Control

All passenger elevator cars are capable of being recalled to their respective lobbies. This control over-rides all individual floor hall calls, prevents heat from calling a car to a "fire floor" and makes the car available for manual operation by building personnel and the Fire Department.

This is in excess of the requirements of the 1968 Code, which required only one elevator capable of serving each floor equipped for emergency return and Fire Department Service.

Fire Alarm System

On each floor of each of the World Trade Center buildings, at a central corridor location, there was a fire alarm emergency telephone which connected with a control center next to the Police Desk on the lower level of Tower A. (In addition, the Port Authority has applied on telephones in its own offices, and has distributed to tenants for their application on their telephones, a conspicuous red label giving the telephone number of the Police Desk to call in case of emergency.) An interior fire alarm system including voice communication has been installed on each floor in the core corridor. Incoming fire calls to the control center illuminate the indicating lamp of a particular fire station and sound an audible signal. In addition, an emergency public address system provides communication from the control center to all locations equipped with loudspeakers, as selected by the control center operator. The system also can transmit, through two individual microphones, different messages to selected loudspeaker areas. It can also receive communications from the elevator starter panels. Pre-recorded announcements can be transmitted through this system and announcements originating from the elevator starter panels can be transmitted through this console to selected loudspeakers. Fire alarm warble tones can be transmitted to any floor or floors from one of these microphones.

Requirements of Local Law No. 5/73

The fire safety amendments to the New York City Building Code embodied in Local Law 5 adopted in 1973 prescribe various measures to be complied with by various dates. The Port Authority has complied with those for which compliance dates have already occurred, and in fact had incorporated in the World Trade Center design a number of such measures before they were adopted under Local Law 5. Some examples are as follows.*

Interior fire alarm system, including voice communication:

The World Trade Center was designed and constructed with a fire alarm and voice communication system in the corridors before any such system was required by code. Local Law 5 required such a system to be installed, including its extension into office spaces as well as stairways. A contract has been prepared and awarded to extend the system into the office spaces and stairways.

Automatic "homing" of elevators, and elevator in readiness:

Manual controls presently installed in the World Trade Center permit recall of all elevators to their home floor, overriding any manual or heat activation of call buttons, where they can be placed under the command of the Fire Department for fire fighting operations. This too was beyond the requirements of the 1968 code. Local Law 5 now requires automatic homing of elevators when

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* While combustibility of furnishings is not dealt with in Local Law 5 or other parts of the New York City Building Code, the Port Authority addressed itself to this problem in planning the World Trade Center and after extensive study adopted and applied standards rigidly limiting its own furnishings to a low rate of flammability. A copy of the Port Authority's flammability standards was communicated to tenants, pointing out the advisability of their use.

a smoke detector, to be installed in the elevator lobby of each floor, is activated. Such additional smoke detectors and automatic activation will be installed at the World Trade Center.

Sprinklers or Compartmentation and Other Measures

Under Local Law 5, owners of buildings (existing and future) of a class in which the World Trade Center would be included, are given the option of sprinklering throughout or of installing certain measures such as compartmentation of each floor into maximum areas of 7,500 square feet each separated by fire rated partitions, as well as smoke detectors as above described and pressurization of stairwells.

In certain types of locations, such as below grade areas and restaurants, and other commercial spaces, sprinklering is required without allowance for an option, and in those locations the World Trade Center as originally constructed included sprinklers.

Fire Safety Plan

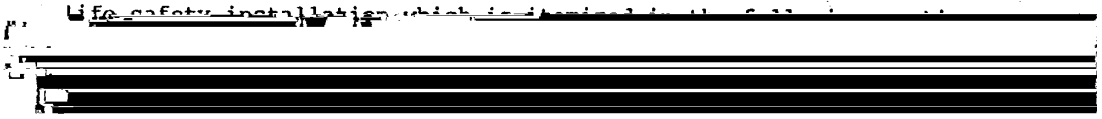
Local Law 5 calls for a plan of regular fire drills and evacuation procedures, approved by the City, under the supervision and control of a building fire safety director and one or more deputies. The Port Authority's plan exceeds these requirements, and the New York Board of Fire Underwriters, after investigating the February 13th fire, observed: "The Fire Safety Program of the World Trade Center is an excellent one." The Board, while recommending examination of additional safety measures, such as limiting combustibility of furnishings, further observed: "In the overall, these towers may be considered as among the safest buildings in New York City." See Page 10 of The New York Board of Fire Underwriters report.

* * *

PART II

Evaluation of Life Safety

The World Trade Center contains a complete fire protection and life safety installation which is [illegible]



1. Existing Life Safety Features

As noted in Part I of this report, the World Trade Center has extensive life safety features which are in accordance with and beyond the requirements of New York City Code. These features include the following:

- fireproof construction
- fire standpipe system
- smoke purge mode for air conditioning systems
- fire alarm and voice communication system
- sprinklers for restaurants, concession areas, and other public areas
- elevator return for Fire Department service
- smoke detectors at the return air system on each floor
- smoke detectors at the main air conditioning system fans.

The above protective systems are described in Part I of this report.

2. Off Hour Protection

As previously noted, smoke detectors are installed at the return air intakes in four locations on each floor. Tests were conducted to determine the effective time lapse for detection by initiation of smoke bombs. The most remote office area with different combinations of fans operating. As a result of these tests, it is current procedure to operate one return air fan to each quadrant of the building throughout the off-hour period. This procedure will permit detection of a fire in its incipient stage within a maximum of five minutes.

3. Proposed Life Safety Features

To further improve the life safety provisions with the Trade Center and to include protective measures required by Local Law 5, the following steps are underway.

Elevator Lobby Smoke Detectors

A contract for the installation of smoke detectors in each elevator lobby has been prepared and bids received. The activation of any detector would automatically cause all elevators within the bank serving that floor to return to their respective lobby to permit full use by the Fire Department.

Extension of Fire Alarm and Communication System

As previously noted in Part I, the present alarm system which includes voice communication between the Police Deck as well as communications through speaker systems in the core corridors on each floor, will be extended to provide warble tone alarm within the office areas and message communications within the stairways. A contract for this work has been awarded and is underway.

Plenum Segregation

Where not presently installed, the walls delineating the corridors will be carried to the underside of the floor slab above to minimize smoke spread.

Stair Pressurization Studies

To provide the added safety of insuring smoke-free stairways, a study is underway to evaluate the feasibility and effectiveness of pressurizing the stairways relative to the office areas. This study includes a study of technical papers prepared throughout the world, a re-review of the tests conducted at 30 Church Street, an inspection of the 50-story Seattle bank building which has

an operational stair pressurization system, preliminary testing at the World Trade Center to determine the methodology and instrumentation required for conducting an in-situ survey of the World Trade Center stairs prototype system to pressurize 40 floors in one stairway.

Sprinkler Extension Provision

In addition to sprinklering the core area mail and storage rooms, supplementary fire standpipe and drainage risers will provide extension of the sprinkler system as future occupancy changes or as conditions may dictate.

4. Consultants Life Safety Survey of the World Trade Center

In addition to the studies and investigations performed by staff for life safety protection in the World Trade Center towers, a consultant was engaged by the Port Authority to make a survey. The consultant engaged for the survey was the National Loss Control Service Corporation, an organization

[redacted]

atmosphere can be maintained. The consultant set as criteria that the basic requirements for an area to remain tenable are:

1. maintain structural integrity of the building;
2. absence of exposure to a direct flame;
3. presence of sufficient oxygen for life support;
4. absence of toxic combustion products at concentrations

sufficient to cause serious injury or even temporary disability; and,

5. absence of significant visible smoke.

In the consultant's survey of the Trade Center, he established that the structural fire resistance of the building is sufficient to make the probability of serious progressive structural collapse extremely remote, and the degree of vertical compartmentation effectively limits the spread of fire and its attendant oxygen depletion to the floor of fire origin. Adequate exit capacity for the fire floor along with the presence of the Fire Safety Plan to evacuate the fire floor and the floor above, limits the exposure of building occupants to direct fire effects. Therefore, the consultant concluded; "it is the spread of smoke and toxic combustion products that require principal attention from a life safety standpoint."

On the basis of these premises the consultant proceeded to study the effect of fires originating in different areas of the complex, and the effects of these fires on the life safety of the occupants. In completing his studies and evaluations of the World Trade Center Towers, which included a comparative analysis of the relative life safety of the occupants relative to conforming the towers with either the compartmentation option or sprinkler option of Local Law 5, the consultant concluded that either of the two fire protection options provided for under Local Law 5 would provide a good level of occupant life safety within the World Trade Center complex, provided that whichever is selected, it is supplemented by certain additional measures. In the case of the compartmentation option, the consultant recommended that this option be supplemented with the following additional features:

A) Sprinklering of rooms in the central corridor area

which could contribute excessive quantities of smoke to the corridor systems.

B) Doors which are normally kept open to the corridor system should be equipped with electro-magnetic "hold-open" devices and inter-connected to smoke detection devices to activate the closing of the door.

C) Provide fail-safe automatic door closers, arranged to close upon activation by smoke detectors for the overhead rolling fire doors separating the below grade truck door from the elevator lobby.

D) Perform an investigation to determine the optimum mode of operation of the building air conditioning system to remove smoke from the central core compartments without contaminating adjacent areas.

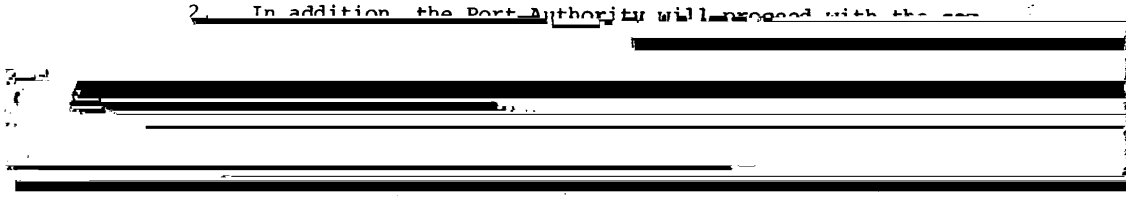
In the case of the sprinkler option, the consultant recommended that this option be supplemented with items B, C and D noted above for the compartmentation option, and that in addition, automatic smoke detection, in the immediate vicinity of elevators at each floor level, should also be provided.

5. Summary and Conclusions

As a result of the studies and investigations performed by both staff and consultants, it has been concluded that the World Trade Center Towers do provide life safety protection for its inhabitants. This life safety protection can be enhanced by the incorporation of several improvements into the structures as follows:

1. The openings between floors of telephone closets, which was a source of fire spread during the February 13, 1975 fire should be closed. This work has been accomplished to prevent any reoccurrences of a similar condition;

2. In addition, the Port Authority will proceed with the com-



5. Equipping those doors which are normally kept open to the corridor system, such as doors at consumer service areas, with electro-magnetic "hold open" devices which would be activated by smoke detectors to close the doors.

6. Providing fail-safe automatic doors closers, arranged to close upon activation by smoke detectors, for the overhead rolling fire doors separating the below-grade truck dock from the elevator lobby.

7. Developing an optimum mode of operation of the building air-conditioning system to remove smoke from the central core compartments without contaminating adjacent areas.

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NIST NCSTAR 1-1I

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Post-Construction Modifications to Fire Protection, Life Safety, and Structural Systems of World Trade Center 7

Raymond A. Grill
Duane A. Johnson
David A. Fanella

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Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Post-Construction Modifications to Fire Protection, Life Safety, and Structural Systems of World Trade Center 7

Raymond A. Grill
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Rolf Jensen & Associates, Inc.

September 2005

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Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

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In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

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NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

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National Institute of Standards and Technology National Construction Safety Team Act Report 1-1I
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ABSTRACT

This report was prepared to support the analysis of building and fire codes and standards of the National Institute of Standards and Technology World Trade Center (WTC) Investigation. This report was prepared to support the overall objective of determining how and why WTC 7 collapsed. The purpose of this report is to document modifications and/or repairs of the fire protection, life safety, and structural framing systems of WTC 7.

Keywords: Beams, building modifications, cover plates, fire alarm, fire protection, fire safety, fire sprinklers, floor slab openings, high-rise buildings, life safety, means of egress, pressurization, structural framing, tenant alterations, voice communication, web openings, wide-flange T-sections, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

ASTM	ASTM International
BCNYC	Building Code of the City of New York (Local Law No. 76)
HVAC	heating, ventilating, and air conditioning
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
PANYNJ	Port Authority of New York and New Jersey
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

ft	foot
in.	inch
WT15x74	American Institute of Steel Construction/ASTM standard abbreviation for a box (tube) beam of cross section 15 in. by 74 in.
WT24x55	American Institute of Steel Construction/ASTM standard abbreviation for a wide flange beam of cross section 24 in. flange and 55 in. web.

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GLOSSARY

active fire protection – A means to help prevent the loss of life and property from fire by extinguishing, suppressing, or controlling a fire through functional systems. Sprinkler systems, fire alarm systems, and smoke control systems are examples of active fire protection.

area of refuge – A floor area to which egress is made through a horizontal exit or supplemental vertical exit.

combustible – A material that is not determined to be noncombustible.

damper – A device installed in heating, ventilating, and air conditioning ductwork used to prevent the spread of fire and/or smoke. Dampers are provided to maintain a fire resistance rating of the assembly being penetrated.

detector – An initiation device that automatically detects a change in state, such as presence of smoke, high temperature, or abnormal rate of temperature rise.

fire alarm system – A system, automatic or manual, arranged to give a signal indicating a fire emergency and initiate the appropriate response.

fire resistance rating – The time in hours that materials or their assemblies will withstand fire exposure as determined by a fire test.

fireproofing – Materials or assemblies used to provide a fire resistance rating to a building component.

firestop – A solid or compact, tight closure to retard the spread of flames or hot gases within concealed spaces.

initiation device – A system component that originates a change-in-state signal in the fire alarm system. An initiation device begins the life safety processes, such as evacuation; heating, ventilating, and air conditioning shut down; elevator recall, etc.

manual fire alarm box – A manually operated initiation device that originates a change-in-state signal in the fire alarm system.

means of egress – A continuous and unobstructed path of vertical and horizontal travel from any point in a building to a public way. The means of egress consist of the exit access, the exit, and the exit discharge.

noncombustible – A material that, in the form in which it is used in construction, will not ignite and burn when subjected to fire. However, any material which liberates flammable gas when heated to any temperature up to 1,380 ºF for 5 min shall not be considered noncombustible.

notification appliance – A fire alarm system component such as a bell, horn, speaker, or strobe that provides audible, tactile, or visible outputs, or any combination thereof.

passive fire protection – Fire protection features that are incorporated into the building construction or building materials that do not rely on active fire protection methods to limit fire ignition, fire growth, or material failure. Fire separations and divisions, sprayed-on fire proofing, and enclosing structural members with noncombustible materials are examples of passive fire protection.

smoke and heat venting – A process used to move products of combustion to the outdoor air.

PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

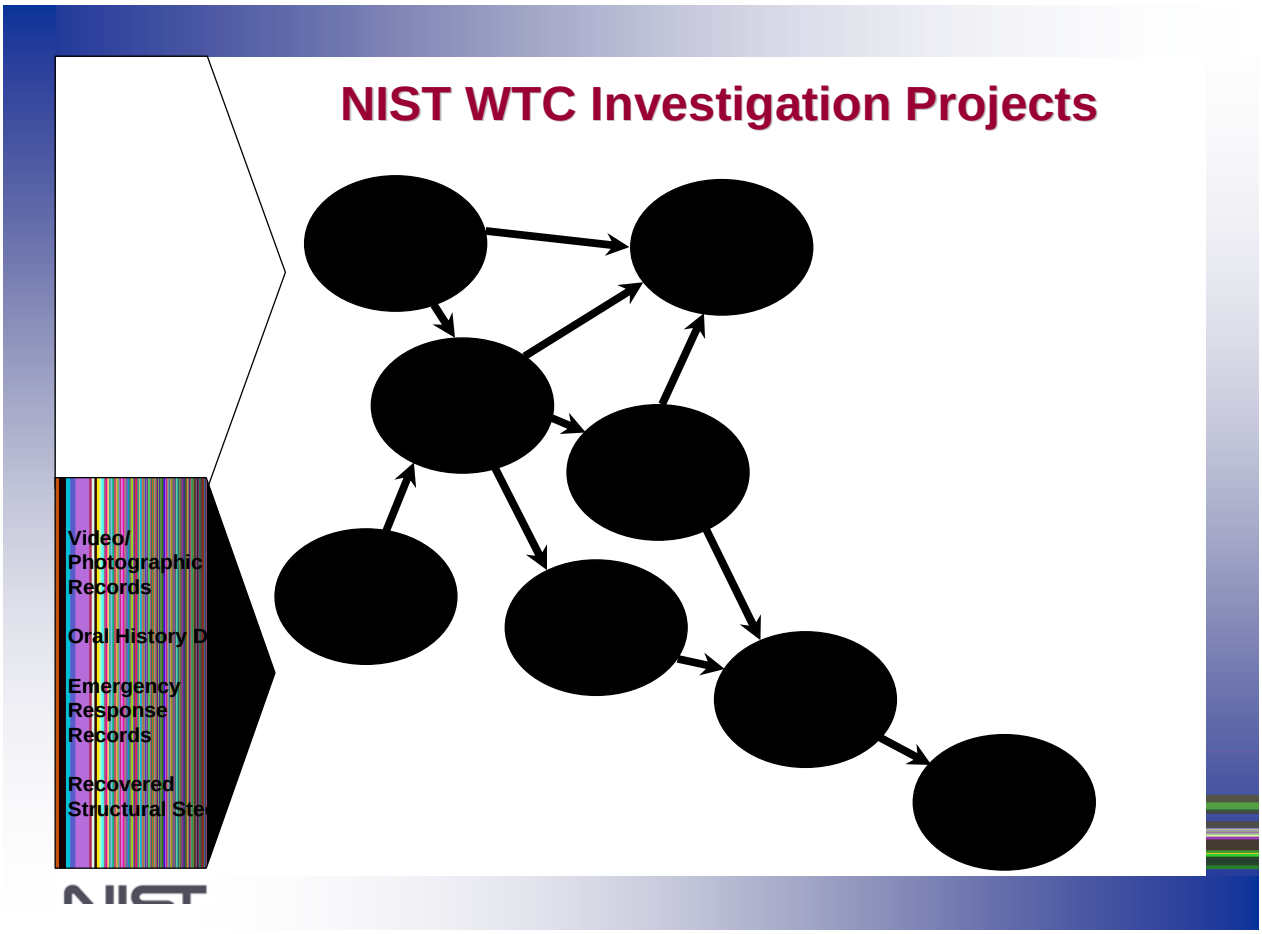

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

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EXECUTIVE SUMMARY

The purpose of this report is to identify the repairs and/or modifications made to the fire protection, life safety, and structural framing systems of World Trade Center (WTC) 7 from initial occupancy to September 11, 2001. Documentation for more than 120 tenant alterations to WTC 7 was located and reviewed. Fire protection, life safety, and structural framing systems for these alterations are summarized in this report.

The fire protection and life safety systems were modified to accommodate new tenant layouts. As walls were removed, added, and relocated, the requirements for the fire protection and life safety systems changed. As wall layouts were modified, fire sprinkler and fire alarm devices were relocated. Fire and smoke dampers were installed as required by the Building Code of the City of New York (BCNYC). Life safety requirements of the BCNYC, such as travel distance requirements, were analyzed. A list is provided of the tenant alterations that modified the fire protection and life safety systems.

Most of the structural modifications were done to accommodate tenant requirements. Horizontal members of the floor framing system were strengthened due to increased loading from high-density files. Strengthening of these beams and girders was achieved by welding cover plates to the bottom flanges, the underside of the top flanges, or both. In some cases, new beams were introduced to carry a portion of the new load.

Floor slabs were completely removed on the east side of the building to accommodate trading floors for Salomon Brothers, Inc., but were subsequently replaced when the trading floors were moved to another location. Columns in this area, which had twice the unsupported length after the slab removal, were reinforced. Other openings were cut into a few floor levels to accommodate new stairways connecting adjoining floors.

Web openings were cut through some beams and girders to allow passage of ductility work. In some cases, the beams or girders had to be reinforced in order to increase capacity.

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Chapter 1
INTRODUCTION

Over the life of World Trade Center (WTC) 7, enhancements to the fire protection, life safety, and structural framing systems were made. Tenant alterations, fires, revised building code provisions, and new technology all were the reasons for the enhancements of the systems. Changes made to these systems ultimately affected the building performance. Thus, in order to analyze the performance of WTC 7 in response to the attacks of September 11, 2001, it is crucial to have the most current configuration of the systems installed. The purpose of this report is to identify the repairs and/or modifications made to the fire protection, life safety, and structural framing systems of WTC 7 from initial occupancy to September 11, 2001.

1.1 FIRE PROTECTION AND LIFE SAFETY

Tenant alteration projects included modifications of the fire protection and life safety systems within WTC 7. Tenant spaces were modified to accommodate new floor layouts as tenants moved in and out. New wall layouts, changed occupancy use, and mission continuity objectives in tenant spaces introduced different code requirements.

Tenant alterations performed in WTC 7 included typical business occupancy modifications to the fire protection and life safety systems. A typical office alteration included rearranging walls to accommodate the desired layout of the tenant while maintaining proper fire separations and divisions from other tenants within the building. Fire and smoke dampers were installed in the heating, ventilating, and air conditioning systems where penetrations of fire rated walls occurred. The base building wet pipe sprinkler system was modified by the addition and/or relocation of sprinkler heads and branchlines in the tenant space as called for in National Fire Protection Association (NFPA) 13 and the Building Code of the City of New York (BCNYC) requirements for minimum spacing from these walls. Hydraulic calculations were performed to justify the pipe sizes of the branch lines as necessary. Documentation indicates that calculations were conducted back to the floor control valve assembly of each floor where system pressures were previously known. Fire alarm and voice communication systems were installed in accordance with NFPA 72 and the BCNYC requirements within each tenant space, again to maintain minimum spacing from relocated walls. Although documentation does not exist for each project, an egress analysis was generally performed to verify that travel distances and other means of egress requirements in the BCNYC were not exceeded. Providing exit and emergency lighting within the tenant space, which was required by the BCNYC, was also included in the tenant alteration project. The system modifications were submitted to the Port Authority of New York and New Jersey (PANYNJ or Port Authority) for approval or were approved using the self-certification process established by the PANYNJ. Tenant Construction Review Manuals, provided by the PANYNJ Engineering Department, were used for establishing minimum design criteria and design details.

Whenever work was done in the WTC buildings, a project number was assigned by the Port Authority under which all contracts, drawings, and correspondence was filed. These numbers are typically of the format W(yy)-1234 (where yy is the year initiated and 1234 is a four-digit number). This report includes

these numbers as references to individual projects, and files retained by the Port Authority are identified by these numbers.

1.2 STRUCTURAL FRAMING

Most of the structural modifications were done to accommodate tenant requirements. These generally involved strengthening the horizontal members of the floor framing system due to increased loading from high-density files (see Table 3–1 in Chapter 3). Strengthening of the beams and girders was achieved by welding cover plates to the bottom flanges and/or to the underside of the top flanges. In some cases, deficiencies were remedied by introducing a new beam between existing beams to reduce the tributary load on the deficient beams. In other cases, wide-flange T-sections were welded directly to the underside of deficient girders.

Floor slabs were completely removed on the east side of the building to accommodate the trading floors for Salomon Brothers, Inc., but were subsequently replaced when the trading floors were moved to another location (Cantor 1989). The only framing members that remained on these floors from the original design were the columns and the girders that were part of the lateral-force-resisting system. The columns, which had twice the unsupported length after the slab removal, were reinforced in this area. Other openings were cut into a few floors to accommodate new stairways connecting adjoining floors. New framing members were introduced where needed.

Web openings were cut through some beams and girders to allow passage of utility ductwork. These openings were typically reinforced with plates. In some cases, an inverted T-section was welded to the bottom flange of the existing beam to increase the capacity of the beam in the area of the opening. Shallow notches were cut in the top and bottom flanges of some of the beams to accommodate ductwork. To make up for lost capacity, plates were introduced just under the top flanges and just above the bottom flanges.

