

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

**ANALYSIS OF BUILDING AND FIRE
CODES AND PRACTICES**

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WTC Investigation Objective #3

Determine procedures and practices used in the design, construction, operation, and maintenance of WTC 1, 2, and 7.

Project #1 Areas of Focus

Criteria and Procedures for:

- Design and construction
- New and innovative design features
- New and innovative technologies and materials
- Passive and active fire safety systems
- Emergency access and egress systems
- Structural modifications, inspection, and maintenance

Scope

- Document the design and construction of structural systems
- Document the design and construction of fire protection and egress systems
- Compare then current building regulatory and code requirements
- Document maintenance and modifications to structural, fire protection, and egress systems
- Document the fuel system for emergency power in WTC 7

Building Code Used

WTC 1 and WTC 2:

- Not required to comply with any building code (Port of New York Authority was established as an interstate agency under a clause of the U.S. Constitution)
- May 1963: PONYA instructed designers to comply with NYCBC (1938 edition)
 - Designers were to follow “acceptable engineering practices” where code provisions were obsolete
- September 1965: PONYA instructed designers to comply with second and third drafts of new NYC Building Code for the final design of WTC 1 and WTC 2
- NYC adopted a new code in December 1968

Building Code Used

WTC 7:

- Developed and owned by Silverstein Development Corporation
- Built as a PONYA Tenant Alteration Project
- NYC Building Code 1968 edition

Building Codes Reviewed (Structural System)

- NYC Building Code - 1968 edition
- NY State Building Code - 1964 edition
- Chicago Building Code - 1967 edition
- BOCA Basic Building Code - 1965 edition
(National Model Building Code)
- NYC Building Code - 2001 edition

National Standards Adopted by Building Codes

For structural design

- NYCBC (1968)
1963 AISC Spec., 1963 ACI 318 Code
- NY State BC (1964)
Appropriate national standards
- Chicago BC (1967)
1963 AISC Spec., 1963 ACI 318 Code
- BOCA Basic Building Code (1965)
1963 AISC Spec., 1963 ACI 318 Code
- NYC Building Code (2001)
1989 AISC Spec., 1989 ACI 318 Code

Structural Requirements Reviewed

- Dead loads
- Live loads
- Live load reduction
- Lateral loads (wind and earthquake)
- Progressive collapse resistance

Dead Loads

- Weights of materials and constructions
- Building codes provide unit weights (densities) of materials for design
 - Most codes have similar unit weights for building materials
e.g., steel = 490 pcf; concrete = 150 pcf

Live Loads

- Loads produced by use and occupancy
- Codes specify basic live load values for design
- Code provisions are based on experience and load surveys
- Expressed as equivalent uniform loads
 - e.g., office = 50 psf; lobby = 100 psf
 - All five codes have the same values
- Concentrated loads treated separately

Live Load Reduction

- Codes allow reduction of basic live load, because it is unlikely that all floors are fully loaded simultaneously
- Accumulation of loads on columns and walls
 - Character of live loads
 - Tributary area on a single floor
 - Number of supported floors
 - Ratio of dead load to live load
- Accumulation of loads on girders and beams
 - Contributory area
 - Magnitude of live loads
 - Ratio of dead load to live load

Live Load Reduction Methods

- Percentage method
 - 100% (roof), 85%(top floor), 80% (next floor),...
 - 50% (limit)
- Dead load to live load ratio method for live loads ≤ 100 psf (ASNI A58 1955 to1981)
 - 0.08% per square foot of area supported by any member
 - Nor more than 60% or R%
 - where, $R = 100 \times [(D+L) / (4.33 L)]$
 - D = Dead load
 - L = Live load

Reduced Live Load for Beams, Girders and Columns (Dead Load to Live Load Ratio Method)

Contributory Area (sq ft)	NYC Building Code*	Chicago Code	NY State / BOCA** Codes
100 or less	100	100	100
100 - 150	100	95	100
150 - 200	80 - 85	Also depends on the D/L ratio	84 - 88
200 - 300	80 - 85		76 - 84
300 - 450	60 - 75		64 - 76
450 - 600	50 - 70		52 - 64
600 - and more	40 - 65		40 - 52

All numbers in % * For columns, limited to 80% ** Limited to 40% (D/L Method)

