



**NIST Response to the World Trade Center Disaster**

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

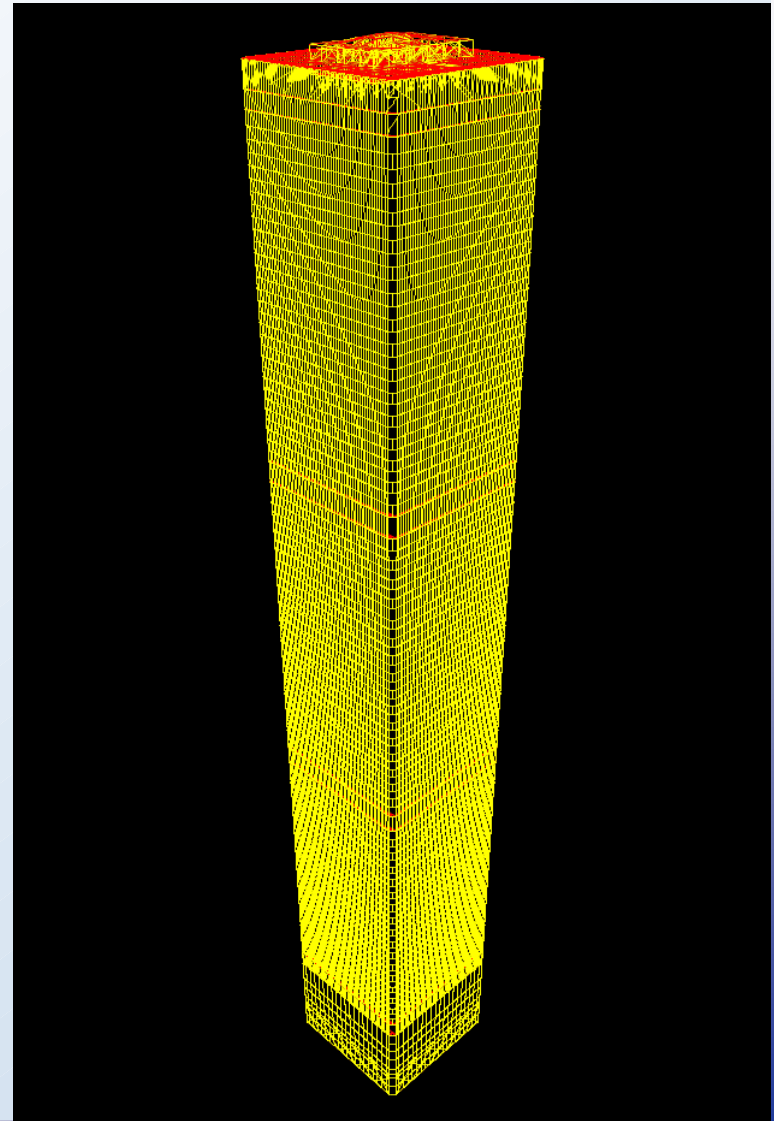
**Part V – Procedures and Practices**

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**National Institute of Standards and Technology  
Technology Administration  
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# Procedures and Practices

- The 110-story WTC towers were among the world's tallest buildings, while the 47-story WTC 7 represented a more typical tall building.
- These buildings provide case studies to document, review, and, if needed, improve the procedures and practices used in the design, construction, operation, and maintenance of tall buildings.
- This investigation objective is independent of other objectives which are focused specifically on the consequences of the attack on September 11, 2001, specifically the building collapses, evacuation, and emergency response.
- While some findings under this objective are directly relevant to the events of September 11, 2001, others are concerned with normal building and fire safety procedures and practices.



# Procedures and Practices

- Applicable building codes and policies
  - NYC codes; PANYNJ policy and rationale; PANYNJ MOU with NYC
  - Comparison with contemporaneous codes
- Building design and construction
  - Structure; fire safety; egress; elevators
  - Design criteria and requirements
  - Comparison with code requirements
  - Innovative features; code variances
  - Fabrication and construction inspections
- Maintenance and modifications
  - Local laws; modifications after 1993 bombing
  - Tenant alteration review manuals
  - Condition surveys and structural inspections
- WTC 7 Fuel System

# Applicable Building Codes and Policies

- Although not required to conform to NYC codes, the PANYNJ elected to adopt 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 that was in effect when design began for the WTC towers in 1962. The 1968 code:
  - Eliminated a fire tower as a required means of egress;
  - 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.;
  - Reduced the fire rating of the shaft walls in the building core from 3 h to 2 h;
  - Changed partition loads from 20 psf to loads based on weight of partitions per unit length (that reduced such loads for many buildings including the WTC buildings);
  - 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).
  - Permitted wind tunnel testing using models to establish design values for the wind load.