Other minor modifications were made, including the installation of supports for folding partitions.

The remainder of this report identifies the specific major modifications and repairs that were made to the fire protection, life safety, and structural framing systems of WTC 7.

1.3 REFERENCES

Cantor (The Office of Irwin G. Cantor P.C.). 1989. “Salomon Brothers, Inc., Base Building Modifications – 7 World Trade Center Structural Computations.” W-7004, Port Authority. Newark, January.

Chapter 2
MODIFICATIONS TO FIRE PROTECTION AND LIFE SAFETY SYSTEMS

The fire protection and life safety modifications of World Trade Center (WTC) 7 are listed in Table 2–1. Most of the tenant alterations followed the typical business occupancy modification summary previously identified in Chapter 1 of this report. Tenant alterations with additional modifications or modifications that varied from the typical modification summary of Chapter 1 are noted in the last column of Table 2–1. The year and floor location of the alteration are also given to provide a history of the floor or portion thereof. Tenant alteration documentation was not located for all floors, and thus, not every floor is identified in Table 2–1.

Table 2–1. Summary of modifications to WTC 7 fire protection and life safety systems.

TAA No.	Floor(s)	Location on Floor	Year	Tenant	Systems Modified
W98-1734	1	Core	1998	Office of Emergency Management	Typical, including Inergen system for fuel tanks
W-7005	2, 4	Northeast	1989	Salomon Brothers, Inc.	Typical
W00-7108	3	Core	2000	Salomon Smith Barney	Typical
W-8006	3	Southeast	1990	Tobacco Shop	Typical
W95-7140	3	Northeast	1995	Salomon Brothers, Inc.	Typical
W98-7195	3	Lobby	1998	WTC 7	Egress analysis
W00-7004	4, 29–37, 39–44, 47	Various	2002	Salomon Smith Barney	Various modifications, mostly utilities and structural but includes new halon system (34th floor)
W95-7109	7	Entire	1995	American Express Bank	Typical
W98-1734	7	South	1998	Office of Emergency Management	Removal of sprinklers from generator room
W98-7230	7	Core	1999	Silverstein Properties	Typical
W99-7175	7	Northeast	1999	American Express	Typical

Table 2–1. Summary of modifications to WTC 7 fire protection and life safety systems (continued).

TAA No.	Floor(s)	Location on Floor	Year	Tenant	Systems Modified
W93-7233	7, 8	Entire	1994	American Express	Typical
W01-7131	7, 8, 13	Northwest	2001	Unknown	Typical
W00-7143	8	Northwest	2000	American Express	Typical
W94-7187	8	West	1995	American Express Bank Check Processing Department	Typical
W94-7176.02	9, 10	Entire	1994	Ambassador Construction Project	Typical
W-8005	10–12	Various	1990	Spicer and Oppenheimer	Typical
W92-7056	11, 12	Entire	1992	Securities Exchange Commission	Typical
W00-7185	13	Southeast	2000	Standard Chartered	Typical
W92-7056	13	North	1992	Securities Exchange Commission	Typical
W97-7202	13	Northeast	1997	Salomon Brothers, Inc.	Typical
W99-7137	13	Northeast	1999	Standard Chartered	Typical
W96-7183, W97-7150	14–16	Various	1996, 1997	Insurance Services Office	Typical
W-8004, W-8013, W95-7110	14–17	Entire	1990, 1993, 1995	Insurance Services Office	Typical
W-7002	15	Southeast	1988	Cameron and Colby	Typical
W-8004	18	Southwest	1990	Insurance Services Office	Typical
W-8009	18	Core	1991	Silverstein	Typical
W92-7150	18	Northeast	1992	Equal Employment Opportunity Commission	Typical

Table 2–1. Summary of modifications to WTC 7 fire protection and life safety systems (continued).

TAA No.	Floor(s)	Location on Floor	Year	Tenant	Systems Modified
W96-7189	18	South	1996	Insurance Services Office	Typical
W98-7203	18	West	1998	ISO 2	Typical
W-8010	19	East	1991	Hartford Insurance Group	Typical
W96-7118	19	West	1996	National Association of Insurance Commissioners	Typical
W97-7101	19	North	1997	ITT Hartford	Typical
W95-7153	20	Entire	1995	Hartford Insurance Group	Typical
W-8010	20, 21	Entire	1991	Hartford Insurance Group	Typical
W95-7179, W95-7205	21	East	1995, 1995	ITT Hartford	Typical
W96-7150	21	Southwest	1996	ITT Hartford	Typical
W97-7129	21	West	1997	Salomon Brothers, Inc.	Typical
W97-7135	21	Core	1997	ITT Hartford	Typical
W94-7107	22	Entire	1994	Federal Home Bank of New York	Typical, including new pre-action system
W98-7109	22	Southwest	1998	Federal Home Loan Bank of New York	Typical
W98-1734	23	Entire	1998	Office of Emergency Management	Typical, including new pre-action system
W-8003	24, 25	Entire	1989	Department of Treasury – IRS	Typical
W95-7163	26, 27	Entire	1995	Standard Chartered	Typical
W93-7160, W93-7138, W93-7246	28	Entire	1993	Salomon Brothers, Inc.	Typical
W94-7180	28	Northeast	1994	Salomon Brothers, Inc.	Typical

Table 2–1. Summary of modifications to WTC 7 fire protection and life safety systems (continued).

TAA No.	Floor(s)	Location on Floor	Year	Tenant	Systems Modified
W96-7185	28	Various	1996	Salomon Brothers, Inc.	Typical
W97-7173, W97-7186	28	Various	1997, 1997	Salomon Brothers, Inc.	Typical
W99-7168	28–32, 34	Core	1999	Salomon Smith Barney	Typical
W00-7194	29	Southeast	2000	Hartford Insurance	Typical
W93-7148	29	Entire	1993	Salomon Brothers, Inc.	Typical
W97-7172	29	East	1997	Salomon Brothers, Inc.	Typical
W00-7122	30	Core	2000	Salomon Smith Barney	Typical, including new pre-action system
W94-7141	30	East	1994	Salomon Brothers, Inc.	Typical
W94-7207	30	East	1994	Salomon Brothers, Inc.	Typical
W97-7132	30	Southeast	1997	Salomon Brothers, Inc.	Typical
W97-7152	30	Southeast	1997	Department of Defense	Typical
W00-7127	31	Core	2000	Salomon Smith Barney	Typical, including new pre-action system
W00-7128	32	Core	2000	Salomon Smith Barney	Typical, including new pre-action system
W00-7225	32	Entire	2000	Salomon Smith Barney	Typical
W93-7155	33	Southwest	1993	Salomon Brothers, Inc.	Typical
W93-7212	33	South	1994	Salomon Brothers, Inc.	Typical
W99-7160	33	Southwest & Core	1999	Salomon Smith Barney	Typical
W99-7161	33	Core	1999	Salomon Smith Barney	Typical, including new pre-action systems

Table 2–1. Summary of modifications to WTC 7 fire protection and life safety systems (continued).

TAA No.	Floor(s)	Location on Floor	Year	Tenant	Systems Modified
W93-7137, W93-7157, W93-7207, W93-7237, W94-7134, W94-7230	34	Entire	1993, 1993, 1993, 1993, 1994, 1994	Salomon Brothers, Inc.	Typical
W97-7119	34	South	1997	Salomon Brothers, Inc.	Typical
W93-7151	35	Southeast	1993	Salomon Brothers, Inc.	Typical
W93-7231	35	Southeast	1994	Salomon Brothers, Inc.	Typical
W94-7195	35	Southwest	1994	Salomon Brothers, Inc.	Typical
W-7005	35,44	Entire	1989	Salomon Brothers, Inc.	Typical, including egress analysis for assembly space
W00-7139	36	East	2000	Salomon Smith Barney	Typical
W96-7196	36	Various	1996	Salomon Brothers, Inc.	Typical
W99-7122	36	Northeast	1999	Salomon Smith Barney	Typical
W99-7144	36, 39	Core	1999	Salomon Smith Barney	Typical, including new pre-action systems
W99-7148	36–43	Core	1999	Salomon Smith Barney	Typical, including new pre-action systems
W00-7188	37	Entire	2000	Salomon Smith Barney	Typical
W99-7134	37	Entire	1999	Salomon Smith Barney	Typical
W00-7224	38	Northeast	2000	Salomon Smith Barney	Typical
W94-7102	38	Entire	1994	Salomon Brothers, Inc.	Typical
W96-7179	38	North	1996	Salomon Brothers, Inc.	Typical
W97-7167	38	Northeast	1997	Salomon Brothers, Inc.	Typical

Table 2–1. Summary of modifications to WTC 7 fire protection and life safety systems (continued).

TAA No.	Floor(s)	Location on Floor	Year	Tenant	Systems Modified
W00-7202	39	Entire	2000	Salomon Smith Barney	Typical
W93-7102	39	Entire	1993	Salomon Brothers, Inc.	Typical, includes egress analysis for auditorium
W95-7173	39	Core	1995	Salomon Brothers, Inc.	Typical
W96-7120	39	Northeast	1996	Salomon Brothers, Inc.	Typical
W97-7138	39	Northeast	1997	Salomon Brothers Inc.	Typical
W99-7119	39	Northeast	1999	Salomon Smith Barney	Typical
W99-7127	39–46	East	1999	Salomon Smith Barney	Typical
W99-7172	40	Entire	1999	Salomon Smith Barney	Typical
W93-7118	41	Northwest	1993	Salomon Brothers, Inc.	Typical
W96-7140	41	West	1996	Salomon Brothers, Inc.	Typical
W97-7142	41	Core	1997	Salomon Brothers, Inc.	Typical
W97-7153	41	North	1997	Salomon Brothers, Inc.	Typical
W99-7177	41	Entire	1999	Salomon Smith Barney	Typical
W99-7178	42	Entire	1999	Salomon Smith Barney	Typical
W99-7178	42	Entire	1999	Salomon Smith Barney	Typical
W00-7111	43	Entire	2000	Salomon Smith Barney	Typical, including new pre-action system
W01-7111	44	Entire	2001	Salomon Smith Barney	Typical, including new pre-action systems
W95-7195	45	North	1995	Salomon Brothers, Inc.	Typical

Table 2–1. Summary of modifications to WTC 7 fire protection and life safety systems (continued).

TAA No.	Floor(s)	Location on Floor	Year	Tenant	Systems Modified
W99-7120	45	West	1999	Salomon Smith Barney	Typical
W99-7194	45	East	1999	Salomon Smith Barney	Typical
W93-7167, W93-7168	46	Entire	1993, 1993	Salomon Brothers, Inc.	Typical
W97-7196	46	South	1997	Salomon Brothers, Inc.	Typical
W00-7203	47	Northeast	2000	Salomon Smith Barney	Typical
W93-7221	47	Northeast	1994	Salomon Brothers, Inc.	Typical
W97-7140	47	East	1997	Salomon Brothers, Inc.	Typical
W00-7202	39	Entire	2000	Salomon Smith Barney	Typical
W93-7102	39	Entire	1993	Salomon Brothers, Inc.	Typical, includes egress analysis for auditorium
W95-7173	39	Core	1995	Salomon Brothers, Inc.	Typical

Key: TAA, Tenant Alteration Application.

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Chapter 3
STRUCTURAL MODIFICATIONS DUE TO TENANT ALTERATIONS

Structural modifications due to tenant alterations are listed in Table 3–1. Included is a brief description of the work that was performed with respect to the modifications. In most cases, members were reinforced to accommodate floor loads that were greater than the loads for which these members were originally designed.

In all of the cases cited in Table 3–1, structural calculations were included on the check of the existing structural members and on the design of new structural members. In the documents related to the 1988 modifications, there were comments made by the Tenant Construction Review Unit of the Port Authority of New York and New Jersey (PANYNJ or Port Authority) in regard to the project submittal. Also included were responses from the structural engineer to the Port Authority on these comments. Similar documents are available for the modifications made in 1999 on the 40th floor, which include a copy of the Tenant Construction or Alteration Application that was submitted to the Port Authority on behalf of the tenant.

Table 3–1. Modifications made due to tenant alterations.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference Work Order Number
1988	38	Salomon Brothers, Inc.	Office of Irwin G. Cantor	Bottom and top cover plates were added to the existing W24x55 beams along column lines 37 and 40, and bottom cover plates were added to the existing W24x55 beams along column lines 30 and 35 to support new hanger loads.	W-7004 PANYNJ (Newark)
1989	24	General Auditing Office	Office of Irwin G. Cantor	Bottom cover plates were added to the existing W21x44 beam on column line 45 and the two adjacent W21x44 beams to the west of column line 45 to support additional load due to new file storage. The existing W36x135 girder framing between columns 76 and 79, which supported these beams, was also reinforced with a bottom cover plate.	W-8003 PANYNJ (Newark)

Table 3–1. Modifications made due to tenant alterations (continued).

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference Work Order Number
1989	47	Salomon Brothers, Inc.	Office of Irwin G. Cantor	Bottom cover plates were added to the existing W16x31 beam along column line 2, the W16x26 beam along column line 3, and the W14x22 beams along column lines 4 and 5 to support additional mechanical equipment. The W33x130 girder on column line 56, which supported these beams, was reinforced with bottom and top cover plates.	W-7004 PANYNJ (Newark)
1990	11, 12	Spicer & Oppenheimer	Office of Irwin G. Cantor	Bottom cover plates were added to eight existing beams and girders in the northwest corner of the building on the 11th floor to support larger live loads. Similarly, bottom cover plates were added to three existing beams between column lines 48 and 49 and the girder between columns 70 and 73 on the 12th floor.	W-8005 PANYNJ (Newark)
1991	19	ITT Hartford	Office of James Ruderman	Bottom cover plates were added to existing W24x55 and W24x76 beams to support new files and shelves. Exact location of these beams could not be determined from the documentation.	W-8010 PANYNJ (Newark)
1992	12	Securities Exchange Commission	Office of Irwin G. Cantor	Bottom cover plates were added to eleven existing beams in the northwest corner of the building to support legal files. A new W12x19 beam was also added between two of the existing beams.	W92-7056 PANYNJ (Newark)
1992	18, 19	Equal Employment Opportunity Commission	Office of Irwin G. Cantor	Bottom cover plates were added to existing W24 beams on the 18th floor on column lines 31, 32, and 33 to support larger live loads.	W92-7150
1993	28	Salomon Brothers, Inc.	Office of Irwin G. Cantor	Eight additional shear studs were added to an existing W16x26 beam located in the mechanical/electrical room to support new equipment loads.	W93-7138 PANYNJ (Newark)
1993	7, 8	American Express Bank	Office of James Ruderman	A new W12x14 beam located on the west side of the building between column lines 7 and 8 was added on the 8th floor to support a new concrete masonry unit wall.	W93-7233 PANYNJ (Newark)

Table 3–1. Modifications made due to tenant alterations (continued).

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference Work Order Number
1994	7–29	Salomon Brothers, Inc.	Office of Irwin G. Cantor	Bottom cover plates were added to 22 existing beams between columns 5 and 25 on the south side of the building on each floor between levels 7 and 29 to support larger live loads. Similarly, bottom cover plates were added to eight beams on the east side of the building between column lines 31 and 37 on each of these floors.	W93-7232
1995	20	ITT Hartford	The Cantor Seinuk Group	Bottom cover plates were added to the existing W16x26 beams along column lines 23 and 25 to support new filing cabinets. Similarly, WT sections were welded to the bottom of the existing W16x26 beams that framed in between the above-mentioned beams. WT sections were welded to the bottom of the existing W16x26 beam east of column line 18 and the W16x26 beam on column line 19 to support new filing cabinets. Similarly, a bottom cover plate was added to the existing W16x26 beam east of column line 19.	W95-7153
1999	37	Salomon Smith Barney	Gilsanz Murray Steficek	A new W16x40 beam was added between two existing W14x22 beams along column lines 76 and 77 to support a new high-density filing system.	W99-7134 PANYNJ (Newark)
1999	13	The Standard Chartered Bank	The Cantor Seinuk Group	Ten additional shear studs were added to an existing W24x55 beam to support additional loads from a new file room and a new UPS/LAN room. Exact location of this beam could not be determined from the documentation.	W99-7137-02 PANYNJ (Newark)
1999	40	Salomon Smith Barney	Gilsanz Murray Steficek	Four new W18x35 beams were added to support the new high-density files near column 76. WT4x20 sections were welded to the bottom of two existing W14x22 beams that supported the files. New W16x50 beams were connected below to the existing W36x135 girders that supported the beams in this area.	W99-7172 PANYNJ (Newark)

Table 3–1. Modifications made due to tenant alterations (continued).

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference Work Order Number
2000	31	Salomon Smith Barney	Gilsanz Murray Steficek	Top and bottom cover plates were added to an existing W27x94 beam between columns 77 and 80 to support a new high-density filing system. The existing beam connections were also reinforced with stiffened seat connections.	W00-7122 PANYNJ (Newark)
2000	38	Salomon Smith Barney	Gilsanz Murray Steficek	Bottom cover plates were added to existing W14x22 beams between columns 76 and 77 and between columns 77 and 78 to support a new high-density filing system. Also, the following existing girders were reinforced with bottom cover plates: (1) W36x135 between columns 76 and 79, (2) W27x94 between columns 77 and 80, and (3) W27x84 between columns 78 and 81.	W00-7224 PANYNJ (Newark)
2000	39	Salomon Smith Barney	Gilsanz Murray Steficek	New W14x53 beams were added under each rail of a new high-density filing system in lieu of reinforcing existing W14x22 beams between columns 76 and 77.	W00-7202 PANYNJ (Newark)

Key: WT, wide-flange T-sections.

Chapter 4
OPENINGS MADE IN FLOOR SLABS

4.1 DESCRIPTION OF THE MODIFICATIONS

According to the Base Building modifications (Cantor 1989) for World Trade Center 7, columns 76, 78, 79, 80, and 81 were reinforced with plates that ran from the top of the 39th floor to the underside of the 40th floor due to the removal of the floor slab at the 39th floor. Similarly, column 74 was reinforced with plates that ran from the top of the 43rd floor to the underside of the 44th floor due to the removal of the floor slab at the 43rd floor. These slabs were removed to accommodate the trading floors for Salomon Brothers, Inc. Furthermore, it is stated in the *Facility Condition Survey Program* report (PANYNJ 1997), that the 41st and 43rd floor slabs were completely removed on the east side of the building to accommodate the trading floors for Salomon Brothers, Inc. Structural modifications involving openings made in the floor slabs are listed in Table 4–1. Included is a brief description of the work that was performed with respect to the modifications.

Table 4–1. Openings made in floor slabs.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference Work Order Number
1989	3, 4	Salomon Brothers, Inc.	Skidmore, Owings & Merrill	On the 3rd floor, openings were cut on the west, north, and east sides of the building. New framing was introduced around these openings. On the 4th floor, new openings and framing were introduced on the north side of the building.	W-7004 PANYNJ
1989	3	Salomon Brothers, Inc.	Office of Irwin G. Cantor	Two 2 ft 6 in. by 3 ft 6 in. openings were cut near columns 24 and 25. New C8x11.5 framing members were added around the openings.	W-7005 PANYNJ (Newark)
1990	11	Spicer & Oppenheimer	Office of Irwin G. Cantor	A new stair opening was made between columns 77, 78, 80, and 81. New W12x16 beams were added around the opening.	W-8005 PANYNJ (Newark)
1994	43	Salomon Brothers, Inc.	Skidmore, Owings & Merrill	A new slab opening was made near column 71 in the core area. New beams were added around the opening.	W94-7746

Note: Structural calculations on the design of new structural members and on the check of the existing structural members were included for the modification made in 1989 (3rd floor) and 1990.

4.2 REFERENCES

Cantor (The Office of Irwin G. Cantor P.C.). 1989. "Salomon Brothers, Inc., Base Building Modifications – 7 World Trade Center Structural Computations." W-7004, Port Authority. Newark, January.

PANYNJ (The Port Authority of New York and New Jersey). 1997. *Port Authority Facility Condition Survey Program – 7 World Trade Center*. Engineering Quality Assurance Division, Engineering Department. April.

Chapter 5
MODIFICATIONS MADE TO BEAM WEBS AND FLANGES

Modifications made to beam webs and flanges are summarized in Table 5–1. Included is a brief description of the work that was performed with respect to the modifications.

Table 5–1. Modifications made to beam webs and flanges.

Date	Floor(s)	Tenant	Structural Engineer	Description of Modification	Reference Work Order Number
1993	28	Salomon Brothers, Inc.	Office of Irwin G. Cantor	Two 1 in. by 36 in. openings, located 3 ft apart, were cut into the web of an existing W24x55 beam (unknown location). Plates were welded on each side of the web along the upper and lower edges of the openings.	W93-7138 PANYNJ (Newark)
1993	4–7, 16, 21, 29, 38, 45	Salomon Brothers, Inc.	Office of Irwin G. Cantor	Notches were cut in the bottom flanges of various beams on these floors to accommodate ductwork. Plates were welded to the upper side of the bottom flanges.	W93-7221
1998	1	Mayor's Office of Emergency Management	The Cantor Seinuk Group	A notch was cut into the top flange of an existing beam (unknown location). Two plates, one on each side of the web, were welded under the top flange.	W98-1734
1999	36–44	Salomon Smith Barney	The Cantor Seinuk Group	Two new openings (68 in. by 22 in. and 76 in. by 22 in.) spaced 3 ft 10 in. apart were cut into the web of the existing W24x62 beam framing into column 75. Horizontal and vertical stiffener plates were added on all sides of the openings. Also, a new WT15x74 section was welded to the bottom of the beam. The same size openings were made in an existing W27x94 beam on the 43rd floor, which was reinforced in a similar manner.	W99-7127 PANYNJ (Newark)
1999	42, 44	Salomon Smith Barney	Gensler	New web openings were cut in numerous beams along the north and east sides of the building.	W99-7127

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Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Documentation of the Fuel System for Emergency Power in World Trade Center 7

Raymond A. Grill
Duane A. Johnson

NIST National Institute of Standards and Technology • Technology Administration • U.S. Department of Commerce

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Raymond A. Grill
Duane A. Johnson
Rolf Jensen & Associates, Inc.

September 2005

U.S. Department of Commerce
Carlos M. Gutierrez, Secretary

Technology Administration
Michelle O'Neill, Acting Under Secretary for Technology

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The policy of NIST is to use the International System of Units (metric units) in all publications. In this document, however, units are presented in metric units or the inch-pound system, whichever is prevalent in the discipline.

Disclaimer No. 3

Pursuant to section 7 of the National Construction Safety Team Act, the NIST Director has determined that certain evidence received by NIST in the course of this Investigation is "voluntarily provided safety-related information" that is "not directly related to the building failure being investigated" and that "disclosure of that information would inhibit the voluntary provision of that type of information" (15 USC 7306c).

In addition, a substantial portion of the evidence collected by NIST in the course of the Investigation has been provided to NIST under nondisclosure agreements.

Disclaimer No. 4

NIST takes no position as to whether the design or construction of a WTC building was compliant with any code since, due to the destruction of the WTC buildings, NIST could not verify the actual (or as-built) construction, the properties and condition of the materials used, or changes to the original construction made over the life of the buildings. In addition, NIST could not verify the interpretations of codes used by applicable authorities in determining compliance when implementing building codes. Where an Investigation report states whether a system was designed or installed as required by a code *provision*, NIST has documentary or anecdotal evidence indicating whether the requirement was met, or NIST has independently conducted tests or analyses indicating whether the requirement was met.

Use in Legal Proceedings

No part of any report resulting from a NIST investigation into a structural failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a; as amended by P.L. 107-231).

National Institute of Standards and Technology National Construction Safety Team Act Report 1-1J
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ABSTRACT

This report was prepared to support the analysis of building and fire codes and standards of the National Institute of Standards and Technology World Trade Center (WTC) Investigation. As part of the investigation of WTC 7, the fuel oil distribution system is being analyzed as a possible cause of fire initiation. The purpose of this report is to document the fuel oil distribution systems (including all fuel oil tanks, pumps, generators, routing of the piping, and system functions) and the associated fire protection features of the fuel oil system that existed in WTC 7 at the time of the collapse.