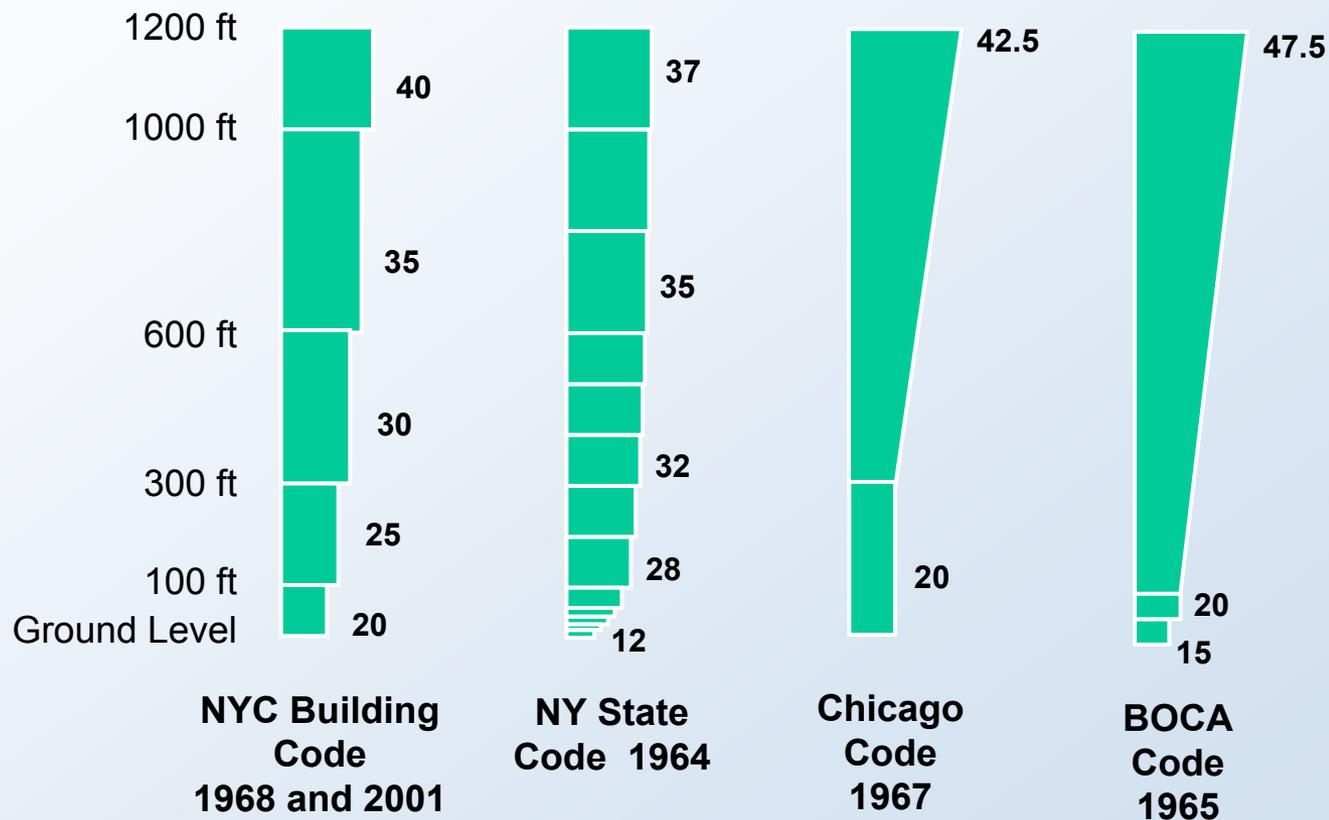
Separate requirements for computing the contributory areas for beams and slabs.

Reduced Live Loads for Columns and Walls (Percentage Method)

	NYC Building Code (Alternative Method) Chicago Code	NY State Building Code
Roof	100%	80%
1 st floor below	85%	80%
2 nd floor below	80%	80%
3 rd floor below	75%	75%
4 th floor below	70%	70%
5 th floor below	65%	65%
6 th floor below	60%	60%
7 th floor below	55%	55%
8 th and subsequent floor below	50%	50%



Wind Pressure Distributions of Different Building Codes



Earthquake Load

- NYC Building Code (1968) - No provisions
- NY State Building Code (1964) - No provisions
- Chicago Building Code (1967) - No provisions
- BOCA Basic Building Code (1965)
 - Based on 1961 UBC (*Base shear $V = ZKCW$*)
- NYC Building Code (2001)
 - Based on 1988 UBC (*Base shear $V = ZIKCSW$*)