## Applicable Building Codes and Policies (2)

- **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 of the issues identified in the NYC review appear to deal with egress issues, not with any of the innovative features of the buildings.
- In 1993, the PANYNJ and the NYC Department of Buildings entered into a memorandum of understanding that:
  - **Restated the PANYNJ's longstanding policy to assure that its facilities in the City of New York meet and, where appropriate, exceed the requirements of the NYC Building Code.**
  - Provided specific commitments to the NYC Department of Buildings regarding procedures to be undertaken by the PANYNJ to assure that buildings owned or operated by the PANYNJ are in conformance with the Building Standards contained in the NYC Building Code.

## Applicable Building Codes and Policies (3)

- 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 in 1993, the PANYNJ entered into an agreement with FDNY which reiterated the policy adopted by the PANYNJ and set forth procedures to assure that new or modified fire safety systems are in compliance with local codes and regulations.
- 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, a “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.

# Rationale for the Selection of the 1968 NYC Building Code for the WTC Towers

June 22, 1965 letter from John M. Kyle, Chief Engineer to Malcolm Levy, Chief, Planning Division, WTC:

“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.”**

# Rationale for the Selection of the 1968 NYC Building Code for the WTC Towers

September 29, 1965 letter from Malcolm P. Levy, Chief, Planning Division, WTC to Minoru Yamasaki, Architect:

“... Generally the tower core should be redesigned to eliminate the fire tower and **to take advantage of the more lenient provisions regarding exit stairs...**”

May 19, 1966 memorandum from Guy F. Tozzoli, Director, World Trade Department to John M. Kyle, Chief Engineer:

“The decision to follow the new Code was, as you pointed out, in your memorandum to Mr. Levy of June 22, 1965, based on the fact that: (1) **The new Code had been thoroughly reviewed by interested technical groups and was modified to meet all major objections;** (2) it would probably be adopted before we constructed our buildings; and (3) **the Commissioner favored the approach of using advanced techniques in the design of the World Trade Center** and that the Port Authority, according to him, was not subject to the provisions of the Building Code.”



# Rationale for the Selection of the 1968 NYC Building Code for the WTC Towers

Memorandum dated January 15, 1987, from Lester S. Feld (Chief, Structural Engineer, World Trade Department, PANYNJ) to Robert J. Linn (Deputy Director for Physical Facilities, WTD, PANYNJ):  
Subject: The World Trade Center – Towers and Plaza Buildings  
Fire Rating per NYC Building Code Revision Effective 12-6-68.

Paragraph 2. B. of the memo states:

**“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 a three hour rating and floor construction with a 2 hour rating.”**

# Condition Surveys and Structural Inspections

- PANYNJ developed the Standards for Structural Integrity Inspection of the World Trade Center Towers A & B in 1986.
- Beginning in 1990, PANYNJ implemented a systematic facility condition survey program for the WTC Towers. Prior to 1990, both WTC 1 and WTC 2 were inspected occasionally.
- WTC 7, which was not owned by PANYNJ, was also inspected based on the criteria in the Standards.
- The condition survey program included:
  - WTC 2 condition survey, 1990, PANYNJ Engineering Quality Assurance Division
  - WTC 1 condition survey, 1991, Office of Irwin G. Cantor, Consulting Engineers
  - WTC 7 survey, 1997, Ammann & Whitney
  - Due diligence physical condition survey of WTC 1 and WTC 2, 2000, Merritt and Harris
- Periodic inspections under the Structural Integrity Inspection Program were conducted by LERA and other engineering firms.

# Standards for Structural Integrity Inspection

- Statistical inspections:
  - Periodic visual inspection of selected structural components in “higher-potential trouble prone areas” supplemented by occasional visual inspections when the structure was exposed during tenant remodeling or general maintenance work.
- Review of maintenance and tenant complaint reports:
  - Examination of various reports to shed light on underlying structural problems – maintenance reports of non-structural repairs; water leakage; and tenant complaints about unusual building movements, vibration, noise, etc.
- Building movement and deformation measurements:
  - Performance of systems within buildings evaluated 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.