Keywords: Compartmentation, day tanks, diesel fuel, emergency generators, emergency power, fire protection, fire safety, fire sprinklers, fuel oil distribution system, fuel oil pumps, inspections, storage tanks, World Trade Center.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronyms

BCNYC	Building Code of the City of New York (Local Law 76)
BSA	New York City Board of Standards and Appeals
FOR	fuel oil return
FOS	fuel oil supply
MER	Mechanical Equipment Room
NIST	National Institute of Standards and Technology
OEM	Mayor's Office of Emergency Management
PANYNJ	Port Authority of New York and New Jersey
RS	Reference Standard to the Building Code of the City of New York
WTC	World Trade Center
WTC 1	World Trade Center 1 (North Tower)
WTC 2	World Trade Center 2 (South Tower)
WTC 7	World Trade Center 7

Abbreviations

°F	degrees Fahrenheit
ft	foot
ft^2	square foot
gal	gallon
gph	gallons per hour
gpm	gallons per minute
h	hour
hp	horsepower
Hz	hertz
in.	inch
kVa	kilovoltampere
kW	kilowatt
psi	pounds per square inch

rpm	revolutions per minute
V	volt

METRIC CONVERSION TABLE

To convert from	to	Multiply by
AREA AND SECOND MOMENT OF AREA		
square foot (ft^2)	square meter (m^2)	9.290 304 E-02
square inch ($in.^2$)	square meter (m^2)	6.4516 E-04
square inch ($in.^2$)	square centimeter (cm^2)	6.4516 E+00
square yard (yd^2)	square meter (m^2)	8.361 274 E-01
ENERGY (includes WORK)		
kilowatt hour (kW · h)	joule (J)	3.6 E+06
quad (1015 BtuIT)	joule (J)	1.055 056 E+18
therm (U.S.)	joule (J)	1.054 804 E+08
ton of TNT (energy equivalent)	joule (J)	4.184 E+09
watt hour (W · h)	joule (J)	3.6 E+03
watt second (W · s)	joule (J)	1.0 E+00
FORCE		
dyne (dyn)	newton (N)	1.0 E-05
kilogram-force (kgf)	newton (N)	9.806 65 E+00
kilopond (kilogram-force) (kp)	newton (N)	9.806 65 E+00
kip (1 kip=1,000 lbf)	newton (N)	4.448 222 E+03
kip (1 kip=1,000 lbf)	kilonewton (kN)	4.448 222 E+00
pound-force (lbf)	newton (N)	4.448 222 E+00
FORCE DIVIDED BY LENGTH		
pound-force per foot (lbf/ft)	newton per meter (N/m)	1.459 390 E+01
pound-force per inch (lbf/in.)	newton per meter (N/m)	1.751 268 E+02
HEAT FLOW RATE		
calorieth per minute (calth/min)	watt (W)	6.973 333 E-02
calorieth per second (calth/s)	watt (W)	4.184 E+00
kilocalorieth per minute (kcalth/min)	watt (W)	6.973 333 E+01
kilocalorieth per second (kcalth/s)	watt (W)	4.184 E+03

To convert from	to	Multiply by
LENGTH		
foot (ft)	meter (m)	3.048 E-01
inch (in)	meter (m)	2.54 E-02
inch (in.)	centimeter (cm)	2.54 E+00
micron (m)	meter (m)	1.0 E-06
yard (yd)	meter (m)	9.144 E-01
MASS and MOMENT OF INERTIA		
kilogram-force second squared per meter ($kgf \cdot s^2/m$)	kilogram (kg)	9.806 65 E+00
pound foot squared ($lb \cdot ft^2$)	kilogram meter squared ($kg \cdot m^2$)	4.214 011 E-02
pound inch squared ($lb \cdot in.^2$)	kilogram meter squared ($kg \cdot m^2$)	2.926 397 E-04
ton, metric (t)	kilogram (kg)	1.0 E+03
ton, short (2,000 lb)	kilogram (kg)	9.071 847 E+02
MASS DIVIDED BY AREA		
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428 E+00
pound per square inch (*not* pound force) ($lb/in.^2$)	kilogram per square meter (kg/m^2)	7.030 696 E+02
MASS DIVIDED BY LENGTH		
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164 E+00
pound per inch (lb/in.)	kilogram per meter (kg/m)	1.785 797 E+01
pound per yard (lb/yd)	kilogram per meter (kg/m)	4.960 546 E-01
PRESSURE or STRESS (FORCE DIVIDED BY AREA)		
kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	9.806 65 E+04
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	9.806 65 E+00
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	9.806 65 E+06
kip per square inch (ksi) ($kip/in.^2$)	pascal (Pa)	6.894 757 E+06
kip per square inch (ksi) ($kip/in.^2$)	kilopascal (kPa)	6.894 757 E+03
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026 E+01
pound-force per square inch (psi) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
pound-force per square inch (psi) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00
psi (pound-force per square inch) ($lbf/in.^2$)	pascal (Pa)	6.894 757 E+03
psi (pound-force per square inch) ($lbf/in.^2$)	kilopascal (kPa)	6.894 757 E+00

To convert from	to	Multiply by
TEMPERATURE		
degree Celsius (°C)	kelvin (K)	T/K = t/°C + 273.15
degree centigrade	degree Celsius (°C)	t/°C ≈ t /deg. cent.
degree Fahrenheit (°F)	degree Celsius (°C)	t/°C = (t/°F - 32)/1.8
degree Fahrenheit (°F)	kelvin (K)	T/K = (t/°F + 459.67)/1.8
kelvin (K)	degree Celsius (°C)	t/°C = T/K 2 273.15
TEMPERATURE INTERVAL		
degree Celsius (°C)	kelvin (K)	1.0 E+00
degree centigrade	degree Celsius (°C)	1.0 E+00
degree Fahrenheit (°F)	degree Celsius (°C)	5.555 556 E-01
degree Fahrenheit (°F)	kelvin (K)	5.555 556 E-01
degree Rankine (°R)	kelvin (K)	5.555 556 E-01
VELOCITY (includes SPEED)		
foot per second (ft/s)	meter per second (m/s)	3.048 E-01
inch per second (in./s)	meter per second (m/s)	2.54 E-02
kilometer per hour (km/h)	meter per second (m/s)	2.777 778 E-01
mile per hour (mi/h)	kilometer per hour (km/h)	1.609 344 E+00
mile per minute (mi/min)	meter per second (m/s)	2.682 24 E+01
VOLUME (includes CAPACITY)		
cubic foot (ft^3)	cubic meter (m^3)	2.831 685 E-02
cubic inch ($in.^3$)	cubic meter (m^3)	1.638 706 E-05
cubic yard (yd^3)	cubic meter (m^3)	7.645 549 E-01
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412 E-03
gallon (U.S.) (gal)	liter (L)	3.785 412 E+00
liter (L)	cubic meter (m^3)	1.0 E-03
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353 E-05
ounce (U.S. fluid) (fl oz)	milliliter (mL)	2.957 353 E+01

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GLOSSARY

active fire protection – A means to help prevent the loss of life and property from fire by extinguishing, suppressing, or controlling a fire through functional systems. Sprinkler systems, fire alarm systems, and smoke control systems are examples of active fire protection.

combustible – A material that is not determined to be noncombustible.

dry pipe sprinkler system – A fire sprinkler system in which the piping up to the sprinkler heads is initially filled with air. Once a sprinkler head operates, water is released into the piping and continues to flow out the activated sprinkler(s) until the system is shut off.

fire alarm system – A system, automatic or manual, arranged to give a signal indicating a fire emergency and initiate the appropriate response.

fire resistance rating – The time in hours that materials or their assemblies will withstand fire exposure as determined by a fire test.

fireproofing – Materials or assemblies used to provide a fire resistance rating to a building component.

firestop – A solid or compact, tight closure to retard the spread of flames or hot gases within concealed spaces.

noncombustible – A material that, in the form in which it is used in construction, will not ignite and burn when subjected to fire. However, any material which liberates flammable gas when heated to any temperature up to 1,380 °F for 5 min shall not be considered noncombustible.

passive fire protection – Fire protection features that are incorporated into the building construction or building materials that do not rely on active fire protection methods to limit fire ignition, fire growth, or material failure. Fire separations and divisions, sprayed fire-resistive material, and enclosing structural members with noncombustible materials are examples of passive fire protection.

wet pipe sprinkler system – A fire sprinkler system in which the piping is filled with pressurized water at all times. Water is immediately discharged when a sprinkler head operates and continues to flow out the activated sprinkler(s) until the system is shut off.

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PREFACE

Genesis of This Investigation

Immediately following the terrorist attack on the World Trade Center (WTC) on September 11, 2001, the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers began planning a building performance study of the disaster. The week of October 7, as soon as the rescue and search efforts ceased, the Building Performance Study Team went to the site and began its assessment. This was to be a brief effort, as the study team consisted of experts who largely volunteered their time away from their other professional commitments. The Building Performance Study Team issued its report in May 2002, fulfilling its goal "to determine probable failure mechanisms and to identify areas of future investigation that could lead to practical measures for improving the damage resistance of buildings against such unforeseen events."

On August 21, 2002, with funding from the U.S. Congress through FEMA, the National Institute of Standards and Technology (NIST) announced its building and fire safety investigation of the WTC disaster. On October 1, 2002, the National Construction Safety Team Act (Public Law 107-231), was signed into law. The NIST WTC Investigation was conducted under the authority of the National Construction Safety Team Act.

The goals of the investigation of the WTC disaster were:

- To investigate the building construction, the materials used, and the technical conditions that contributed to the outcome of the WTC disaster.
- To serve as the basis for:
  - Improvements in the way buildings are designed, constructed, maintained, and used;
  - Improved tools and guidance for industry and safety officials;
  - Recommended revisions to current codes, standards, and practices; and
  - Improved public safety.

The specific objectives were:

1. Determine why and how WTC 1 and WTC 2 collapsed following the initial impacts of the aircraft and why and how WTC 7 collapsed;
2. Determine why the injuries and fatalities were so high or low depending on location, including all technical aspects of fire protection, occupant behavior, evacuation, and emergency response;
3. Determine what procedures and practices were used in the design, construction, operation, and maintenance of WTC 1, 2, and 7; and
4. Identify, as specifically as possible, areas in current building and fire codes, standards, and practices that warrant revision.

NIST is a nonregulatory agency of the U.S. Department of Commerce's Technology Administration. The purpose of NIST investigations is to improve the safety and structural integrity of buildings in the United States, and the focus is on fact finding. NIST investigative teams are authorized to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST does not have the statutory authority to make findings of fault nor negligence by individuals or organizations. Further, no part of any report resulting from a NIST investigation into a building failure or from an investigation under the National Construction Safety Team Act may be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a, as amended by Public Law 107-231).

Organization of the Investigation

The National Construction Safety Team for this Investigation, appointed by the then NIST Director, Dr. Arden L. Bement, Jr., was led by Dr. S. Shyam Sunder. Dr. William L. Grosshandler served as Associate Lead Investigator, Mr. Stephen A. Cauffman served as Program Manager for Administration, and Mr. Harold E. Nelson served on the team as a private sector expert. The Investigation included eight interdependent projects whose leaders comprised the remainder of the team. A detailed description of each of these eight projects is available at http://wtc.nist.gov. The purpose of each project is summarized in Table P–1, and the key interdependencies among the projects are illustrated in Fig. P–1.

Table P–1. Federal building and fire safety investigation of the WTC disaster.

Technical Area and Project Leader	Project Purpose
Analysis of Building and Fire Codes and Practices; Project Leaders: Dr. H. S. Lew and Mr. Richard W. Bukowski	Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of WTC 1, 2, and 7.
Baseline Structural Performance and Aircraft Impact Damage Analysis; Project Leader: Dr. Fahim H. Sadek	Analyze the baseline performance of WTC 1 and WTC 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
Mechanical and Metallurgical Analysis of Structural Steel; Project Leader: Dr. Frank W. Gayle	Determine and analyze the mechanical and metallurgical properties and quality of steel, weldments, and connections from steel recovered from WTC 1, 2, and 7.
Investigation of Active Fire Protection Systems; Project Leader: Dr. David D. Evans; Dr. William Grosshandler	Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
Reconstruction of Thermal and Tenability Environment; Project Leader: Dr. Richard G. Gann	Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.
Structural Fire Response and Collapse Analysis; Project Leaders: Dr. John L. Gross and Dr. Therese P. McAllister	Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of composite steel-trussed floor systems, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
Occupant Behavior, Egress, and Emergency Communications; Project Leader: Mr. Jason D. Averill	Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
Emergency Response Technologies and Guidelines; Project Leader: Mr. J. Randall Lawson	Document the activities of the emergency responders from the time of the terrorist attacks on WTC 1 and WTC 2 until the collapse of WTC 7, including practices followed and technologies used.

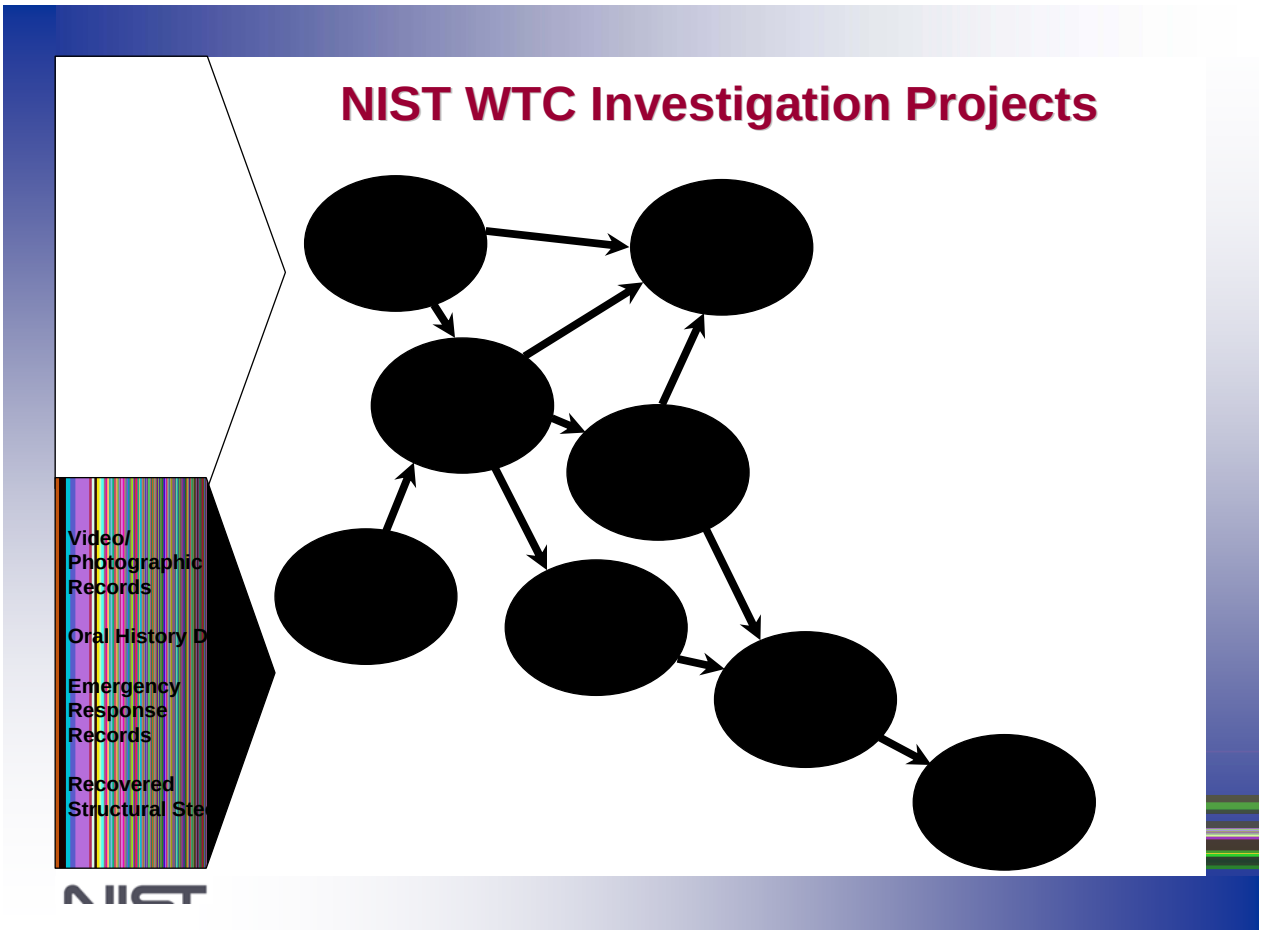

Figure P–1. The eight projects in the federal building and fire safety investigation of the WTC disaster.

National Construction Safety Team Advisory Committee

The NIST Director also established an advisory committee as mandated under the National Construction Safety Team Act. The initial members of the committee were appointed following a public solicitation. These were:

- Paul Fitzgerald, Executive Vice President (retired) FM Global, National Construction Safety Team Advisory Committee Chair
- John Barsom, President, Barsom Consulting, Ltd.
- John Bryan, Professor Emeritus, University of Maryland
- David Collins, President, The Preview Group, Inc.
- Glenn Corbett, Professor, John Jay College of Criminal Justice
- Philip DiNenno, President, Hughes Associates, Inc.

- Robert Hanson, Professor Emeritus, University of Michigan
- Charles Thornton, Co-Chairman and Managing Principal, The Thornton-Tomasetti Group, Inc.
- Kathleen Tierney, Director, Natural Hazards Research and Applications Information Center, University of Colorado at Boulder
- Forman Williams, Director, Center for Energy Research, University of California at San Diego

This National Construction Safety Team Advisory Committee provided technical advice during the Investigation and commentary on drafts of the Investigation reports prior to their public release. NIST has benefited from the work of many people in the preparation of these reports, including the National Construction Safety Team Advisory Committee. The content of the reports and recommendations, however, are solely the responsibility of NIST.

Public Outreach

During the course of this Investigation, NIST held public briefings and meetings (listed in Table P–2) to solicit input from the public, present preliminary findings, and obtain comments on the direction and progress of the Investigation from the public and the Advisory Committee.

NIST maintained a publicly accessible Web site during this Investigation at http://wtc.nist.gov. The site contained extensive information on the background and progress of the Investigation.

NIST's WTC Public-Private Response Plan

The collapse of the WTC buildings has led to broad reexamination of how tall buildings are designed, constructed, maintained, and used, especially with regard to major events such as fires, natural disasters, and terrorist attacks. Reflecting the enhanced interest in effecting necessary change, NIST, with support from Congress and the Administration, has put in place a program, the goal of which is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation.

The strategy to meet this goal is a three-part NIST-led public-private response program that includes:

- A federal building and fire safety investigation to study the most probable factors that contributed to post-aircraft impact collapse of the WTC towers and the 47-story WTC 7 building, and the associated evacuation and emergency response experience.
- A research and development (R&D) program to (a) facilitate the implementation of recommendations resulting from the WTC Investigation, and (b) provide the technical basis for cost-effective improvements to national building and fire codes, standards, and practices that enhance the safety of buildings, their occupants, and emergency responders.

Table P–2. Public meetings and briefings of the WTC Investigation.

Date	Location	Principal Agenda
June 24, 2002	New York City, NY	Public meeting: Public comments on the *Draft Plan* for the pending WTC Investigation.
August 21, 2002	Gaithersburg, MD	Media briefing announcing the formal start of the Investigation.
December 9, 2002	Washington, DC	Media briefing on release of the *Public Update* and NIST request for photographs and videos.
April 8, 2003	New York City, NY	Joint public forum with Columbia University on first-person interviews.
April 29–30, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on plan for and progress on WTC Investigation with a public comment session.
May 7, 2003	New York City, NY	Media briefing on release of *May 2003 Progress Report.*
August 26–27, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status of the WTC investigation with a public comment session.
September 17, 2003	New York City, NY	Media and public briefing on initiation of first-person data collection projects.
December 2–3, 2003	Gaithersburg, MD	NCST Advisory Committee meeting on status and initial results and release of the *Public Update* with a public comment session.
February 12, 2004	New York City, NY	Public meeting on progress and preliminary findings with public comments on issues to be considered in formulating final recommendations.
June 18, 2004	New York City, NY	Media/public briefing on release of *June 2004 Progress Report.*
June 22–23, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on the status of and preliminary findings from the WTC Investigation with a public comment session.
August 24, 2004	Northbrook, IL	Public viewing of standard fire resistance test of WTC floor system at Underwriters Laboratories, Inc.
October 19–20, 2004	Gaithersburg, MD	NCST Advisory Committee meeting on status and near complete set of preliminary findings with a public comment session.
November 22, 2004	Gaithersburg, MD	NCST Advisory Committee discussion on draft annual report to Congress, a public comment session, and a closed session to discuss pre-draft recommendations for WTC Investigation.
April 5, 2005	New York City, NY	Media and public briefing on release of the probable collapse sequence for the WTC towers and draft reports for the projects on codes and practices, evacuation, and emergency response.
June 23, 2005	New York City, NY	Media and public briefing on release of all draft reports for the WTC towers and draft recommendations for public comment.
September 12–13, 2005	Gaithersburg, MD	NCST Advisory Committee meeting on disposition of public comments and update to draft reports for the WTC towers.
September 13–15, 2005	Gaithersburg, MD	WTC Technical Conference for stakeholders and technical community for dissemination of findings and recommendations and opportunity for public to make technical comments.

- A dissemination and technical assistance program (DTAP) to (a) engage leaders of the construction and building community in ensuring timely adoption and widespread use of proposed changes to practices, standards, and codes resulting from the WTC Investigation and the R&D program, and (b) provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

The desired outcomes are to make buildings, occupants, and first responders safer in future disaster events.

National Construction Safety Team Reports on the WTC Investigation

A final report on the collapse of the WTC towers is being issued as NIST NCSTAR 1. A companion report on the collapse of WTC 7 is being issued as NIST NCSTAR 1A. The present report is one of a set that provides more detailed documentation of the Investigation findings and the means by which these technical results were achieved. As such, it is part of the archival record of this Investigation. The titles of the full set of Investigation publications are:

NIST (National Institute of Standards and Technology). 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers.* NIST NCSTAR 1. Gaithersburg, MD, September.

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Sadek, F. 2005. *Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Baseline Structural Performance and Aircraft Impact Damage Analysis of the World Trade Center Towers.* NIST NCSTAR 1-2. National Institute of Standards and Technology. Gaithersburg, MD, September.

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EXECUTIVE SUMMARY

As part of the analysis of building and fire codes and standards of the National Institute of Standards and Technology (NIST) World Trade Center (WTC) Investigation, this report supports the effort to document the fuel oil distribution system located in WTC 7. Studies are under way to determine whether internal fires may have led to the collapse. A possible factor to the collapse of WTC 7 was the fuel system for emergency power located throughout the 47-story building. The purpose of this report is to document the fuel oil distribution system (including all fuel oil tanks, pumps, generators, routing of the piping, and system functions) and the associated fire protection features of the fuel oil system that existed in WTC 7 on September 11, 2001.

The document search for this report located design drawings and specifications that were submitted to and approved by the Port Authority of New York and New Jersey (PANYNJ or Port Authority) in accordance to the Building Code of the City of New York (BCNYC) requirements. In addition to the above documents, a set of certified as-built drawings for the Ambassador Construction project was located.

WTC 7 contained two independently supplied and operated fuel systems for emergency power: the Base Building system and the Salomon Brothers system. The Base Building system consisted of four sub-systems: the Silverstein sub-system (original system), the Ambassador Construction sub-system, the American Express sub-system, and the Mayor's Office of Emergency Management sub-system. The Ambassador Construction and American Express sub-systems were supplied with fuel from the original Base Building storage tanks installed below the loading dock. The Mayor's Office sub-system contained its own storage tank that was filled from the original system tanks. The other system (the Salmon Brothers system), was supplied by a separate set of fuel storage tanks, also located below the loading dock. The systems had differing design features with each system operating independently. The two systems combined with all of the sub-systems, contained more than an estimated 43,000 gal of fuel, assuming all tanks were filled near capacity. Since the owners had contracts with fuel delivery services to maintain the tanks full at all times, this assumption is considered reasonable.