Load Combination

- Account for most unfavorable combination of loads
- Account for likelihood of simultaneous occurrence of different loads
 - Load factor < 1.0
 - Increased allowable stresses

Load Combination

- NYC Building Code (1968)

$$0.75 (D + L + W)$$

- NY State Building Code (1964)

Increase allowable stress by 33% if $\sigma_{wind} > 0.33 \sigma_{D+L}$

Ignore stress due to wind if $\sigma_{wind} < 0.33 \sigma_{D+L}$

- Chicago Building Code (1967)

Increase allowable stress by 33% for $D + L + W$

- BOCA Basic Building Code (1965)

Same as Chicago Building Code

- NYC Building Code (2001)

$$0.75 (D + L + W \text{ or } E)$$

D = dead load, L = live load, W = wind load, E = earthquake load

Provision for Progressive Collapse Resistance

- 1968 NYC Building code
 - No provision
- 1981 NYC Building Code
(Rules of the City of New York, 1973)
 - Alternative load path method
 - Specific local resistance method

Interim Findings

1. PONYA adopted 1968 NYC Building Code for final design of WTC 1 and WTC 2, and WTC 7
2. Designers were allowed to use “acceptable engineering practices” with approval of PONYA where code provisions were obsolete (1963 directive)
3. Minimum basic live loads are the same for five codes reviewed
4. All five codes have live load reduction provisions.
 - For beams and girders: 1967 Chicago Code is slightly more conservative than other codes.
 - For columns and walls: Permitted reduction is about the same in all five codes.

Interim Findings

5. All five codes have similar wind pressure distributions.
 - For tall buildings (e.g., over 1000 ft), the largest base shear is obtained from BOCA (1965).
6. The 1968 NYC Building Code does not have seismic design provisions. The 2001 NYC Building Code assigns NYC a seismic zone factor of 0.15 ($0.075 \leq Z \leq 0.40$).
7. All five codes recognize low probability of the simultaneous occurrence of design gravity and wind loads.
 - Load factor of 0.75
 - Increase allowable stress by 33%
8. NYC by Rule introduced progressive collapse resistance requirement in August 1973.

Fire Protection and Egress Systems

Building Codes Reviewed (Fire Protection and Egress Systems)

- NYC Building Code - 1968 edition
- NY State Building Code - 1964 edition
- Chicago Building Code - 1967 edition
- BOCA Basic Building Code - 1965 edition
(National Model Building Code)
- NYC Building Code - 2001 edition
- NFPA 101 - 1966 edition

National Fire Safety Standards Adopted by 1968 NYC Building Codes

- Sprinkler systems
 - RS 17-2:NFPA 13 (1966)
- Fire alarm systems
 - RS 17-5:NFPA 72 (1967)
- Smoke management
 - RS 13-1:NFPA 90A (1967)
- Egress systems
 - Covered in the Building Code

Review of Code Provisions

- Construction Classes – Unsprinklered
 - Class 1A and 1B: NYC 68, NYS 64, BOCA 65 (Unlimited height)
 - Class 1A and 1B: NYC 01 (Height limited to 75 ft. unless sprinklered)
 - Class 1A only: Chicago 67 (Unlimited height)
- Fire Resistance Rating (all codes, except NYC 01)
 - Class 1A
 - Columns: 4 hours (supporting more than one floor)
 - Beams : 3 hours (floor construction)
 - Class 1B
 - Columns: 3 hours (supporting more than one floor)
 - Beams : 2 hours (floor construction)

NYC Building Code Provisions (Fire Resistance in hours)

	1938	1968	2001
Columns	4	3	2
Floors	3	2	1-1/2

Review of Code Provisions

- Codes do not provide criteria for selecting Construction Class (1A vs. 1B)
- Selection of Construction Class is at discretion of Owner/Architect

Review of Code Provisions

- NYC Local Law 5 (1973) for New and Existing Buildings (Full compliance by 1988)
 - Applicable to new office buildings and retroactively to existing office buildings over 100 ft in height
 - Compartmentation required for unsprinklered floor areas greater than 7500 ft²
 - Complete sprinkler protection could be provided in lieu of compartmentation
 - Automatic stair door unlocking or unlocked every 4 floors
 - Approved evacuation plan and drills