E.1 BASE BUILDING SYSTEM

The Silverstein system was installed in 1987. The system contained two 12,000 gal capacity storage tanks located below the 1st floor loading dock. The tanks supplied no. 2 diesel fuel to a duplex fuel oil pump set located in the 1st floor Fuel Oil Pump Room situated between the west banks of passenger elevators. The pumps supplied fuel to a 275 gal capacity day tank[1] in the 5th floor Generator Room, which supplied fuel to two 900 kW generators. The fuel oil return (FOR) pipes ran in parallel with the fuel oil supply (FOS) pipes returning fuel back to the day tank and storage tanks.

In 1994, the Silverstein system was modified for the Ambassador Construction project. The Base Building system was extended by tapping off the existing FOS pipe to the duplex pump set in the 1st floor

[1] A day tank is a small-capacity fuel storage tank located near the generator(s) and kept full by a transfer pump from a main tank at or below grade. The BCNYC limits fuel supplies to no more than one 275 gal (maximum) day tank on any floor above the 1st.

Fuel Oil Pump Room. The pump supplied fuel to the engine mounted day tank (50 gal capacity) of the 125 kW generator located on the 9th floor. The FOR pipe ran back to the existing FOR at the 1st floor.

Again in 1994, the Silverstein system was modified for the American Express project. The Base Building system was extended by tapping off the existing FOS suction pipe and adding another duplex pump set in the 1st floor Fuel Oil Pump Room. A 275 gal day tank was added on the 8th floor, which supplied fuel to the 350 kW generator.

In 1999, the Silverstein system was modified for the Mayor's Office of Emergency Management project. The system added two additional duplex pump sets. The 1st pump set was used to fill a new 6,000 gal above ground storage tank on the 1st floor. The second pump set was used to supply fuel from the new storage tank to the new 275 gal day tank and three 500 kW generators on the 7th floor.

The four Base Building sub-systems were similarly designed, but were independently operated by the fuel pump set controllers for each system. The sub-systems included many similar devices, such as anti-syphon valves, foot valves, fusible link gate valves, solenoid valves, fuel level switches, rupture basins and leak detectors, all performing specific operations. Although each sub-system was not designed exactly like the other, the four sub-systems operated and performed similarly. Each sub-system operated based on the liquid level in the day tanks. Each sub-system control panel (four total) started and stopped the respective pump set by the liquid level switch in each day tank.

The various fuel devices listed above provided increased assurance that unwanted fuel discharge would not occur. The devices listed above would have prevented, in most if not all scenarios, unwanted fuel discharge unto the floor below. The devices were installed to isolate fuel from open piping breaks, prevent backflow and drainage of fuel unto the floor below and shut off the pump set to prevent fuel flow.

E.2 SALOMON BROTHERS SYSTEM

In 1990, a second fuel oil distribution system was installed for the Salomon Brothers project. The fuel for the system was supplied by two 6,000 gal storage tanks located under the loading dock. FOS pipes ran to the duplex pump set on the 1st floor. The FOS discharge pipes ran up to the 5th floor supplying fuel to nine 1,750 kW generators. The FOS discharge pipe ended at a valve rig where the FOR pipe started and ran back to the pump set and storage tanks.

The Salomon Brothers fuel system had a similar but slightly different design than the Base Building system. Similar to the Base Building system, the pump set provided fuel from two underground storage tanks. However, there was already a day tank on the 5th floor associated with the base system and the BCNYC did not permit more than one day tank per floor. Thus, the Salomon Brothers system used a continuously pressurized fuel supply piping system without a day tank. The fuel pressure in the FOS discharge piping was maintained by a liquid level switch and back pressure regulator in the 5th floor valve rig. The liquid level switch started and stopped the pump set in accordance with the liquid level in the FOS discharge pipe. The pump was powered from the generators such that any time any one generator was running, the pump was powered.

Chapter 1
INTRODUCTION

World Trade Center (WTC) 7 collapsed on September 11, 2001. The collapse of WTC 7 is under study to determine whether the internal fires on that day were probable causes for the building collapse. A possible contributor to the fires within WTC 7 is the fuel oil distribution system for emergency power located throughout the building. As part of the WTC 7 study, it is important to know where the fuel oil distribution components were located and to understand the system performance. The purpose of this report is to document the fuel oil distribution systems (including all fuel oil tanks, pumps, generators, routing of the piping and system functions) and the associated fire protection features of the fuel oil system that existed in WTC 7 at the time of the collapse.

WTC 7, located between Vesey and Barclay streets and Washington Street West Broadway in New York City, was an air rights building constructed over the existing two-story Con Edison Substation. The 47-story building (constructed out of steel and concrete) underwent numerous modifications as tenants moved in and out of WTC 7. Certain tenants required emergency power for their operations. To accommodate specific tenant requirements, the Base Building fuel oil distribution system was modified. The original Base Building fuel system (Silverstein system) was installed in 1987. The system contained numerous components located from below grade to the 5th floor. In 1994 and 1999, the Base Building system was modified three times to accommodate tenant requirements. Many components were added and the system was extended up to the 9th floor. Also, in 1990, a second fuel oil distribution system was installed for a multi-floor tenant (Salomon Brothers). The system was installed from below grade to the 5th floor. The following chapters describe in detail the fuel oil distribution system designs, layouts, performances, and modifications.

The document search for this report located design drawings and specifications that were submitted to and approved by the Port Authority of New York and New Jersey (Port Authority) in accordance with the Building Code of the City of New York requirements. In addition to the above documents, a set of certified as-built drawings for the Ambassador Construction project was located.

Whenever work was done in the WTC buildings, a project number was assigned by the Port Authority under which all contracts, drawings, and correspondence was filed. These numbers are typically of the format W(yy)-1234 (where yy is the year initiated and 1234 is a four-digit number). This report includes these numbers as references to individual projects, and files retained by the Port Authority are identified by these numbers.

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Chapter 2
FUEL OIL PROVISIONS OF THE BCNYC

The facilities of the Port Authority of New York and New Jersey (PANYNJ) are not subject to the requirements of the local building codes, although PANYNJ policy was to follow the New York City codes where applicable. The distribution system was to be designed to the provisions of the Building Code of the City of New York (BCNYC). As previously stated, the fuel oil distribution systems were installed in 1987 and 1990 with modifications occurring in 1994 and 1999. Generally, building construction is performed to the most current code provisions at the time of installation. The code provisions are often updated as technology and experience advance. However, between 1987 and 1999, the fuel oil system provisions of the BCNYC remained unchanged. Thus, a single set of code provisions can be summarized for the initial design and the subsequent modifications. The BCNYC code provisions used for the installations and modifications to the fuel oil distribution systems in World Trade Center (WTC) 7 are listed in the remaining sections of this chapter.

2.1 GENERAL REQUIREMENTS

The hydrocarbon fuel oil used shall be as classified in Reference Standards (RS) 14-3 and RS 14-12 and shall have a flashpoint not lower than 100 °F (27-827).[1, 2]

2.2 FUEL OIL STORAGE EQUIPMENT

All fuel oil storage tanks shall be built of steel plates or sheets, made by the open hearth or basic oxygen process (27-828(a)(1)).

Tanks shall be welded, riveted and caulked, or riveted and welded. Flanges or other pipe connections may be welded. Filler of any kind between plates shall be prohibited (27-828(a)(2)).

Tanks to be buried shall be cleaned and then coated on the outside with two coats of red lead, or equivalent. Tanks shall be further protected by a coating of hot tar, asphalt, or equivalent rust resistive material, applied at the work site. Tanks installed inside buildings above ground shall be coated with one coat of red lead, or equivalent (27-828(a)(3)).

All buried storage tanks shall be constructed of at least ¼ in. thick metal and shall be designed to withstand any external loads to which the tank may be subjected (27-828(a)(4)).

Shop fabricated storage tanks shall be installed without structural alteration (27-828(a)(5)).

All openings shall be through the top of the storage tank (27-828(a)(6)).

[1] The fuel oil used in WTC 7 was no. 2 fuel oil.

[2] The BCNYC references given, denoted by 27-XXX, is the new numbering system.

Tanks for no. 2 commercial grade oils need not have manholes. However, if manholes are used for such oils, the manhole covers shall be bolted and made gastight (27-828(a)(7)).

Tanks shall be located at least 7 ft, measured in the most direct manner, from any source of exposed flame unless protected as provided in 27-829(a)(2) or 27-829(a)(3) and at least 2 ft from any surface where the temperature exceeds 165 °F (27-828(a)(9)).

Cylindrical tanks, except vertical tanks above ground outside of buildings, of more than 275 gal capacity shall be constructed as follows (27-828(b)):

1. Tanks 36 in. in diameter and less – at least ¼ in. shell and ¼ in. heads.

2. Tanks 37 to 72 in. in diameter – at least ¼ in. shell and 5/16 in. heads.

3. Tanks 73 to 120 in. in diameter – at least 5/16 in. shell and 3/8 in. heads.

4. Tanks over 120 in. in diameter shall be of at least 3/8 in. steel and shall be stiffened by angle rings or equivalent members so as to retain their cylindrical form.

All oil storage tanks of 275 gal capacity or less that are not buried shall have a minimum thickness of shell and head plates of no. 10 manufacturer's standard gauge steel plate. Storage tanks of 60 gal capacity or less shall be similarly constructed but need not be thicker than no. 14 manufacturer's standard gauge (27-828(d)).

2.3 LOCATION OF TANKS

Inside of buildings, above ground, on the lowest floor as follows (27-829(a)):

1. Storage tanks having a capacity of 550 gal or less may be installed above ground on the lowest floor of a building, provided that such tanks are mounted on adequate noncombustible supports, with the tank anchored thereto. No more than 550 gal of total storage capacity may be connected to one burner or may be installed without the protection provided in paragraph 27-829(a)(2) or 27-829(a)(3).

2. Storage tanks having a capacity of more than 550 gal but less than 1,100 gal may be installed above ground on the lowest floor of a building, provided that all portions of such tanks above the floor are completely enclosed with noncombustible construction having at least a 2 h fire resistance rating. Weep holes 1 in. in diameter shall be provided at least every 3 ft along the bottom of the enclosure unless at least 15 in. of clearance, together with access door, is provided between the tank and the enclosure.

3. Storage tanks having a capacity of 1,100 gal or more may be installed above ground on the lowest floor of a building, provided that all portions of such tanks above the floor are completely enclosed with noncombustible construction having at least a 3 h resistance rating. At least 15 in. clearance shall be provided over the tanks and on all sides between the tanks and the enclosure. A noncombustible access door, constructed so as to preserve the integrity of the fire resistive enclosure, shall be installed in the enclosure above the point where the

capacity of the enclosure below the door sill would be equal to the capacity of the largest tank installed. When the longest inside dimension of the enclosure exceeds 35 ft, access doors shall be installed at intervals not exceeding 12 ft. Columns, pipes, or similar obstructions may project into the required 15 in. of space within the enclosure, provided that access door or doors are so arranged that all portions of the enclosure are accessible for servicing.

4. The capacity of individual storage tanks in no case shall exceed 20,000 gal.

Inside of building above the lowest floor as follows (27-829(b)):

1. Fuel oil storage tanks having a capacity of 275 gal or less may be installed inside of buildings above the lowest story when provided with a 4 in. thick concrete or masonry curb, or with a metal pan of gauge equal to the gauge of the tank, completely surrounding the tank and of sufficient height to contain two times the capacity of the tank. The number of such oil storage tanks shall be limited to one per story.

2. Storage tanks having a capacity of 275 gal or less, installed above the lowest floor inside a building shall be filled by means of a transfer pump supplied from a primary storage tank located and installed as otherwise required. A separate transfer pump and piping circuit shall be provided for each storage tank installed above the lowest floor. No intermediate pumping stations shall be provided between the storage tank and the transfer pump. Appropriate devices shall be provided for the automatic and manual starting and stopping of the transfer pumps so as to prevent the overflow of oil from these storage tanks.

3. A float switch shall be provided with the curb or pan around the storage tank and shall be arranged so as to sound an alarm and stop the transfer pump in case of failure of the tank or the control in the tank. The operation of the float switch shall be tested at least once each week. An alarm bell shall be located in the same room with the tank and a visual and audible alarm shall be located in a maintenance office.

Inside of buildings, below ground as follows (27-829(c)):

1. Storage tanks having a capacity greater than 275 gal may be buried inside a building provided that the top of the tank is at least 2 ft below floor level. In lieu of 2 ft of earth over the tank, the tank may be covered by concrete flooring having the same thickness as the basement floor, but not less than 4 in. concrete and reinforced with 2 in. by 2 in. mesh of at least no. 20 U.S. standard gauge steel wire. Tanks shall be placed in firm soil and shall be surrounded by clean sand or well-tamped earth, free from ashes and other corrosive substances, and free from stones that will not pass through a 1 in. mesh. When necessary to prevent floating, tanks shall be securely anchored.

2. No tank shall be buried within 3 ft of any foundation wall or footing.

Outside of building, below ground as follows (27-829(d)):

1. Storage tanks located outside of buildings and below ground shall be buried with the top of the tank at least 2 ft below ground. Tanks shall be placed in firm soil and shall be surrounded

by clean sand or well-tamped earth, free from ashes or other corrosive substance, and free from stones that will not pass through a 1 in. mesh. When necessary to prevent floating, tanks shall be securely anchored.

2. No tank shall be buried within 3 ft of any foundation wall or footing.

2.4 PIPING

Exposed piping shall be protected against mechanical damage and shall be adequately supported with rigid metal fasteners or hangers. All pipes connected to buried tanks, except test well piping, shall be provided with double swing joints at the tank (27-830(a)(1)).

Only new wrought iron, steel, or brass pipe, or type K or heavier copper tubing, or aluminum alloy tubing, properly identified, may be used. Metal tubing when used for conveying oil shall be adequately protected. Such tubing may be installed at the burner without protection. Drawn tubing when used in domestic installations shall be of at least 3/8 in. inside diameter up to the shut-off valve at the burner. Soldered connections shall be prohibited (27-830(a)(2)).

Overflow pipes, where installed, shall not be smaller in size than the supply pipe (27-830(a)(3)).

Where a shut-off valve is installed in the discharge line from an oil pump, a relief valve shall be installed in the discharge line between the pump and the 1st shut-off valve (27-830(b)(1)).

A relief or pressure regulating valve shall be provided in the oil piping system on the heater side of the shut-off valves (27-830(b)(2)).

Relief valves shall be set to discharge at not more than one and one-half times the maximum working pressure of the system. The discharge from relief valves shall be returned to the storage tank or to the supply line. There shall be no shut-off valve in the line of relief (27-830(b)(3)).

Fuel oil heaters shall not be installed within the steam or water space of a boiler. Fuel oil heaters and the connecting piping shall be arranged to prevent oil leakage from being transmitted to the boiler. This may be accomplished by any of the following methods (27-830(c)):

1. By discarding the condensate from the heaters.

2. By using approved double tube or other approved heaters.

3. By means of a secondary hot water or steam heating system where the water or steam from the boiler has no direct contact with the oil heater.

4. By a sight tank arrangement for collecting and inspecting the condensate which is provided with a pump controlled by a hand switch for returning the condensate to the normal return system.

5. By such other method as may be permitted by the commissioner.

A vent pipe of iron or steel, without trap, draining to the tank, shall be provided for each storage tank. The lower end of the vent pipe shall not extend more than 1 in. through the top of the storage tank. Cross-connection between a vent pipe and fill pipe is prohibited (27-830(d)(1)).

Where a battery of storage tanks designed to hold the same grade of oil is installed, vent pipes may be run into a main header (27-830(d)(2)).

Vents shall be at least one and ¼ in. in diameter for storage tanks not exceeding 1,100 gal capacity and at least 2 in. in diameter for storage tanks of 1,100 gal or more except that vents for storage tanks of 60 gal capacity or less shall be at least ½ in. in diameter. Vents for tanks inside of buildings above the lowest floor shall be run into the primary storage tank vent (27-830(d)(3)).

Vent pipes shall be provided with an approved weatherproof hood having a free area of at least the pipe size area. Vent pipes shall terminate outside the building in a non-hazardous location, at least 2 ft from any building opening and not less than 2 ft nor more than 12 ft above the fill pipe terminal, unless otherwise permitted by the commissioner. If the vent pipe terminal is not visible from the fill pipe terminal location, a 1 in. tell-tale line shall be connected to the tank and shall parallel the fill pipe and terminate at the fill pipe terminal with an unthreaded end. Such tell-tale lines shall be provided with a check valve set to prevent flow of surface water to the storage tank (27-830(d)(4)).

Fill pipes shall terminate outside the buildings, with the fill pipe terminal located at or above grade, at least 2 ft from any building opening and 5 ft from any subway grating at or below the level of the fill pipe terminal. No fill pipe shall be less than 2 in. in diameter. Where there are facilities for the delivery tank truck to drive onto the premises, the fill terminal may be located elsewhere than at the curb (27-830(e)(1)).

Each storage tank shall be provided with a separate fill pipe, except that where a battery of tanks is installed containing the same grade of oil, a common fill and header pipe may be installed (27-830(e)(2)).

Where the top of the storage tank is above the fill pipe terminal, the fill pipe shall be connected to the top of the tank and provided with a shut-off valve and swing check valve both of which shall be located at the fill pipe terminal. However, the shut-off and check valves may be installed in an accessible location inside the building at or below the level of the fill pipe terminal (27-830(e)(3)).

All fill pipe terminals shall be of an approved type, and shall be provided with lugs for embedding in concrete. In lieu of lugs, a set screw or threads to fasten the terminal to the fill pipe may be used (27-830(e)(4)).

Piping from transfer pump to storage tanks above the lowest floor as follows (27-830(f)):

1. The piping from a transfer pump to storage tanks at levels above the lowest floor in buildings, the return piping, and vent piping shall comply with the applicable provisions of subdivisions 27-830(a) and 27-830(d) and shall be enclosed in a shaft constructed of 4 in. concrete or masonry having a 4 in. clearance from all pipe or pipe covering. Provision shall be made for expansion in piping without the use of expansion joints.

2. Where it is necessary to make horizontal offsets in the supply piping and pipe shafts such piping shall be enclosed in a sleeve of other piping of at least no. 10 manufacturer's standard gauge steel, two sizes larger and arranged to drain into the shaft. Horizontal piping offsets shall be further enclosed in construction having a 2 h fire resistance rating.

3. A drain pipe shall be installed at the base of shafts enclosing the supply and overflow piping. The pipe shall lead to an open sight drain or to an open sump.

4. Oil lines for tanks above the level of the lowest floor shall be seamless steel pipe of a weight not less than ASA schedule 40 with welded connections.

5. Pipe shafts shall not be penetrated by or contain other piping or ducts.

The heating of oil in storage tanks shall be by means of coils using low pressure hot water or steam, or by means of electric heaters approved for use in oil storage tanks (27-830(g)).

Where more than one storage tank is connected to a common supply line, a shut-off valve shall be provided in the supply line at each tank. Where more than one burner is connected to a supply line a shut-off valve shall be provided at each burner. Where a single tank and a single burner are installed, a shut-off valve shall be required in the supply line at the tank and another at the burner. Valves shall be brass or equivalent in corrosion and fire resistance, shall provide tight shut-off, and shall be rated at 125 psi or greater as required by the pressure in the system (27-830(h)(1)).

Where a storage tank is located so that the top of the tank is above the oil inlet to the burner or to the fuel pump, and the storage tank capacity is greater than 275 gal, the supply line to the burner shall be provided with an approved anti-syphon device. The device shall be located at the highest point in the supply line. Where an approved foot valve is used in the tank and the tank is constructed with a manhole, an anti-syphon device shall not be required (27-830(h)(2)).

The pressure in oil lines to burners located above the lowest floor of a building shall not be more than is required to circulate oil to and from the burners, and all parts of the oil system shall be capable of withstanding the maximum working pressure in that part of the system (27-830(h)(3)).

A remote control shall be provided to stop the flow of oil to any burner. Such control shall be located outside the entrance to the room in which the burner is located and as close to such entrance as practicable, except that when an outside location is impracticable, such control may be located immediately inside the room in which the burner is located, provided such location is accessible at all times. On storage tanks of 60 gal or less capacity used with manually operated burners, such remote control may be installed in the supply lines between tank and burner (27-830(h)(4)).

Pressure in a storage tank for the purpose of discharging oil shall be prohibited (27-830(h)(5)).

In systems where either steam or air is used for atomizing the oil, the oil and the atomizing supply shall be interlocked so that where the supply of either is interrupted, the supply of the other will be immediately cut off (27-830(h)(6)).

All tanks located inside buildings shall be provided with an oil level indicating device. Test wells shall be prohibited in tanks located inside of buildings. Unused tank openings shall be permanently sealed to prevent the removal of plugs or cover (27-830(i)(1)).

Oil level indicating devices shall be designed and constructed of substantial materials so that there can be no leakage of oil or oil vapor (27-830(i)(2)).

Test wells in storage tanks located outside of buildings shall be capped oil tight and kept closed when not in use (27-830(i)(3)).

2.5 CONTROLS

With each automatic burner a set of safety controls of the electric, pneumatic, hydraulic, or mechanical type shall be installed and maintained in good working order. The controls shall provide the following functions (27-831):

1. Ignition
2. Stack or combustion control
3. High temperature or pressure control

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Chapter 3
BASE BUILDING DESIGN (1987)

The Base Building fuel oil system (Silverstein system) design was submitted to the Port Authority of New York and New Jersey (PANYNJ) for approval in 1987 under PANYNJ submittal number W-01437. The system was designed by the development team of:

- Owner/Developer: Silverstein Properties, Inc.
- Architect: Emery Roth & Sons, P.C.
- Structural Engineer: The Office of Irwin G. Cantor, P.C.
- Engineer: Syska & Hennessy

3.1 BASIC LAYOUT

The fuel distribution system was designed for no. 2 diesel fuel. The design started with two storage tanks located below the 1st floor loading dock located on the south side of the building (Fig. 3–1). The storage tanks were connected with a 2 in. fuel oil supply (FOS) pipe leading to a duplex fuel oil pump set located at the north wall of the 1st floor Fuel Oil Pump room which was located between the two west banks of passenger elevators. The fuel was pumped via a 2 in. FOS pipe to a 275 gal day tank located on the north wall of the 5th floor Generator Room, which was located at the west end of the south wall (Fig. 3–2). The 2 in. FOS pipe, which led to the day tank, ran vertically up a shaft near the west bank of passenger elevators. The shaft where the FOS pipe was located also contained other building utilities. The day tank supplied fuel to two emergency generators located on the east wall of the 5th floor Generator Room. A 2 in. fuel oil return (FOR) pipe, ran parallel with the FOS pipe back to the day tank. The FOR pipe continued back to the pump sets and storage tanks. An elevation diagram showing the floor locations of components is provided as Fig. 3–3.

3.2 COMPONENT DETAILS

The two Silverstein storage tanks had a capacity of 12,000 gal each. Each storage tank had a fuel fill box at grade and was specified to be constructed of fiberglass reinforced plastic.

The fuel oil pump set consisted of a strainer and two positive displacement pumps specified for 3/4 hp. The pump schedule on the drawings listed the pumps as 4.4 gpm at 3,500 rpm with a design pressure of 50 psi. Each pump had a relief valve set at 100 psi. The pump set was designed to have the lead pump start and stop automatically in response to the level controller in the day tank. A hand oil pump was also to be installed in parallel with the pump set. The hand oil pump was specified as a multiple-acting oscillating force type pump with a capacity of 30 gpm at not more than 50 double strokes per minute. The FOS discharge piping also contained a check valve.

The 275 gal day tank was equipped with a high-level alarm, pump on, pump off, and low-level alarm. The tank was specified to be equipped with a double-throw selector switch for active pump selection. Level controls were to automatically start the pump set at the low level and stop the pump set at the high-level settings to maintain oil supply in the day tank. Alarm actuators were programmed to sound an alarm when the oil level in the tank fell below the low-level pump cut-in setting or rose above the high-level pump cutout setting. The day tank supply line (FOS discharge line) had a solenoid valve installed. The day tank sat inside a 550 gal capacity collecting pan. The collecting pan contained an alarm device to detect fuel and a drainpipe with a capped off valve. The collecting pan had a high-level pump cutoff and alarm set to automatically stop the pump set and sound an alarm when the oil reached the high-level setting in the collecting pan. The day tank also had a fuel oil vent pipe that terminated outside of the south Generator Room wall.

The two generators were specified for 900 kW, 460 V, 3 phase and equipped with automatic engine starting controls and alarms. Alarm indicators included:

- Low and high oil pressure
- High cooling water temperature
- Low warm-up jacket water temperature
- Day tank low and high fuel level
- Low battery voltage
- Over speed
- Failure to start

The Silverstein FOS and FOR pipes were contained in an outer pipe that protected the fuel pipe. The outer pipe was joined with welded flanges and oil tight gaskets. The outer pipe was covered with 2 in. calcium silicate (or equivalent) to provide a 2 h fire resistance rating. The outer pipe contained 1 in. couplings with inspection plugs located approximately 50 ft on center. The outer pipe contained inner pipe support spiders approximately 10 ft on center. The high points of the FOS suction pipe were equipped with anti-siphon valves.

3.3 FIRE PROTECTION

Sprinkler drawings indicate that the Mechanical Equipment Rooms were to be protected with a wet pipe sprinkler system designed for ordinary hazard group I with a minimum density of 0.16 gpm/ft^2 over 1,500 ft^2 with a maximum spacing of 130 ft^2 per head.

Sprinkler drawings indicate that the Fuel Oil Pump Room was to be protected with a dry pipe sprinkler system designed for ordinary hazard group III with a minimum density of 0.21 gpm/ft^2 over the entire room with a maximum spacing of 130 ft^2 per head. The drawings show a sprinkler main entering into the room but hydraulic design criteria and the location of sprinkler heads are not shown. The 5th floor Generator Room did not contain an automatic fire suppression system.

The drawings do not indicate the construction type of the Fuel Oil Pump Room. The door had a fire rating of 1½ h.

The Generator Room appears to have been constructed of 8 in. solid concrete block. The fire rating of the walls was not indicated on the drawings. The fire rating of the Generator Room doors was 1½ h.

3.4 REFERENCES

Emery Roth & Sons, P.C. 1986. "7 World Trade Center." Architectural Drawings (1, 3, 6, 11).

Emery Roth & Sons, P.C. 1987. "7 World Trade Center." Electrical Drawings (E-3, E-11, E-23, E-24). January 30.

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Syska & Hennessy, Mechanical and Electrical Systems. 1984. 7 World Trade Center Specifications, Section 15520 – Emergency Diesel Generator Systems. October 29.

Syska & Hennessy, Mechanical and Electrical Systems. 1984. 7 World Trade Center Specifications, Section 16007 – Diesel Engine Driven Standby Power Plant. October 22.

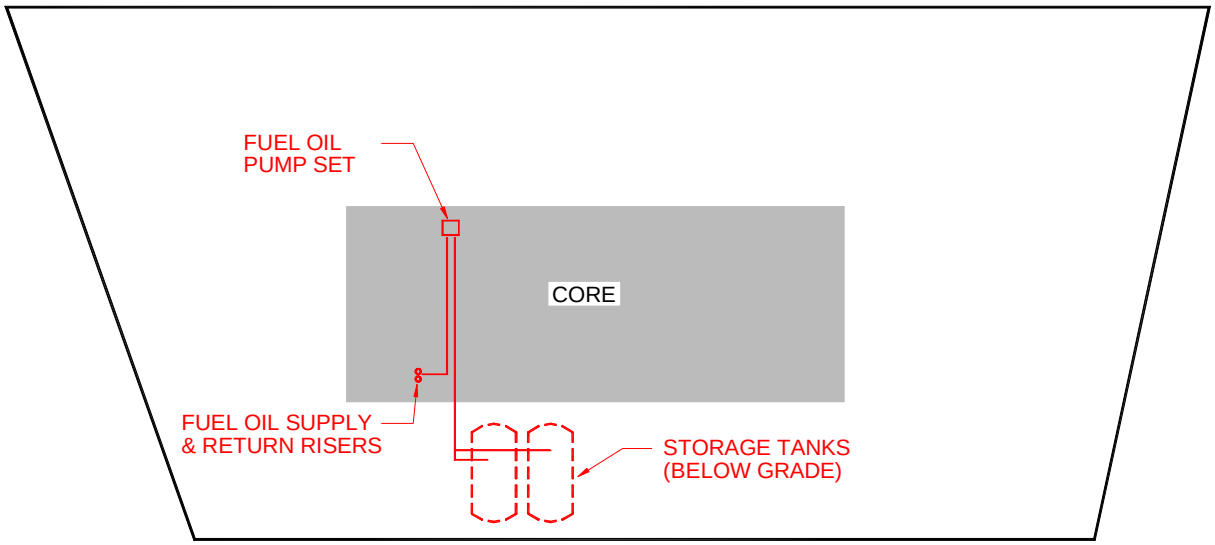

Figure 3–1. Base Building 1st floor fuel oil distribution plan.

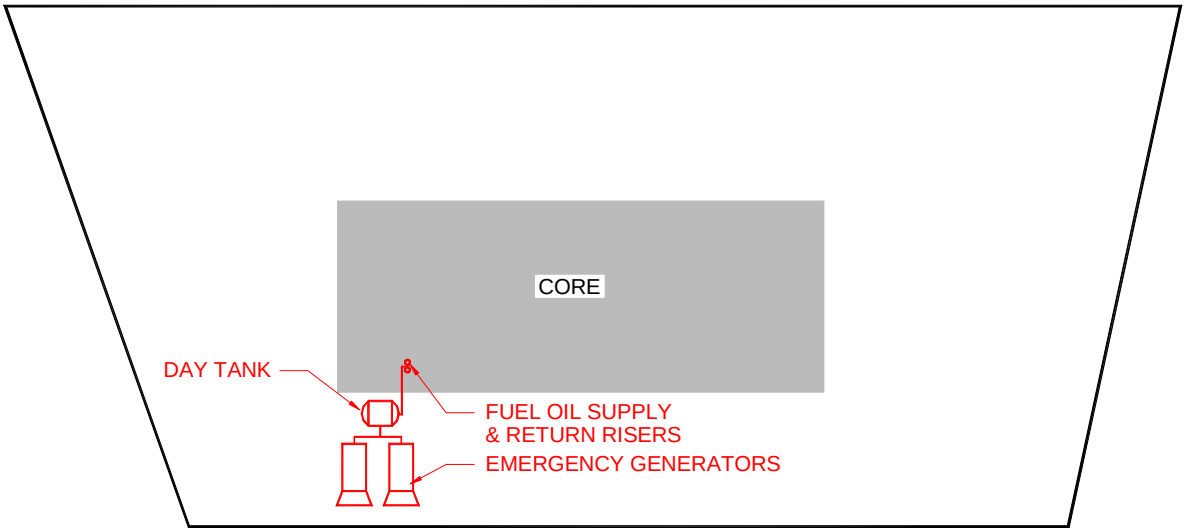

Figure 3–2. Base Building 5th floor fuel oil distribution plan.

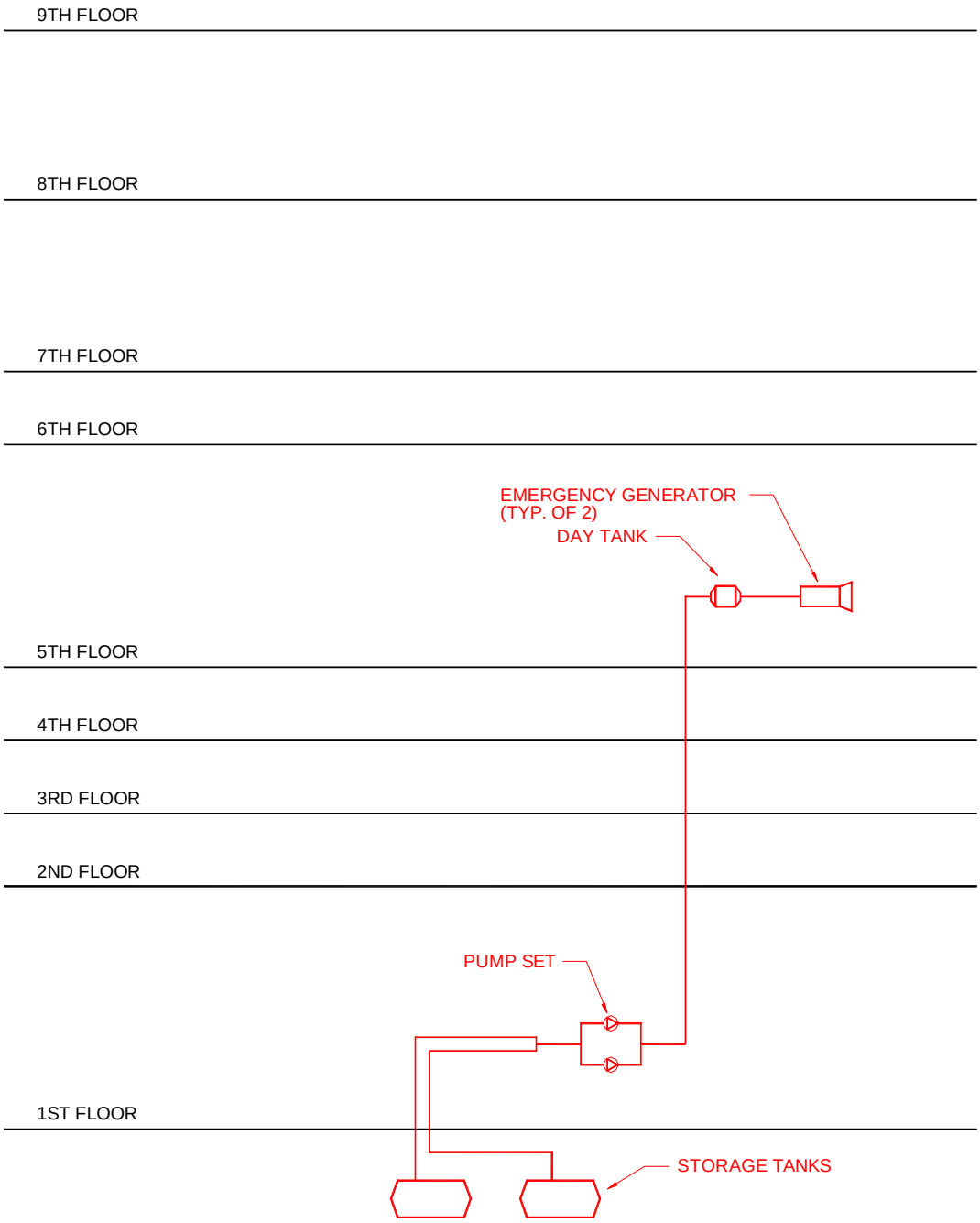

Figure 3–3. Base Building section plan of fuel oil distribution components.

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Chapter 4
AMBASSADOR CONSTRUCTION MODIFICATION (1994)

The Ambassador Construction project occurred in 1994. The project entailed modifying the existing Silverstein system. New fuel oil devices were added to the 1st and 9th floors and connected to the existing system on the 1st floor. The design was submitted to the Port Authority of New York and New Jersey (PANYNJ) for approval as submittal W94-7176.02. The design was developed by the team of:

- Consulting Engineer: GC Eng. & Associates, P.C.
- Milo Kleinberg Design Associates, Inc.

4.1 BASIC LAYOUT

The design called for an additional fuel oil pump set located on the north wall of the existing Fuel Oil Pump Room (Fig. 4–1). The 2 in. fuel oil supply (FOS) pipe for the new pumps was supplied from the suction side of the Silverstein pump set. The fuel oil was pumped up a new 1¼ in. riser located in a new 2 h fire resistance rated shaft dedicated for the fuel oil distribution system. The shaft was constructed out of 4 in. masonry and was located at the south end of the center bank of passenger elevators. The riser supplied fuel to the engine mounted day tank of the emergency generator located on the southwest wall of the 9th floor Mechanical Equipment Room (MER) (Fig. 4–2). The MER was located at the northwest corner of the building. An 1¼ in. fuel oil return (FOR) pipe ran parallel with the FOS pipe from the generator back to the 2 h shaft and then increased in size to 2 in., which returned to the existing FOR pipe of the Silverstein system. A drip pan was installed at the base of the 2 h shaft. The drain of the drip pan emptied into an environmental oil collection tank located at the west wall of the 1st floor Fuel Oil Pump Room. An elevation drawing showing the floor levels of components is provided as Fig. 4–3.

4.2 COMPONENT DETAILS

The fuel oil pump set included a strainer and two pumps specified for 145 gph, 100 psi, 1,725 rpm, and 460 V, 3 phase. The specified model was LO-104A by Preferred Utilities (BSA Approval #412/48-SA). The relief valve was set at 125 psi. The pumps were energized from the float control lever of the emergency generator day tank. A time delayed flow switch in the FOS discharge pipe of the pump set was designed to start the lag pump should the lead pump fail to maintain flow to the day tank. The strainer was specified as model 50, manufactured by Preferred Utilities. The maximum pressure drop specified was less than 1½ in. of mercury.

The transfer pipes (FOS and FOR) were of the same double wall design as the Silverstein system. The inner fuel oil pipes were specified as seamless schedule 40 black steel. The outer containment pipes were specified as 10 gauge welded steel pipe. The piping located outside of the generator room, pump room and vertical masonry shaft was required to be insulated. Details show the pipe located outside the shaft to be enclosed with a 2 h fire rated vermiculite. A shaft detail contains a note to coordinate the risers with the future FOS piping of the American Express distribution system. Details also indicate the FOR riser to

be shared with American Express. An 1½ in. outlet on the 8th floor was installed in the FOR riser for the future American Express system.

The 9th floor emergency generator was shown as 125 kW, 265/460 V, 3 phase. The engine mounted day tank had a capacity of 50 gal and had a 100 gal capacity rupture basin surrounding it.

The drip pan at the base of the masonry shaft consisted of a 2 in. pipe leading to a 20 gal open sight environmental collecting drum/tank. A leak detector was located at the base of the fuel oil riser in the double wall supply pipe drip leg and in the open sight drum. The detectors were specified as model RBS, manufactured by Preferred Utilities-Rimcor Instruments.

4.3 FIRE PROTECTION

The 9th floor Generator Room of the Ambassador Construction project was protected with a wet pipe automatic sprinkler system. The Generator Room was protected with five sprinkler heads being supplied by three branchline pipes. There is no mention of heating provisions for the wet pipe sprinkler system in the Generator Room. No hydraulic design criteria was given for the sprinkler system. The spacing of the sprinkler heads in the Generator Room appears to be 130 ft^2 or less. The branchlines appear to be of the same pipe sizes as the remaining 9th floor sprinkler system that is most likely designed to Light Hazard pipe schedule: 2 heads on 1 in. pipe, 3 heads on 1¼ in. pipe, and 5 heads on 1½ in. pipe. The branchlines were supplied from a 2½ in. looped main that was connected to only the existing east stair standpipe.

The Ambassador Construction Generator Room was enclosed with gypsum board walls consisting of three 5/8 in. 20 gauge metal studs spaced at 16 in. on center and two layers of 5/8 in. fire code C gypsum board on each side. The wall was filled with 3½ in. unfaced batt insulation. The wall extended from slab to slab and was perimeter caulked on both sides at top and bottom. There were three doors to the Generator Room. All three doors were building standard 1 3/4 in. thick hollow metal doors. No fire ratings were given for the walls and doors.

4.4 REFERENCES

GC Eng. & Associates, P.C. 1994. "Ambassador Construction Project." Architectural Drawings (A-5, A-15, A-16). September 9.

GC Eng. & Associates, P.C. 1994. "Ambassador Construction Project." Electrical Drawings (E-1, E-3, E-9). August 24.

GC Eng. & Associates, P.C. 1995. "Ambassador Construction Project." Fire Protection Drawings (SP-2). March 8.

GC Eng. & Associates, P.C. 1995. "Ambassador Construction Project." Mechanical Drawings (H-2, H-4, H-5, H-6, H-9). March 8.

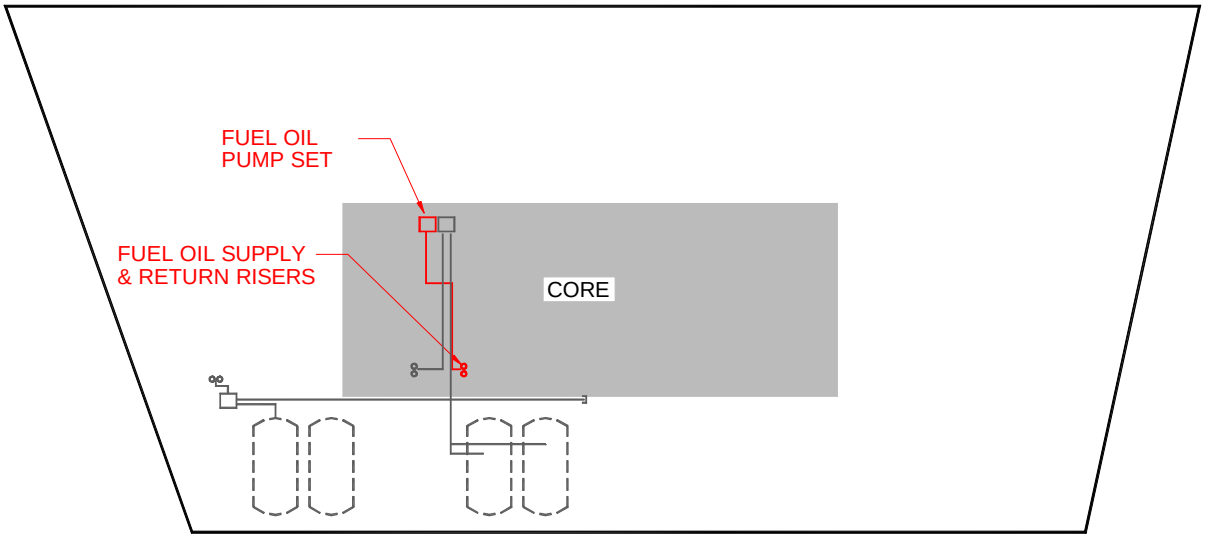


Figure 4–1. First floor fuel oil distribution plan after the Ambassador Construction modification.

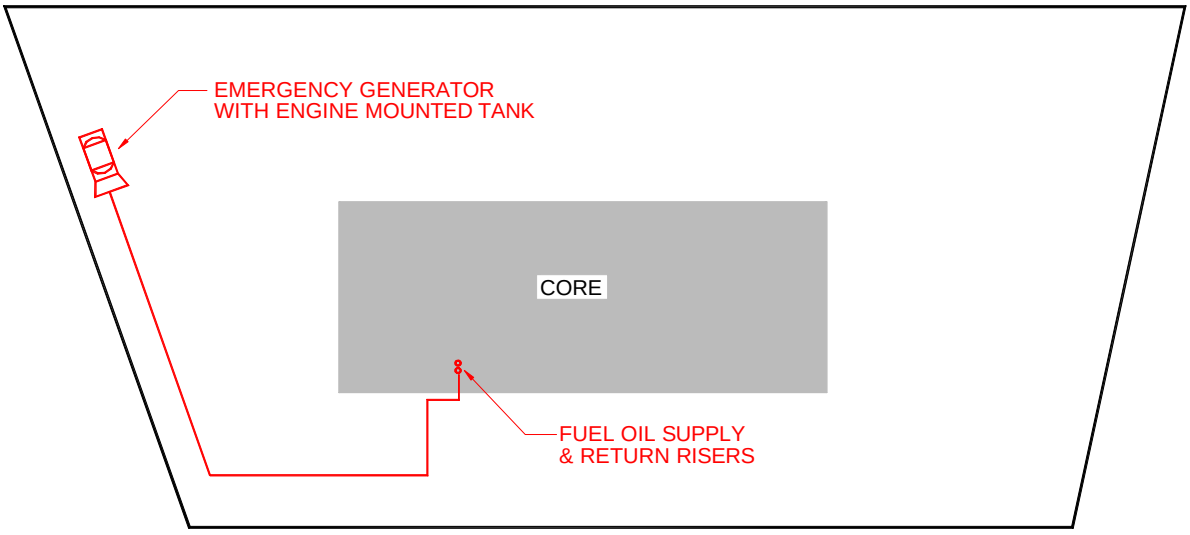
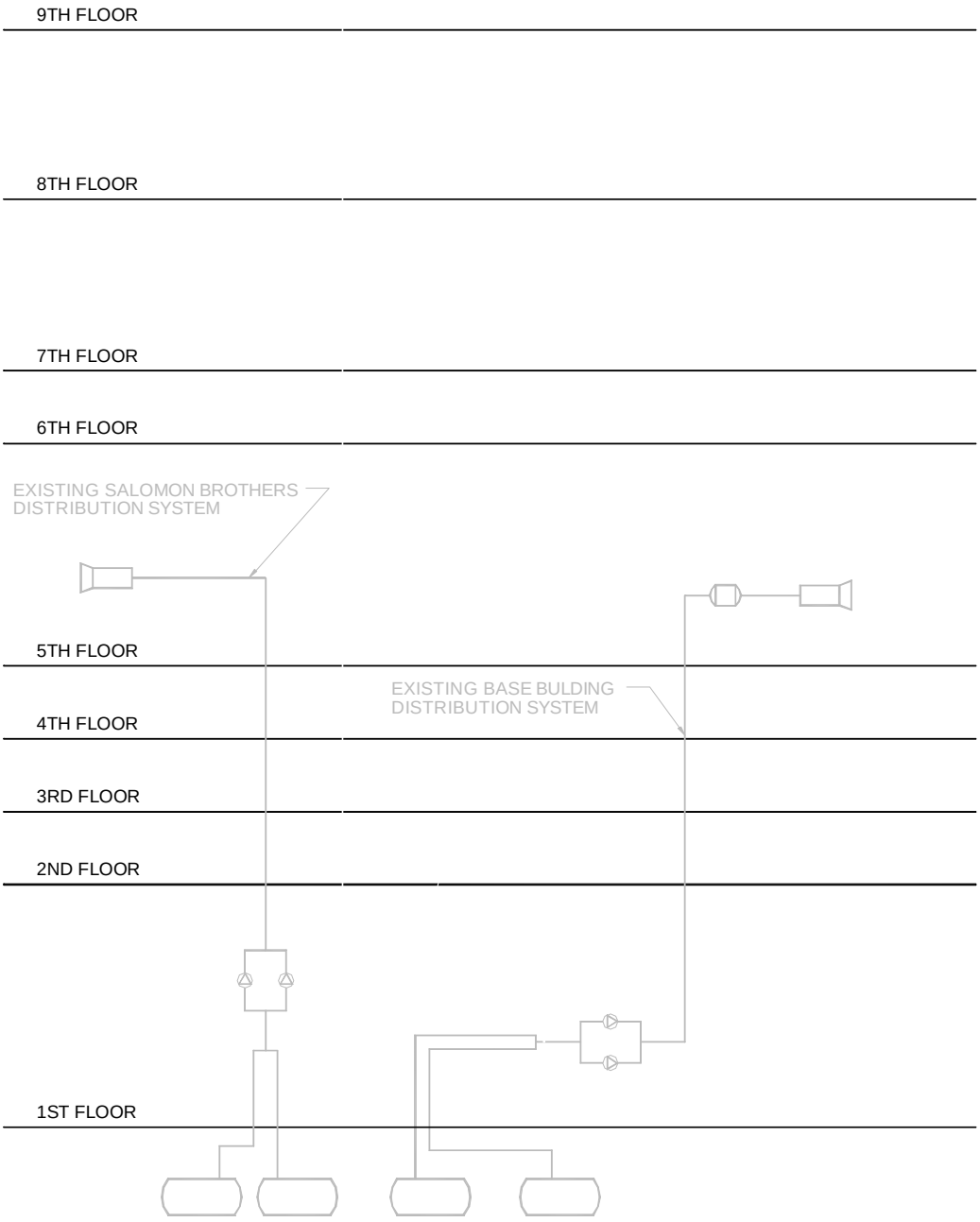


Figure 4–2. Ninth floor fuel oil distribution plan after the Ambassador Construction modification.