Review of Code Provisions

- NYC Local Law 5 (1973) for New and Existing Buildings (Full compliance by 1988)
 - Fire safety director and fire wardens
 - Fire command station in lobby
 - Voice communication system
 - Elevator recall
 - Zone smoke control and stair pressurization
 - Stair pressurization not required if fully sprinklered

Review of Code Provisions

- NYC Local Law 16 (1984)
 - Required sprinklers for buildings taller than 75 ft for new business, new and existing hotels
 - Emergency lighting in exits and corridors
 - Remoteness of exits (30 ft or 1/3 travel distance)
 - Full compliance by 1987

Code Provisions and Contemporary Practice for Fire Protection and Egress Systems

- Sprinklers mainly in industrial and storage spaces
 - Rare even in high-rise buildings (except underground)
- Fire alarm systems
 - Manual initiation for occupant notification
 - Control of fans and dampers to prevent smoke circulation
 - Coded audible to indicate location of fire
- Smoke management not yet developed
 - Required by insurance to mitigate property loss
 - “smoke proof towers” and top vented stairs
- Egress system design based on 22 in. units of exit width
 - Occupant loads and capacities consistent
 - Scissor stairs common in NYC, remoteness addressed in LL16

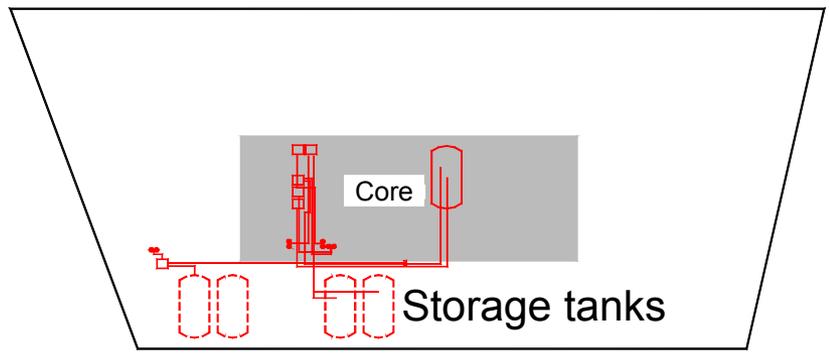
Fuel System for Emergency Power WTC 7

- Four systems
 - Basic system, 1987 (5th floor)
 - Ambassador modification, 1994 (9th floor)
 - American Express modification, 1994 (8th floor)
 - Mayor's Emergency Office, 1999 (7th floor)
- Main tanks under loading dock (12,000 gal) and 1st floor (6,000 gal)
- Day tanks (275 gal) at generators (floors 5, 7, 8, 9)
- Pumps and piping

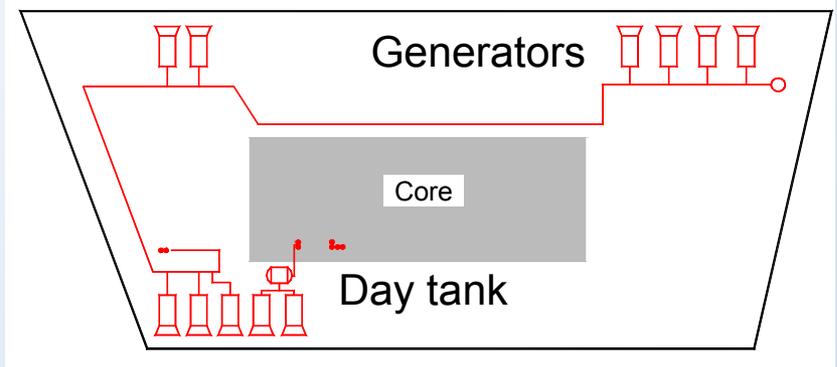
Fuel System for Emergency Power WTC 7

- Protection
 - Main tanks buried
 - 1st floor tank room 4-hr, sprinklers (high hazard)
 - Pump room sprinklered
 - 5th and 7th floor generator room not sprinklered
 - 8th and 9th floor generator room was sprinklered
 - Fuel pipe-in-pipe draining to catch basin with alarm