9TH FLOOR
8TH FLOOR
7TH FLOOR
6TH FLOOR
EXISTING SALOMON BROTHERS
DISTRIBUTION SYSTEM
5TH FLOOR
EXISTING BASE BULDING
DISTRIBUTION SYSTEM
4TH FLOOR
3RD FLOOR
2ND FLOOR
1ST FLOOR

A detail in the drawings indicated a 14 gauge pan installed at the base of the masonry shaft. The pan was connected by a 1½ in. drainpipe to a 50 gal open basin with a liquid detector. The basin was shown at the east wall of the 1st floor Fuel Oil Pump Room.

5.3 FIRE PROTECTION

The American Express Generator Room on the 8th floor was protected by an automatic wet pipe sprinkler system. The hydraulic design criteria for the floor indicates a system design for Light Hazard with a density of 0.10 gpm/1,500 ft^2. Hydraulic calculations were performed with a sprinkler head K factor of 5.62 and a sprinkler head spacing of 120 ft^2. There were five sprinkler heads in the Generator Room supplied by three branchline pipes. The sprinklers in the Generator Room were spaced at approximately 80 ft^2. The branchline sizes of the Generator Room were sized to match the calculated sizes of the remaining office floor: 1 head on 1 in. pipe, 3 heads on 1¼ in. pipe, and 5 heads on 1½ in. pipe. The brachlines were supplied from a 2½ in. looped main that was connected to only the existing east stair standpipe.

It is not clear which partition type was used to enclose the Generator Room. Drawing 8A2.1 indicates that all walls were to be Type A, unless otherwise noted. Type A walls were gypsum walls that consisted of 2½ in. metal studs spaced at 16 in. on center and one layer of 5/8 in. gypsum board on each side. The gypsum board appears to have been extended only to the ceiling, not to the underside of the structure. Type A appears to have no fire resistive rating. It is apparent that the walls around the Generator Room are thicker than the standard Type A walls on drawing 8A2.1. Also, looking more closely at the drawing, small hash marks are apparent along the Generator Room walls suggesting that a wall type other than Type A was to be used in the design. Drawing A9.4 indicates a wall Type H that may have been used for the Generator Room walls. Type H is a 2 h rated wall consisting of 6 in. concrete masonry unit. filled with grout and one layer of 5/8 in. gypsum board on 7 in. hat channel on one side of the wall. The Type H detail on A9.4 also shows a 4 in. high concrete pad adjacent to the wall. The concrete pad further suggests that a Type H wall was used for the Generator Room since the generator sat on a concrete pad against the wall. The double doors to the Generator Room were fire rated for 1½ h and had smoke seals at the sills.

5.4 REFERENCES

Gensler & Associates Architects. 1994. "American Express 7 World Trade Center, NYC." Architectural Drawings (AO.3, A9.1, A9.2, A9.4, 8A2.1). March 14.

Gensler & Associates Architects. 1994. "American Express 7 World Trade Center, NYC." Electrical Drawings (EO.3). July 26.

Gensler & Associates Architects. 1994. "American Express 7 World Trade Center, NYC." Fire Protection Drawings (8-SP1.2). March 16.

Gensler & Associates Architects. 1995. "American Express 7 World Trade Center, NYC." Mechanical Drawings (MO.4.2, 7-M1.1, 8-M1.2). Febr18 -1.f1

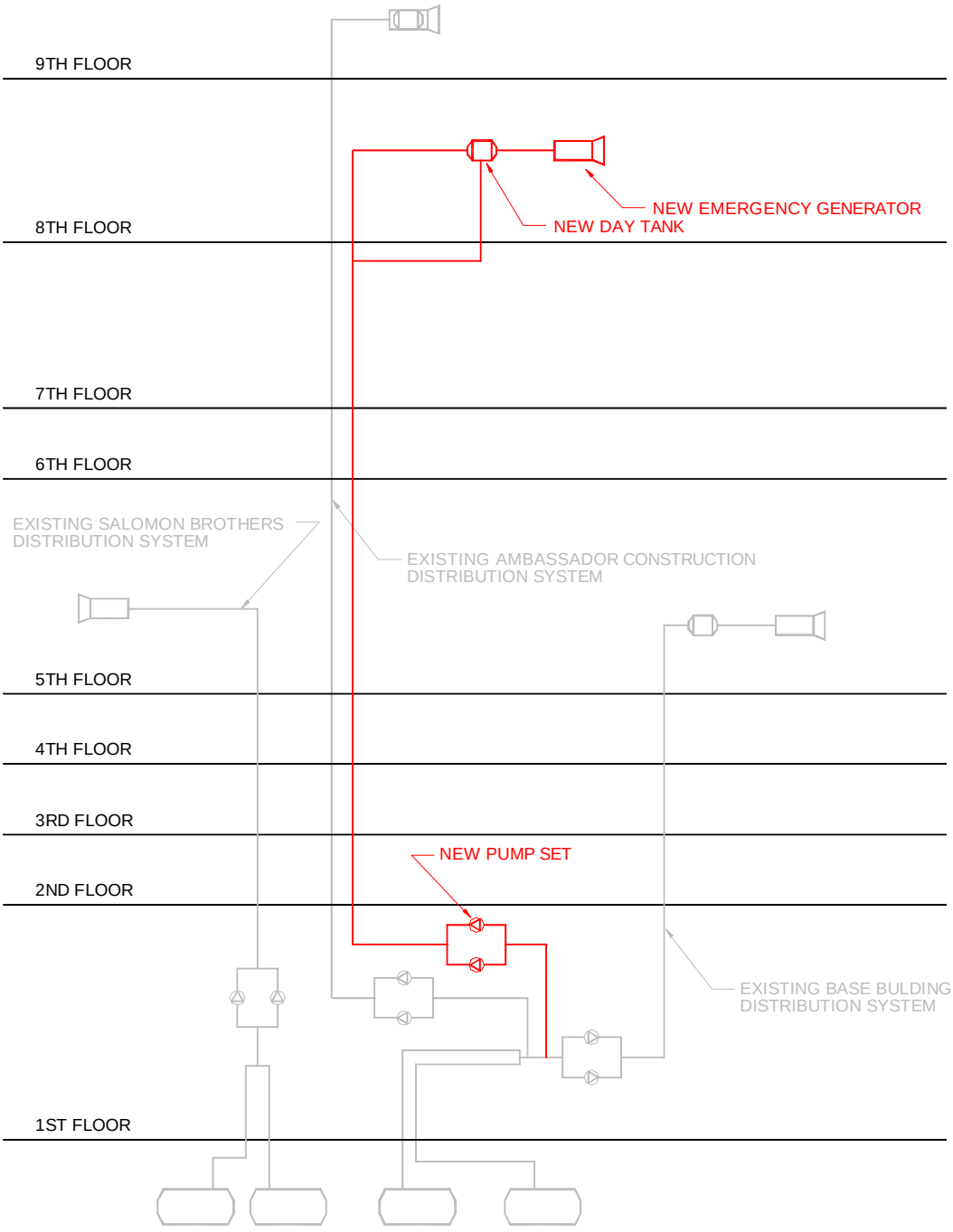


Figure 5–4. Section plan of fuel oil distribution components after the American Express modification.

Chapter 6
MAYOR'S OFFICE OF EMERGENCY MANAGEMENT MODIFICATION (1999)

In 1999, the last modification to the Silverstein system was performed to accommodate the Mayor's Office of Emergency Management (OEM) in World Trade Center (WTC) 7. The design of the fuel oil distribution system was very demanding. The specifications required a design to self-support OEM operations for at least one week. Modifications were made at the 1st and 7th floors. The design was submitted to the Port Authority of New York and New Jersey (PANYNJ or Port Authority) for approval under PANYNJ submittal number W98-7134. The modification was performed by the following team:

- Architect: Swanke Hayden Connell
- Mechanical Engineer: Cosentini Associates, L.L.P.
- Structural Engineer: The Cantor Seinuk Group, P.C.
- Construction Manager: Ambassador Construction Co., Inc.

6.1 BASIC LAYOUT

A fill pump set was connected to the suction side of the existing pump set in the existing Fuel Oil Pump Room (Fig. 6–1). The Fuel Oil Pump Room contained an alarm drum (catch basin for fuel leakage) with leak detection. An 1¼ in. fuel oil supply (FOS) pipe was connected from the fill pump set to a new storage tank located in the existing Televator Room (storage room for battery operated Genie boom lift) between the center and east passenger elevator banks on the 1st floor. An 1¼ in. FOS pipe was run back from the storage tank to an additional transfer pump set in the Fuel Oil Pump Room. From the transfer pump set, a 1¼ in. FOS pipe was connected to the existing FOS riser (it is unclear which existing riser was being referred to, although drawings reference the existing riser being previously approved in submittal number 94-7176 to the PANYNJ). From the 7th floor FOS existing riser, a new 1¼ in. FOS pipe was connected to a day tank at the north wall of the 7th floor Generator Room located on the south side of the building (Fig. 6–2). The Generator Room was classified as Building Code of the City of New York (BCNYC), D-2 Industrial (Low Hazard). The day tank connected three emergency generators using 1¼ in. FOS pipes. A 1½ in. fuel oil return pipe ran from the generators back to the day tank. An elevation diagram showing the floor location of components is provided as Fig. 6–3.

The addition of the new storage tank mandated a fire separation from the existing Televator Room. The separation was accomplished by creating an isolated mezzanine that supported the new storage tank in the Televator Room.

6.2 COMPONENT DETAILS

The fill pump set consisted of a strainer and a pair of 2 hp pumps specified for 2,000 gph, 1,140 rpm, 50 psi total head, 125 psi design pressure, 460 V, 3 phase. The pump was specified as LO-207, manufactured by Preferred Utilities. A relief valve was installed in the FOS discharge pipe. The pump was electrically interlocked with the existing transfer pumps to prevent simultaneous operation.

The transfer pump set consisted of a strainer and a pair of 3/4 hp pumps specified for 700 gph, 50 psi total head, 125 psi design pressure, 460 V, 3 phase. The pump was specified as LO-203, manufactured by Preferred Utilities. A relief valve was installed in the FOS discharge pipe. On a drop in the fuel level below the low level, the lead pump started and stopped when it reached the high level. Should the lead pump fail to supply sufficient flow to the day tank, the fluid level would drop to low-low level control and start the lag pump and sound an alarm. The lag pump was to stop when the level reached high-level control. An alarm was designed to sound at a high-high level.

All fuel oil pipes outside of the Fuel Oil Pump Room and Fuel Oil Tank Room were 10 gauge conduit and in a 2 h fire rated enclosure. A swing check valve was installed in the supply line of the pump. An anti-siphon valve was installed at the high points of the FOS suction pipe.

The alarm drum in the Fuel Oil Pump Room had a capacity of 50 gal and contained a leak detection assembly model TG-EL-D3 manufactured by Preferred Utilities.

The OEM day tank had a capacity of 275 gal and contained a 550 gal rupture basin. The day tank was supplied with two high-level switches wired in-line for safety. If the 1st switch failed to shut down the transfer pump, the second switch's contact was to open and, in turn, shut down the transfer pump, close the solenoid valve and alarm the Building Management System.

The three 7th floor emergency generators were specified as 500 kW, 625 kVA, 480/277 V, 3 phase. A safety interlock was installed to prevent operation of the emergency generator if discharge plenum access was open for service or inspection. The emergency generators were equipped with alarms for in operation, low starting batteries, and emergency shutdown.

The OEM fuel oil storage tank had a capacity of 6,000 gal. The tank was equipped with alarms for low-level, high-level, and leakage/rupture. A solenoid valve was installed in the FOS discharge piping close to the tank. The tank sat on a new structure in the Televator Room constructed specifically for the new storage tank. The new structure was of 4 h fire rated construction and was completely enclosed, with exception to an access hatch. Documentation of the submittal to the PANYNJ indicates that the location, design, and protection of the storage tank were a major issue with the Port Authority, mostly related to an original request to locate the tank on the 7th floor near the generator. This request was denied by New York City Fire Department because the BCNYC does not permit storage tanks above the 1st floor except for small (>275 gal) day tanks. Some important facts that come from the PANYNJ submittal documents include designating the Fuel Oil Tank Room as BCNYC occupancy classification A with the Televator Room below as occupancy classification B-2-Storage. The Fuel Oil Tank Room was to have retaining walls and curbs for leakage.

6.3 FIRE PROTECTION

The 7th floor OEM Generator Room did not contain a suppression system but contained smoke detectors. All of the existing sprinkler piping and heads were removed under the scope of the project. The new 1st floor Fuel Oil Tank Room was protected with an Inergen System. The modification project included adding sprinkler coverage to the Televator Room below. The sprinkler system for the Televator Room was designed to high hazard with a maximum spacing of 100 ft^2 per head. The sprinkler heads were spaced at 168 ft^2 per head. The modification project also included removing the existing sprinkler heads and branchlines from the Fuel Oil Tank Room. Although sprinkler lines were removed, standpipe and hose rack piping remained in the Fuel Oil Tank Room. All of the electrical devices in the Fuel Oil Tank Room were explosion proof, suitable for BCNYC hazardous location classification Class 1, Division 1, Group C.

As previously mentioned, the Fuel Oil Tank Room was enclosed in a 4 h fire rated construction. The walls were constructed of 8 in. concrete masonry unit. The tops of the walls were installed with Thermafiber and sealant on both sides.

The Generator Room was enclosed in 2 h fire rated construction consisting of three 5/8 in., 25 gauge metal studs spaced at 16 in. on center and had three layers of 5/8 in. gypsum board on both sides. The gypsum board inside was water resistant. An 8 in. concrete curb was constructed at the perimeter of the Generator Room. The door to the Generator Room was fire rated for 1½ h.

6.4 REFERENCES

Swanke Hayden Connell Ltd. 1998. "Mayor's Office of Emergency Management, 7 World Trade Center Specification Manual." April 6.

Swanke Hayden Connell Ltd. 1999. "Mayor's Office of Emergency Management, 7 WTC NYC, NY." Architectural Drawings (A-1-1). August 23.

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Swanke Hayden Connell Ltd. 1998. "Mayor's Office of Emergency Management, 7 WTC NYC, NY." Fire Protection Drawings (FP1.01, FP2.07). September 25.

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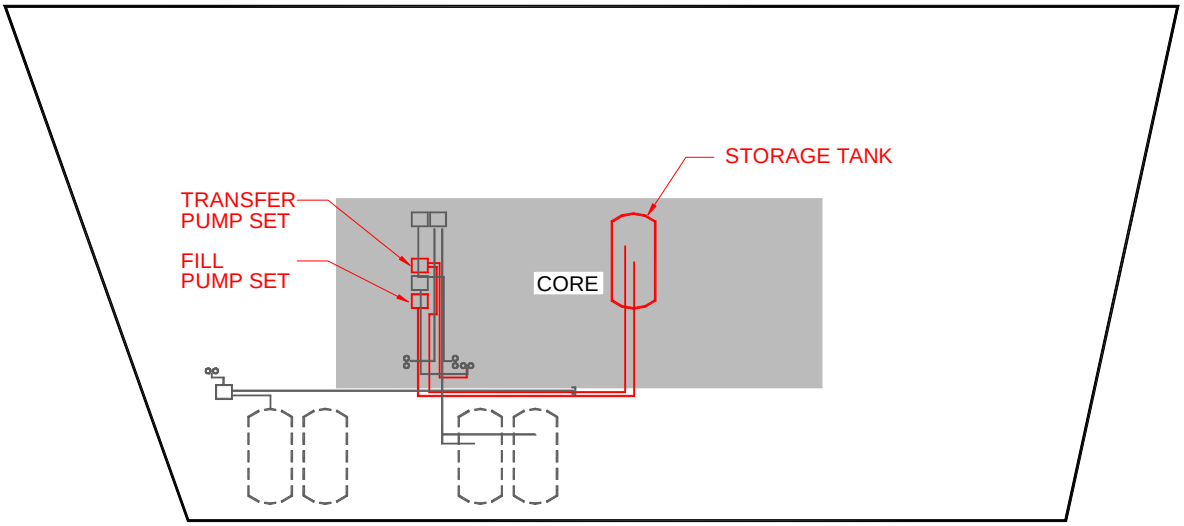

Figure 6–1. First floor fuel oil distribution plan after the OEM modification.

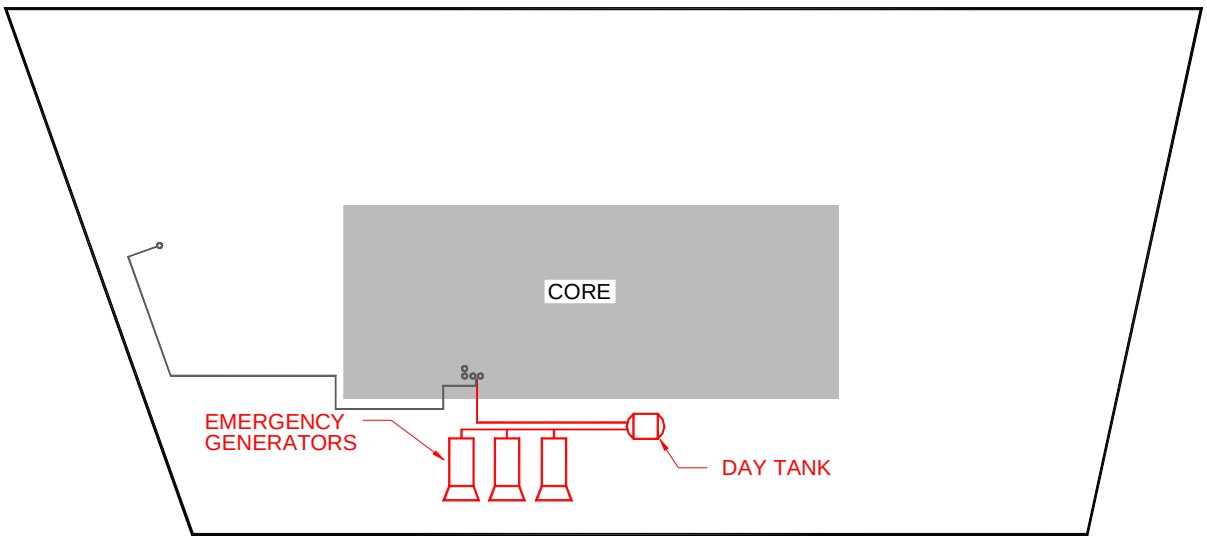

Figure 6–2. Seventh floor fuel oil distribution plan after the OEM modification.

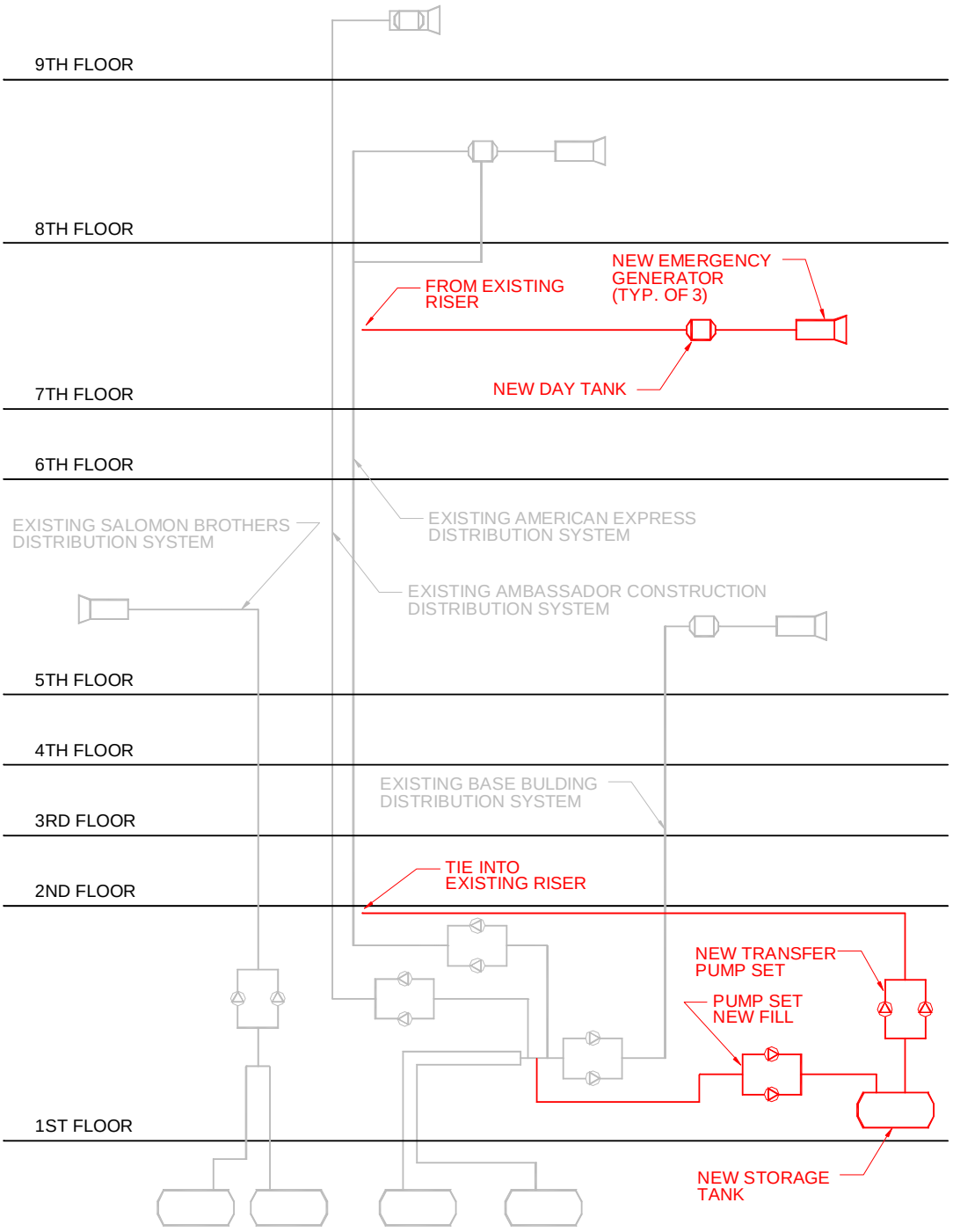

Figure 6–3. Section plan of fuel oil distribution components after the OEM modification.

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Chapter 7
SALOMON BROTHERS ADDITION (1990)

In 1990, Salomon Brothers added a new fuel oil distribution system, independent of the Base Building system of World Trade Center (WTC) 7. The new fuel oil distribution system contained components below the loading dock, the 1st floor and the 5th floor with vertical piping in between. The design was submitted to the Port Authority of New York and New Jersey (PANYNJ) for approval as either PANYNJ submittal number W-7004 or W-7005. The design team consisted of:

- Architect/Engineer: Skidmore, Owings & Merrill
- Mechanical/Electrical Engineer: Flack & Kurtz
- Structural Engineer: Office of Irwin G. Cantor, P.C.

7.1 BASIC LAYOUT

The fuel oil distribution system started with two storage tanks located beneath the loading dock just west of the existing Silverstein storage tanks (Fig. 7–1). A 3 in. fuel oil supply (FOS) pipe ran to a Fuel Oil Pump set located in a dedicated enclosure at the southeast corner of the existing Fire Pump Room located at the southwest corner of the building. An emergency fuel oil fill and return line was run from the pump set towards the central bank of passenger elevators and terminated. The pump set was connected to nine emergency generators via a 2½ in. FOS pipe. The FOS vertical riser was located just north of the pump set. The emergency generators were located throughout the 5th floor (Fig. 7–2). Four generators were located at the northeast corner of the building. Two generators were located at the northwest corner of the building. Three generators were located in the existing Generator Room next to the two existing generators of the Silverstein system. The 2½ in. FOS pipe terminated at just beyond the last generator in the northeast corner and then a 2½ in. fuel oil return (FOR) pipe returned back to the storage tanks. An elevation drawing showing the floor location of components is provided as Fig. 7–3.