Fuel System for Emergency Power WTC 7

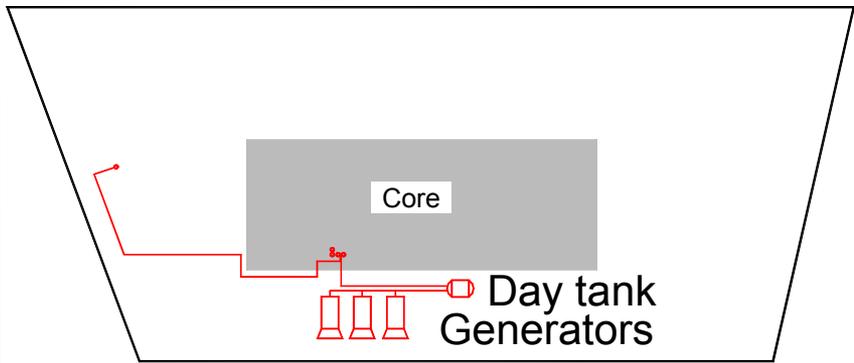


Loading Dock and 1st Floor

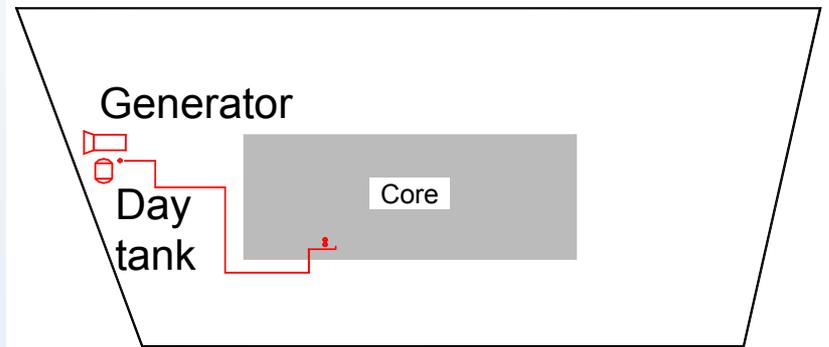


5th floor

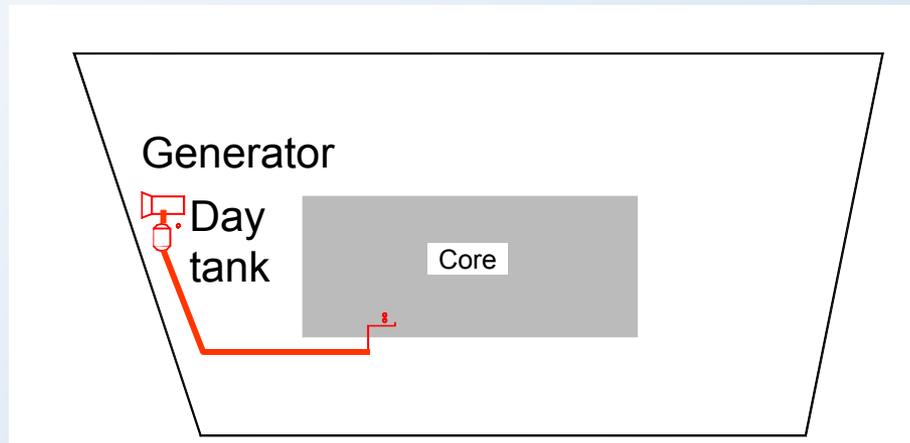
Fuel System for Emergency Power WTC 7



7th floor



8th floor



9th Floor

Interim Findings

1. Construction Class for high-rise buildings:
1968 NYC, 1964 NYS and 1965 BOCA – Class 1A or 1B
1967 Chicago – Class 1A only
2. Fire resistance ratings for Class 1A and 1B are the same in these codes
3. For unsprinklered high-rise buildings, 1967 Chicago Code required more stringent fire resistance rating (1A) than others
4. 1968 NYC Code reduced fire resistance ratings from 1938 edition, 2001 edition reduced further from 1968 edition

Interim Findings

5. 1968 NYC Code contains provisions on topics not covered in other codes
 - e.g., limits on smoke developed by materials
6. NYC Local Law 5 (1973)
 - Compartmentation not needed in fully sprinklered areas
 - Compartmentation of unsprinklered areas by 1988
7. NYC Local Law 16 (1984)
 - Required sprinklers for buildings taller than 75 ft by 1987

Status of Project

- Document the design and construction of structural systems - 60% complete
- Document the design and construction of fire protection and egress systems - 60% complete
- Compare then current building regulatory and code requirements - 70% complete
- Document the maintenance and modifications to structural and fire protection and egress systems - 50% complete
- Document the fuel system for emergency power in WTC 7 - 80% complete

Thank You

Questions?