7.2 COMPONENT DETAILS

The two fuel oil storage tanks each had a capacity of 6,000 gal. They were of fiberglass construction and each was provided with a vent whistle alarm.

The pump set consisted of a strainer and two 7½ hp pumps specified for 70 gpm, 50 psi total head, 1,150 rpm, 460 V, 3 phase. The specified model was 43D275 manufactured by Preferred Utilities.

The 3 in. FOS suction pipe from the storage tanks to the pump set was run underground. The 2½ in. emergency FOS and FOR pipe from the pump set to the various generators were of the double walled construction type previously mentioned throughout the report. Calcium Silicate was used to provide the 2 h fire resistance rating.

The nine emergency generators were specified as 1,750 kW.

The end of the FOS pipe and beginning of the FOR pipe at the 5th floor contained a valve rig in a leak proof box. The valve rig consisted of a backpressure regulator, gauges, and by-pass line. A liquid level switch was also installed in the vicinity. The liquid level switch was a model L6 EPB-B-S-3-H manufactured by Dwyer. The liquid level switch was wired to the pump relay.

7.3 FIRE PROTECTION

WTC 7 was sprinklered except for mechanical floors and generator and electrical rooms as exempted by the Building Code of the City of New York and its Reference Standards.

7.4 REFERENCES

Skidmore, Owings & Merrill. 1996. "Salomon Brothers Inc." Electrical Drawings (E-R1). August 27.

Skidmore, Owings & Merrill. 1989. "Salomon Brothers Inc." Electrical Drawings (E-5). August 15.

Skidmore, Owings & Merrill. 1990. "Salomon Brothers Inc." Mechanical Drawings (HVAC-1, HVAC-1.1, HVAC-5, HVAC-54, HVAC-54.1, HVAC-55).

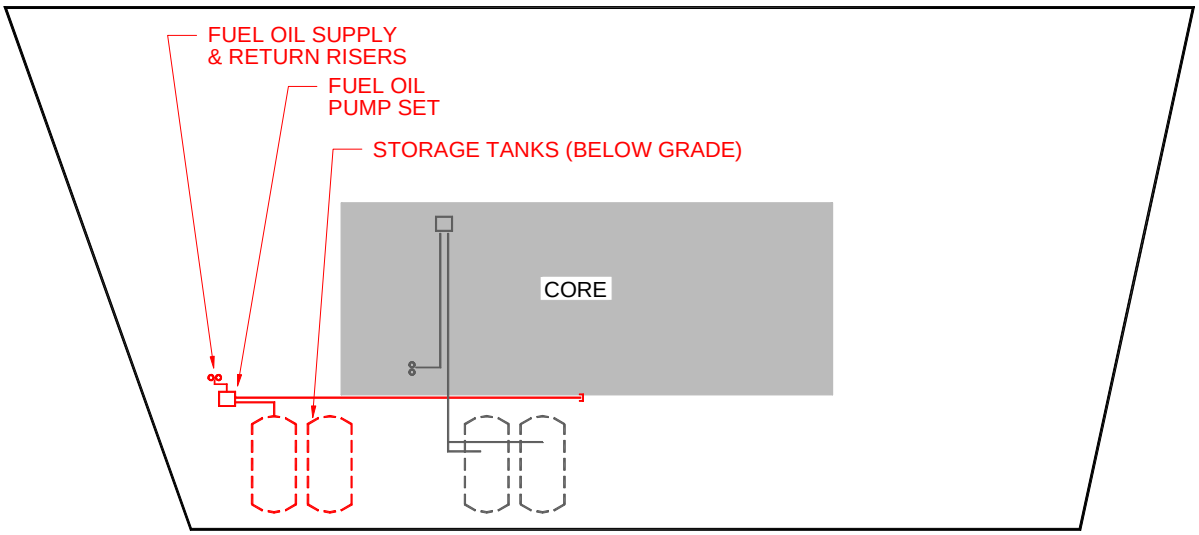


Figure 7–1. First floor fuel oil distribution plan after the Salomon Brothers addition.

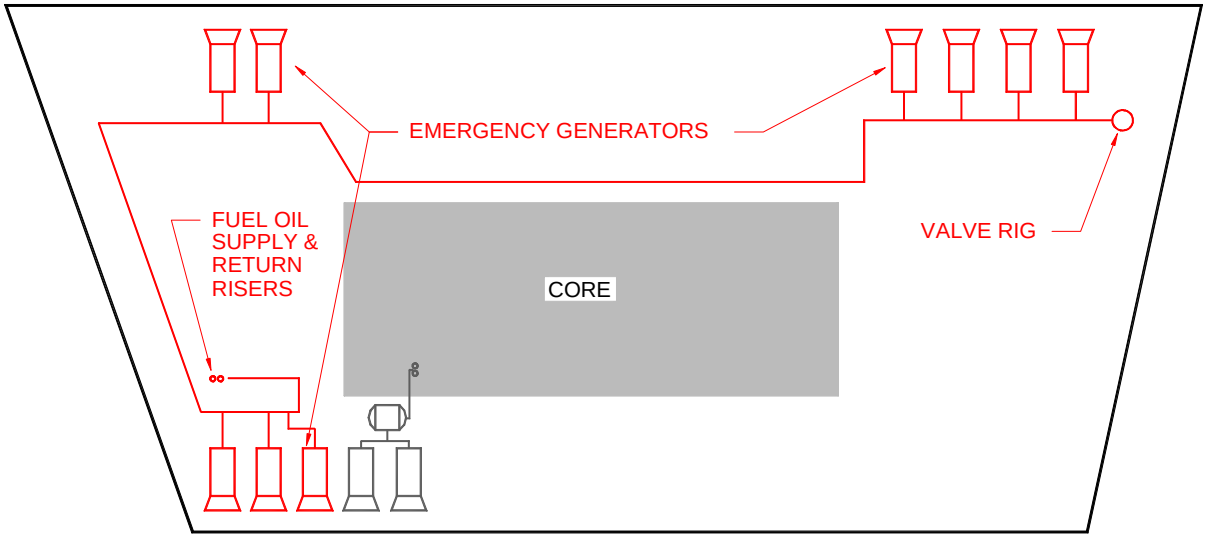


Figure 7–2. Fifth floor fuel oil distribution plan after the Salomon Brothers addition.

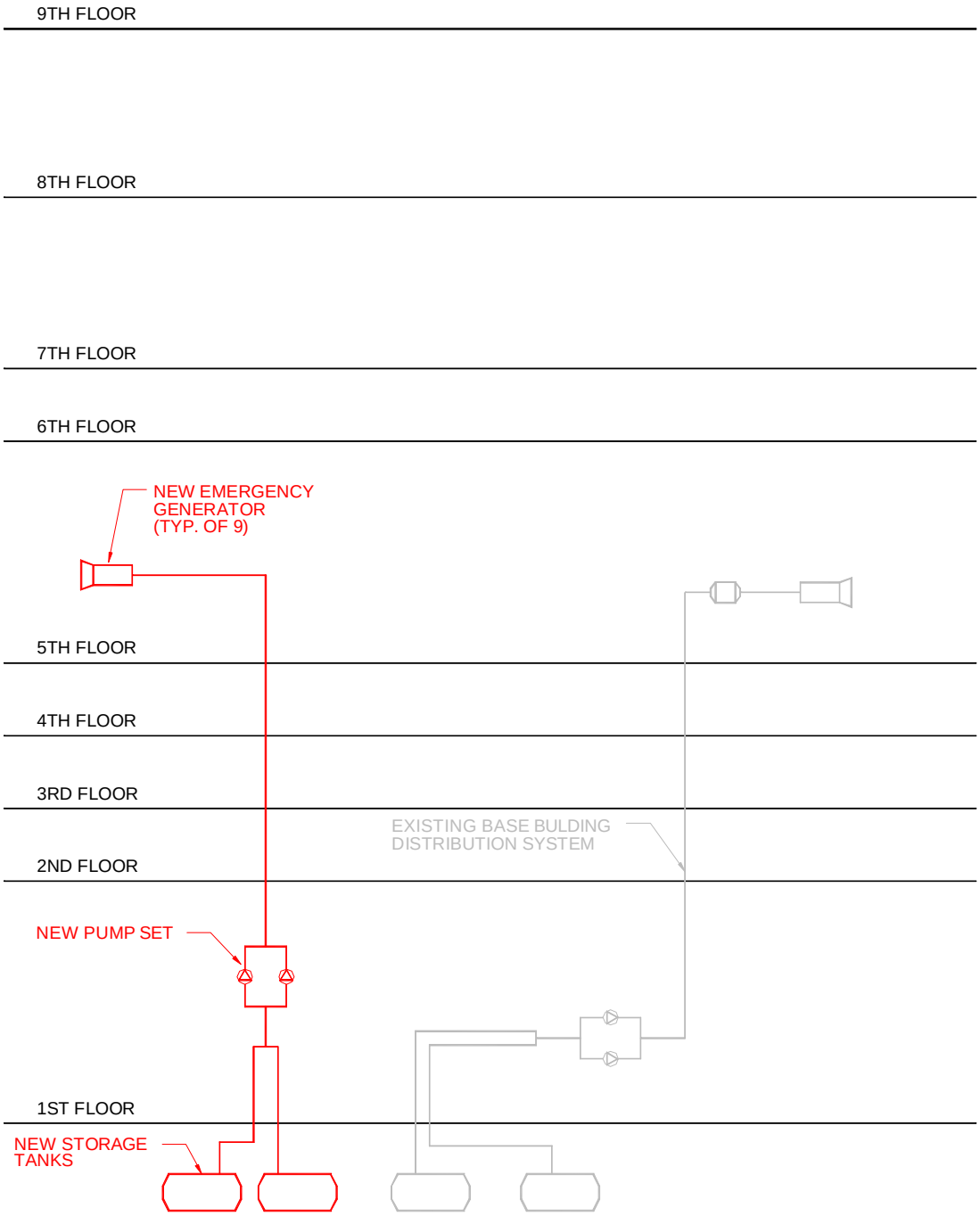


Figure 7–3. Section plan of fuel oil distribution components after the Salomon Brothers addition.

Chapter 8
FINAL CONFIGURATION

World Trade Center (WTC) 7 contained two independent fuel oil distribution systems: the Salomon Brothers system and the Base Building system. The two 12,000 gal Base Building fuel oil tanks provided fuel to the two emergency generators on the 5th floor, which provided emergency power as required. The Base Building fuel oil distribution system also provided fuel to the Ambassador Construction generator on the 9th floor, the American Express generator on the 8th floor and the three generators for the Mayor's Office of Emergency Management on the 7th floor. The two 6,000 gal Salomon Brothers fuel oil tanks provided fuel to the nine generators located on the 5th floor. The final configurations, as of September 11, 2001, of the two fuel oil distribution systems in WTC 7 are represented in Figs. 8–1 through 8–6. The component locations are approximated from the design drawings submitted to the Port Authority of New York and New Jersey for approval. Floor plans not shown between the 1st and 9th floors contain fuel oil risers only. For more specific locations and details, see the documented drawings listed in the Reference sections of each chapter of this report.

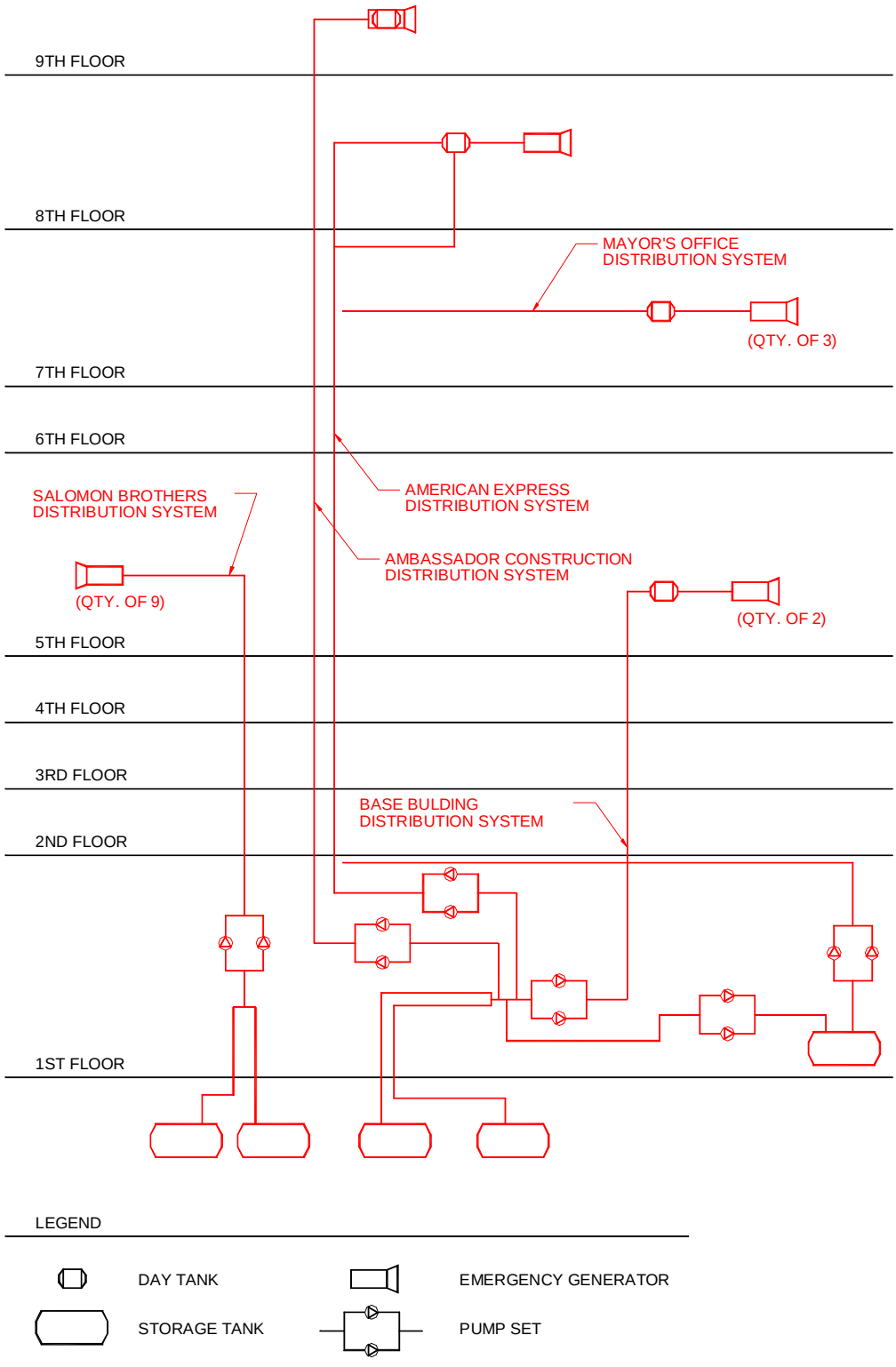


Figure 8–1. Section plan showing the final locations of the fuel oil distribution components.

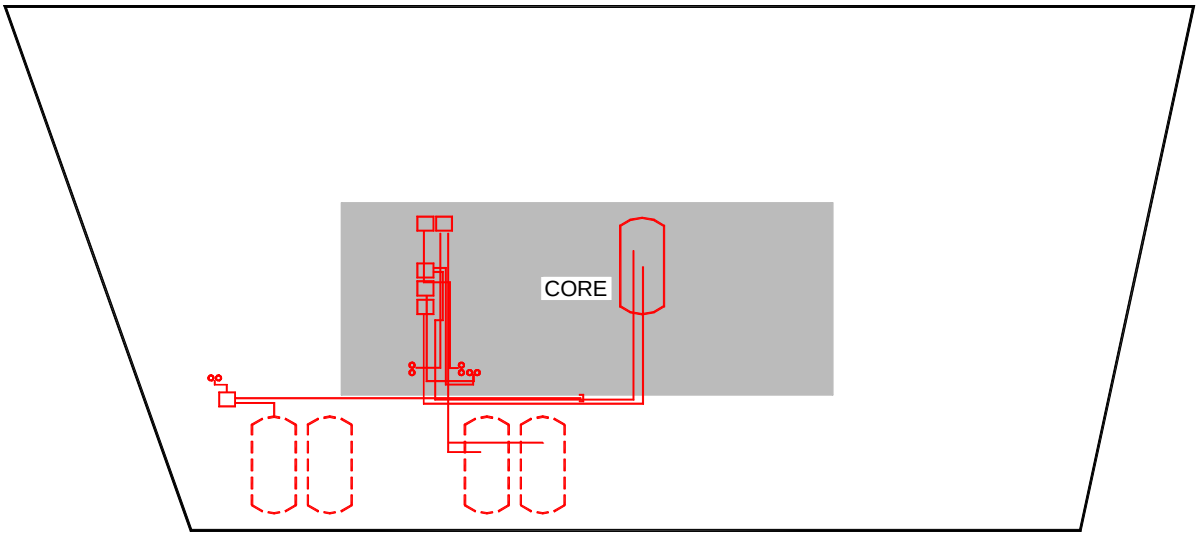


Figure 8–2. Final location of 1st floor fuel oil distribution components.

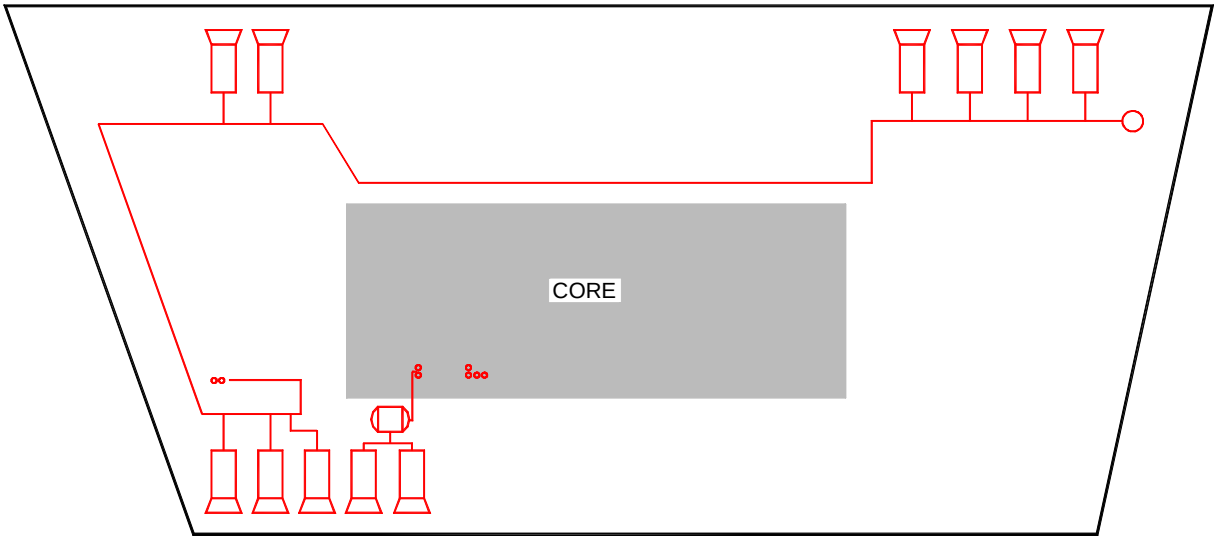
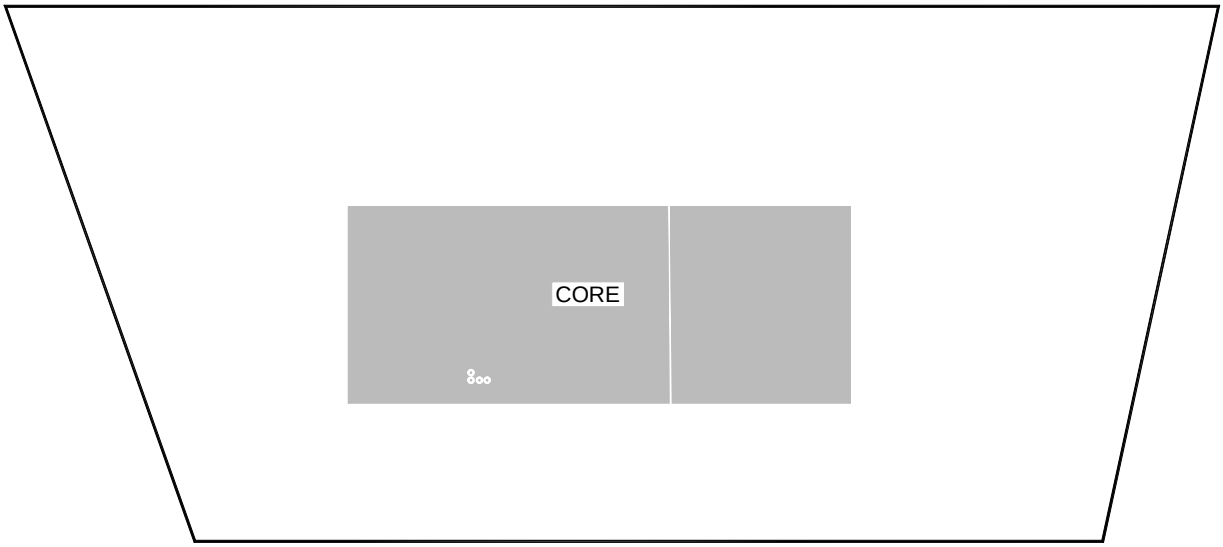


Figure 8–3. Final location of 5th floor fuel oil distribution components.


CORE

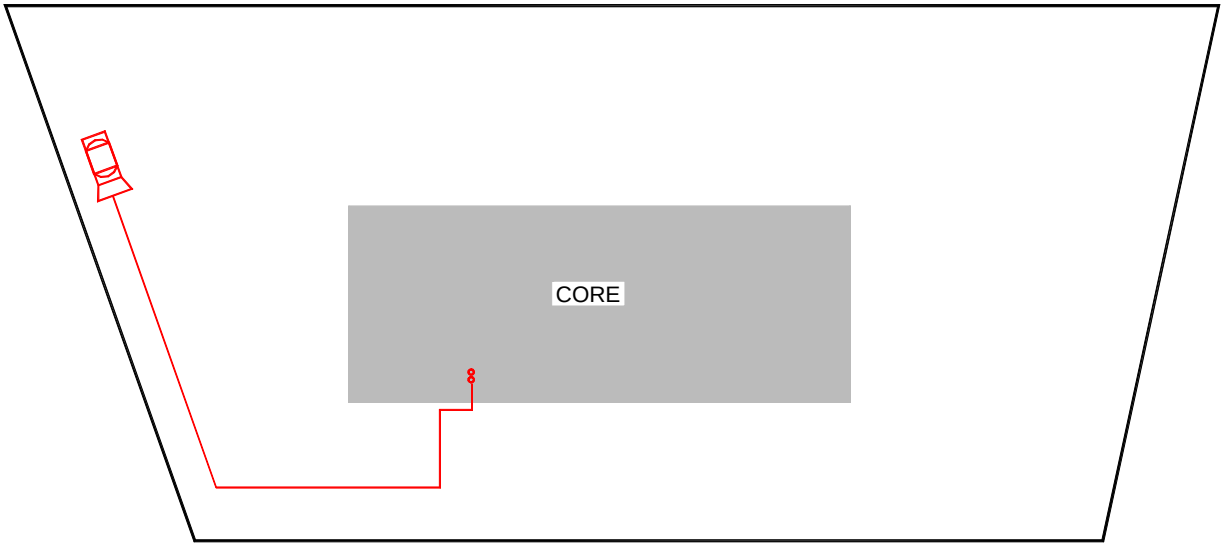


Figure 8–6. Final location of 9th floor fuel oil distribution components.

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Chapter 9
SYSTEM PERFORMANCE

9.1 BASE BUILDING FUEL OIL DISTRIBUTION SYSTEM

The Base Building fuel oil distribution system in World Trade Center (WTC) 7 was composed of four sub-systems, all having the same basic design: the Silverstein system, the Ambassador Construction system, the American Express system, and the Mayor's Office of Emergency Management system. The fuel oil supply to each of the four sub-systems was supplied by the sub-grade storage tanks installed in the original Base Building design. However, the fuel oil pump set of each sub-system was independently regulated by a separate control panel (four total). Each fuel oil pump set was designed to start and stop the fuel oil supply as determined by the oil level in the respective day tank.

Details for all system components have not been identified from the available WTC documents and thus the functions of the components can only be assumed through brief design comments on the drawings, manufacturer's product applications, and an understanding of the typical operation of the various components. Although each sub-system was not identical to the other, each system had the same basic design and many similar components; see Fig. 9–1 for typical locations. Although some components were not indicated in the design, it can be assumed that these components were installed due to the Building Code of the City of New York (BCNYC) requirements and/or basic understanding that the system would not perform without it. See Table 9–1 for a listing of each fuel oil device included in each sub-system design. The following sections discuss the probable functions and components installed in each sub-system.

9.1.1 Liquid Level Switches/Detectors and Collecting Pans/Rupture Basins

As previously stated, the duplex transfer pump set was programmed to operate based on the liquid level of the day tank. Each duplex pump set had a control panel located next to the pump set and/or next to the day tank that regulated the functions of the system. Each system was equipped with at least one liquid level switch in the day tank[1]. The liquid level switch(es) would turn the pump set on and off according to the level of fuel in the day tank. Upon detection of a low level in the day tank, the lead pump of the duplex pump set is started. Once the day tank is filled to the high level, the lead pump is stopped. In the event the lead pump is unable to provide sufficient flow to the day tank, the lag pump is started and operates until the high level is achieved, which stops the pump set.

The day tanks were installed in rupture basins to prevent unwanted fuel discharge from the day tank. The rupture basins installed had capacities of twice the capacity of the day tank. Most if not all of the rupture basins contained a leak detector to further assure that fuel would not continue to flow from a ruptured day tank. If a leak detector was present (most likely scenario since it is required by BCNYC), the system would send an alarm to the Building Management System and stop the pump upon detection of fuel in the

[1] The Ambassador Construction project refers to a liquid control lever. Whether this was a single float switch or multiple switches, the lever would have been capable of starting and stopping the pump set according to the fuel level.

rupture basin. If a leak detector was not present in the day tank rupture basin (not likely), then it would be possible to endlessly pump fuel onto the floor where the day tank is located until the selected storage tank was emptied. The only other scenario that could endlessly pump fuel onto the floor where the day tank is located would occur in the event of a break in the fuel oil supply (FOS) piping down stream of the day tank. This break could allow the day tank to reach a low level and start the pump set. Fuel would flow onto the floor where no fuel detection is present until the storage tank that was selected was emptied. It is unsure how likely this would be, understanding that lack of fuel to the generators would produce lack of power to the pump set.

Leak detectors at the base of the FOS riser and in the collecting pans helped prevent the unwanted flow of fuel. In the event of a break of the FOS discharge piping, the pump set would not start pumping fuel until the low level in the day tank was detected. Thus a break in the FOS discharge piping before a low level in the day tank was detected would not start the pump set. However, if a low level in the day tank was detected and the pump set started, and then a break occurred, there is a possibility that fuel would flow out the break in the pipe. But, it is also likely that the fuel would flow back down the outer pipe of the double wall piping construction to the base of the FOS riser and into the open sight fuel oil collecting pan where leak detectors are installed. The leak detector, upon detection of fuel, would stop the pump set and send an alarm to the Building Management System. Fuel would not likely flow endlessly out the break in the pipe.

There is another scenario that should be evaluated. The electrical wiring of the system should be analyzed. It may have been possible to have an electrical malfunction in the system and have the pump set start, with the possibility of pumping fuel endlessly out a pipe break. But, because the point to point wiring schematic of the control panel showing the connection of all the electrical devices has not been located, this scenario could not be evaluated.

9.1.2 Fusible Link Gate Valve

The fusible link gate valves included in the sub-system designs serve as an automatic shut off valve in the event of a fire. As the heat of the fire, within the room the valve is located, rises to the melting point of the fusible link, the link melts, the valve closes and the fuel flow in the FOS pipe is shut off. At this point, fuel flow is stopped until the gate valve is manually re-opened.

9.1.3 Anti-siphon Valve and Check Valve

Fuel systems that included an anti-siphon valve were protected from fuel siphoning from the storage tanks to the Fuel Oil Pump Room floor. Some designs included an anti-siphon valve installed at the highest point of the FOS pump suction piping (between the storage tanks and the pump set). The anti-siphon valve was installed to prevent the fuel in the storage tank from emptying onto the Fuel Oil Pump Room floor in the event of a pipe break. An anti-siphon valve opens as negative pressure is applied downstream of the valve. A pump creates enough negative pressure in the suction piping to open the valve, whereas, a pipe break in the suction piping does not create a sufficient amount of negative pressure to open the valve. But, siphoning of the fuel in the storage tanks was not likely to occur since the storage tanks were lower in elevation than the Fuel Oil Pump Room floor.

The only other siphoning situation that could occur in the Fuel Oil Pump Room would be siphoning from a day tank back to the Fuel Oil Pump Room. The anti-siphon valve would not be effective for this piping break, but siphoning may or may not occur for two other reasons. The FOS pipe leading to a day tank is connected at the top of the tank and most likely does not extend inside to the bottom of the tank. If the connection does not extend to the bottom of the tank, the air gap between the day tank fuel and the FOS pipe would eliminate the possibility of siphoning the fuel in the day tank to the Fuel Oil Pump Room floor. However, if the connection extended to the bottom of the tank, then siphoning could occur. Second, there are check valves in the pump set piping that prevent backflow of fuel. If the break occurred upstream of the check valve, no fuel would siphon back to the Fuel Oil Pump Room. Although, if the break occurred downstream of the check valve, siphoning may or may not occur, depending on the connection of the FOS piping to the day tank as stated above.

9.1.4 Foot Valve

The purpose of a foot valve was to keep the FOS pump suction piping primed with fuel and prevent the fuel from draining back to the storage tanks. A foot valve is similar to a check valve, but is supposedly more efficient than a check valve at keeping the line primed.

9.1.5 Pressure Relief Valve

The FOS pump discharge piping of every sub-system contained a relief valve that prevented excessive pressures from building up in the discharge piping. It is possible to build up excessive pressure in the pump discharge piping when a control valve or solenoid valve is closed and the pump set is on. The relief valve would prevent the pressure from rising above the predetermined relief valve setting by discharging fuel into the fuel oil return (FOR) pipe until the pressure decreased to below the setting. The designs had the pressure relief valve set to 100 psi to 125 psi.

9.1.6 Solenoid Valve

Most systems, if not all, had a solenoid valve located in the FOS pump discharge piping. The purpose of the solenoid valve in the FOS pump discharge piping was to prevent unwanted fuel discharge to the day tank. The solenoid valve was most likely programmed to close in an alarm situation. The Silverstein system required the solenoid valve to close on high level alarm in the day tank. This would prevent an overflow or continuous flow of fuel through the FOS pump discharge piping. It is unclear whether the solenoid valve was normally in the closed or open position.

9.1.7 Tank Selector Valve

A tank selector valve was installed in the Silverstein system. The switch was used to switch the fuel supply from one tank to the other. The valve was manually operated and only permitted one storage tank at a time to supply fuel to the pump set and day tanks. Thus, if the fuel in the primary tank was emptied, either by normal usage or unwanted discharge, the tank selector valve would have to be manually switched to the secondary storage tank to supply fuel to the pumps.

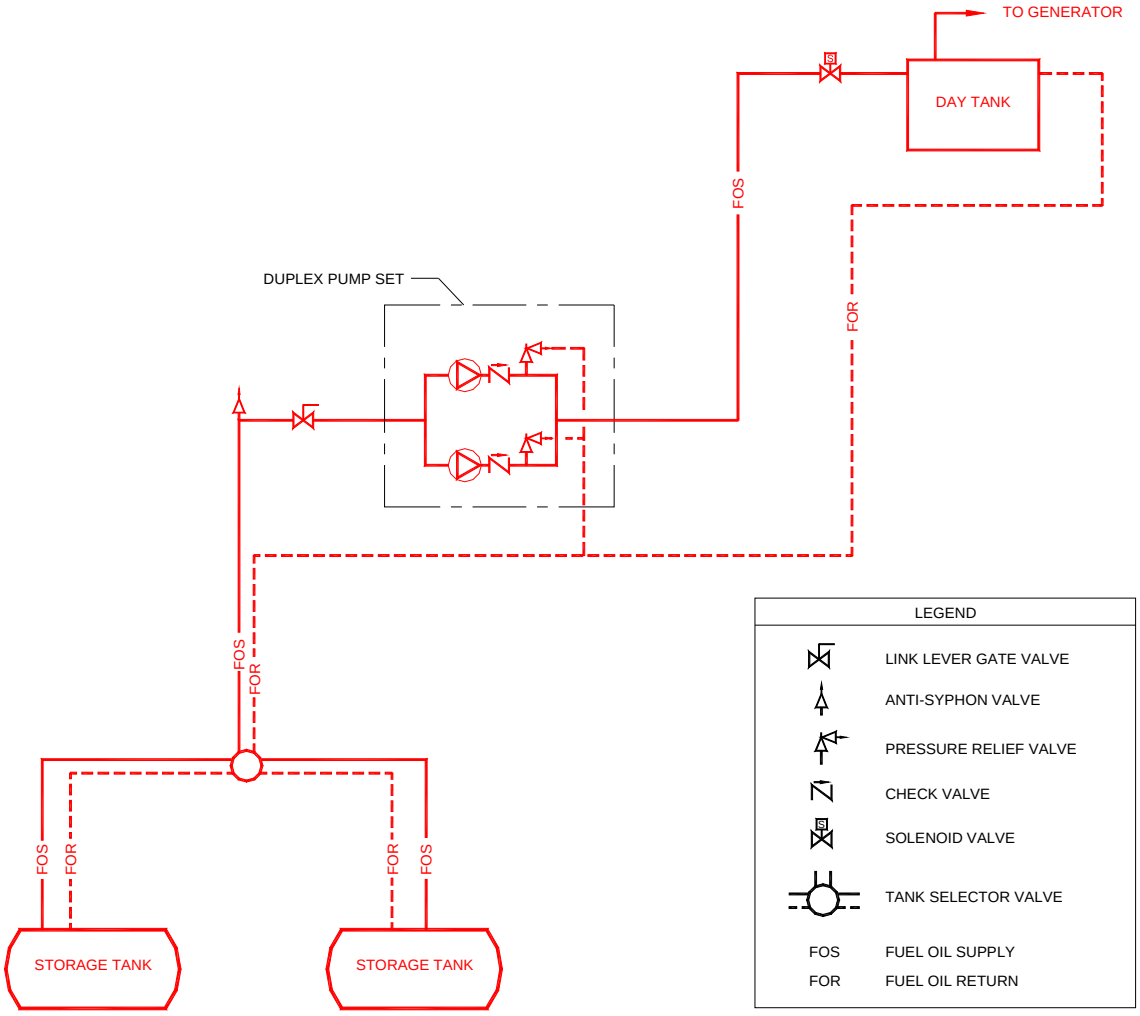

Figure 9–1. Typical layout of critical devices in Base Building sub-systems.

Table 9–1. Critical fuel oil devices installed in Base Building sub-systems.

Fuel Oil Component	Silverstein	Ambassador Construction	American Express	Office of Emergency Management
Fusible link gate valve – Installed in fuel oil supply pump suction piping	No	Yes	No	No
Anti-syphon valve – Installed in fuel oil supply pump suction piping	Yes	Yes	Yes[a]	Yes
Foot valve – Installed in fuel oil supply pump suction piping	Unknown[b]	No	No	Yes
Check valve – Installed in fuel oil supply pump suction piping	Yes	Yes	Yes	Yes
Pressure relief valve – Installed in fuel oil supply pump discharge piping	Yes	Yes	Yes	Yes
Solenoid valve – Installed in fuel oil supply pump discharge piping	Yes	Yes	Unknown[c]	Yes
High level switch – Installed in day tank	Yes	Unknown[d]	Yes	Yes
Low level switch – Installed in day tank	Yes	Unknown[d]	Assumed	Yes
Rupture basin – Installed around day tank	Yes	Yes	Yes	Yes
Fusible link gate valve – In fuel oil supply between day tank and generator	Yes	No	No	No
Leak detector – Installed in day tank rupture basin	Yes	Assumed	Yes	Assumed
Leak detector – Installed at base of fuel oil supply/fuel oil return riser	Unknown[e]	Yes	Yes	Yes
Leak detector – Installed in pump room collecting drum	Yes	Yes	Yes	Yes
Tank selector valve – Installed in pump room collecting drum	Yes	Yes[a]	Yes[a]	Yes[a]

a. Included in the Silverstein system, which supplies fuel to the remaining three sub-systems.
b. The Ambassador Construction modification refers to an existing 2 in. foot valve in the fuel oil supply pump suction piping. It is most likely from the Silverstein system installation.
c. Detailed piping schematic and specifications have not been identified.
d. Specifications indicate that the pump set is to be energized from the float control lever. Operation of this lever is unclear.
e. Riser details have not been located.

Key: Yes, component shown on drawing or listed in design specification; No, component not shown on drawing or specifications; Assumed, based on requirements in the BCNYC, specifications, system capabilities or manufacturer's recommendations, the component is likely to be installed, but not shown.

9.2 SALOMON BROTHERS FUEL OIL DISTRIBUTION SYSTEM

The Salomon Brothers fuel system had a similar but slightly different design in comparison to the Base Building fuel system. See Fig. 9–2 for the location of the critical devices. Two underground storage tanks supplied the duplex pump set with fuel. The fuel system was designed using a pressurized loop rather than day tanks. The FOS side of the loop ended with a valve rig that was designed to start and stop the fuel oil supply. The fuel supply was provided by a duplex pump set. Similar to the Base Building system, if the lead pump of the duplex pump set was unable to provide sufficient pressure in the FOS piping, the lag pump would start and operate until the high level was achieved.

The valve rig controlled the fuel supply pressure in the FOS piping. The liquid level switch in the valve rig controlled the fuel oil supply in the FOS piping. Upon detection of a low fuel level in the FOS pipe, the pump set would start. Once the high fuel level was achieved, the pump set would stop. The back pressure regulator (located just downstream of the liquid level switch) maintained the proper fuel pressure in the FOS piping. If excessive pressure built up in the FOS piping, the back pressure regulator would relieve the excessive pressure in the FOR piping which drained back to the storage tanks. In addition to the back pressure regulator in the valve rig, pressure relief valves on the FOS pump discharge piping were installed to assure the proper pressure in the FOS piping.

A tank selector valve was not included in the design. Drawings indicate that gate valves were included in the FOS pump suction pipes. It is unclear whether the FOS and FOR pipes to each tank were opened, allowing both tanks to supply fuel to the pumps or whether one set of valves were closed, allowing only one storage tank to supply fuel to the duplex pump set. Thus, it cannot be determined, based on the available documentation, whether one or both tanks would have supplied fuel to the pump set in the event of normal operations or unwanted fuel discharge.

A solenoid valve was installed in the FOS pipe to each generator. Documentation does not indicate the normal position (open or closed) of the solenoid valve. The solenoid valve was most likely wired to be closed when the pump was off and then open during the call for fuel to a particular generator. The solenoid valve could have been wired to close upon a detection of high fuel pressure in the FOS piping. The second scenario is not likely due to the presence of the back pressure regulator and pressure relief valve.

A check valve was installed in each FOR pipe from the generator to the FOR loop piping. The purpose of the check valve was to prevent any backflow of fuel from the FOR piping to the FOS piping.

A collecting tank and second valve rig were installed in the pump room. The purpose of an FOS pump suction valve rig is undetermined. The 55 gal collecting tank was connected to the FOR pipes and contained a float switch inside. It is unclear whether the float switch was to notify the presence of fuel or that the tank was nearly full. It is also unclear whether the switch stopped the pumps from supplying fuel to the FOS loop.

Based on the available documentation, the pressurized loop could have endlessly discharged fuel out of a broken FOS pipe. A break in the FOS pipe, between the pump set and FOS valve rig, could have activated the pump set. In the event of a FOS pipe break, the fuel could have emptied out of the valve rig, sending a low level signal to the pump controllers from the liquid level switch and starting the pump set. Fuel would have flowed out the break until the storage tank(s) were emptied. However, if the double

walled construction of the FOS piping was designed similar to that of the Base Building system, it could have been possible that a leak detector switch would have shut off the pump set. This cannot be determined from the available documentation. The electrical characteristics of the system are unknown and need to be analyzed to determine if an electrical malfunction would have started or stopped the fuel pump set.

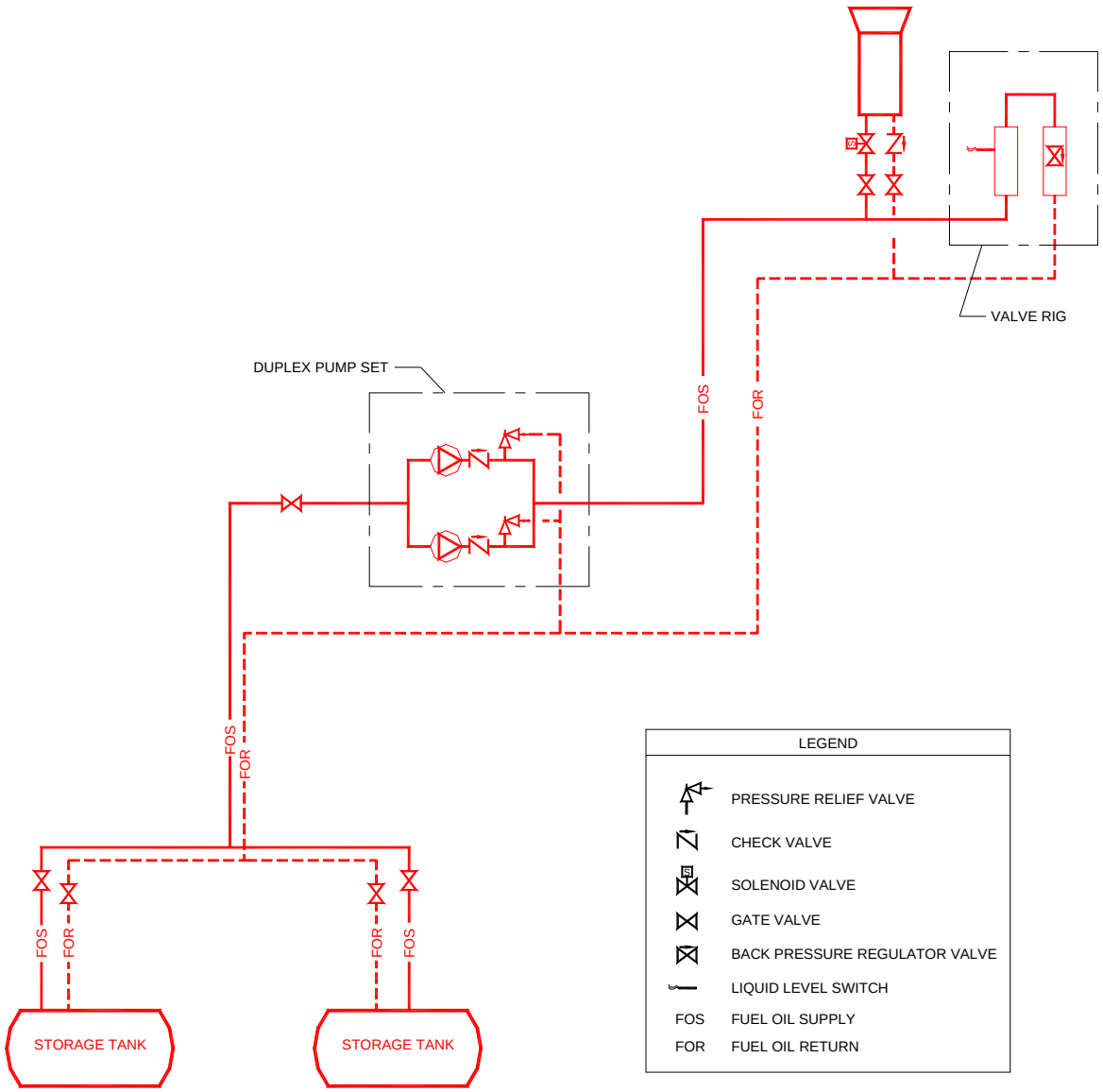

Figure 9–2. Layout of critical devices in Salomon Brothers system.

9.3 SYSTEM CAPACITIES

Based on the documented drawings, the amount of fuel located in the WTC 7 on September 11, 2001, is approximated to be 43,284 gal, see Table 9–2. This quantity of fuel in WTC 7 is based on many assumptions. It was assumed that all of the tanks were filled to capacity. The presence, or lack thereof, of fuel is based on the system performance assumptions previously stated. For example, the FOR pipes were assumed to be empty, except for trapped sections of pipe. This is based on details in the design drawings showing the pipes pitched to drain back to the storage tanks.

Table 9–2. Capacity of fuel oil components throughout WTC 7.

Fuel Oil Component	Fuel Capacity (gallons)
Salomon Brothers System	
Storage tanks (two)	12,000
Fuel oil supply (storage tanks to fuel oil pump set)	22.5
Fuel oil supply (fuel oil pump set to valve rig)	146.1
Valve rig	34.9
Fuel oil return (valve rig to storage tanks)	19.9
Base Building System	
Base Building storage tanks (two)	24,000
Fuel oil supply (storage tanks to Base Building pump sets)	31.7
Fuel oil supply (Ambassador Construction pump set to day tank)	22
Ambassador Construction engine mounted day tank	50
Ambassador Construction fuel oil return (day tank to fuel oil pump room)	1
Fuel oil supply (American Express pump set to day tank)	57.6
American Express day tank	275
American Express fuel oil return (day tank to fuel oil pump room)	2.1
Fuel oil supply (Base Building pump set to day tank)	26.2
Base Building day tank	275
Base Building fuel oil return (day tank to fuel oil pump room)	2.1
Fuel oil supply (OEM fill pump set to OEM storage tank)	10.9
OEM storage tank	6,000
Fuel oil supply (OEM storage tank to OEM transfer pump set)	11.6
Fuel oil supply (OEM transfer pump set to OEM day tank)	16.9
OEM day tank	275
OEM fuel oil return (day tank to fuel oil pump room)	1.2
Common fuel oil return (fuel oil pump room to storage tanks)	2.1
Totals	
Salomon Brothers system	12,223.4
Base Building system	31,060.4
WTC 7 total capacity	**43,283.8**

Chapter 10
MAINTENANCE HISTORY

Documentation for the maintenance history of the two distribution systems could not be located. A Silverstein document indicates the maintenance schedule of three generators and four fuel oil pumps. There are also notes on upgrades for the same items. The only other maintenance history document found is in an inspection report dated April 1997, which indicates that the fuel lines in the 5th floor Generator Room were missing pipe supports. The maintenance schedule for the Silverstein items as indicated in the Silverstein document are as follows.

Table 10–1. Maintenance schedule of fuel oil pumps and generators.

Description	Location	Maintenance Schedule	Upgrades
Generator 1	5th floor Generator Room	Weekly, monthly, semiannual, annual	New load bank and voltage regulator
Generator 2	5th floor Generator Room	Weekly, monthly, semiannual, annual	New load bank and voltage regulator
Generator 9-1	9th floor USSS	Weekly, monthly, semiannual, annual	New generator
Fuel Oil Pump 1	Fuel Oil Pump Room	Weekly, quarterly, semiannual	
Fuel Oil Pump 2	Fuel Oil Pump Room	Weekly, quarterly, semiannual	
Tenant Fuel Oil Pump 1	Fuel Oil Pump Room	Weekly, quarterly, semiannual	New pump and controls
Tenant Fuel Oil Pump 2	Fuel Oil Pump Room	Weekly, quarterly, semiannual	New pump and controls

Source: Silverstein.

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