# Structural Integrity Inspection Program

- In general, the structural integrity inspections (SII) 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.
- The SII reports identify some of the same deficiencies from report to report, including missing fireproofing on structural steel members.
- 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.
- Fireproofing was reported to be missing or damaged in the floors below the Plaza Level (Levels B1 to B6 of WTC 1 and WTC 2) and in the hat-truss zone.
- Fireproofing on beams and columns was also found missing or damaged in elevator shafts. The causes for missing and damaged fireproofing were attributed to high-speed traveling of elevator cabs and elevator cables hitting fireproofing on structural members. It is also noted that a large portion of missing or damaged fireproofing in elevator cores occurred at lower levels of the towers.

# Retention of Building Documents

- State and local jurisdictions do not require retention of documents related to the design, construction, operation, maintenance, and modification of buildings, with few exceptions. These documents are in the possession of building owners, contractors, architects, engineers, and consultants.
- **Building 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 NIST investigation.**
- In the case of WTC 7, several key documents could not be reviewed since they were lost in the collapse of the building.

# Roles of Architects and Engineers

- Consistent with the practice at the time, the code architect was responsible for specifying the fire protection and designing the egress system for the WTC Towers in accordance with the prescriptive provisions of the NYC 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.
- **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.**
  - The technical base and sophistication of the practice of fire protection engineering today is well advanced of where it was during the design and construction of the WTC towers.
- **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.**

# Mitigation of Progressive Structural Collapse

- **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.**

# Structural Integrity of Means of Egress

- **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 tests 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 in the WTC towers, especially above the floors of impact, may have been less extensive.**



# Standards for Estimating Design Wind Loads

- **Standards and code provisions do not exist for conducting wind tunnel tests and for the methods used in practice to estimate design wind loads from test results.**
- 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 leading engineering design firm contracted by NIST and a NIST expert on wind effects on structures indicated that the documentation of the test results did not provide sufficient basis to reconcile the major differences.**
- Wind loads were a major governing factor in the design of structural components that made up the frame-tube steel framing system.

## Sources of Major Differences in Wind Load Estimation Methods Used in Current Practice

- Design wind speed (codes, standards, site-specific estimates)
- Hurricane wind profile (whether or not hurricane wind profiles are flatter than the profiles for extratropical windstorms)
- Estimation of “component” wind effects with a specified mean recurrence interval by integrating wind tunnel data with wind speed and direction information (e.g., up-crossing method, sector-by-sector method, storm passages approach)
- Estimation of “resultant” wind effects using load combination methods (e.g., principle of companion loads, companion point-in-time loads)

# Standard Fire-Resistance Tests

- **Code provisions with detailed procedures do not exist to analyze and evaluate data from fire resistance tests of other building components and assemblies to qualify an untested building element.**
- **Based on available data and records, no technical basis was found for selecting the spray-applied 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.
  - 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.

## Standard Fire-Resistance Tests (2)

- **Code provisions are needed to 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.**
- 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 informed NIST that there are no such test records in its files.**

# Fire-Resistance Ratings (1)

- 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.

## Fire-Resistance Ratings (2)

- **A technical basis is needed 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.**
- 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.
- **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-Resistance of Structural Connections**

- **Code provisions are needed to ensure that structural connections are provided the same degree of fire protection as the more restrictive protection of the connected elements.**
- **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 in the WTC towers were when the connecting elements had different fire ratings and whether the applied fireproofing achieved that rating.**

# Fireproofing: Field Application and Inspection

- **Rigorous field application and inspection provisions and regulatory requirements are needed to assure 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.**
  - 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.
  - 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.



# Fireproofing: Requirements for In-Service Performance

- **A technical basis is needed to establish whether the minimum mechanical and durability related properties of SFRM are sufficient to ensure acceptable in-service performance in buildings.**
- **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 would have assisted in assessing the post-impact fireproofing condition of the WTC towers.

# Performance-Based Design for Fire-Resistance of Structures

- **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:**
  - **evaluate the system performance of tall-building structures under real fire scenarios, and**
  - **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.

# Design-Basis Fire Scenarios

- **Detailed procedures are needed 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.**
- 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)
  - 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 are unknown, and it is difficult to evaluate the performance of fire protection systems in these buildings under specific fire scenarios.**

# Performance-Based Design Tools to Evaluate Fire-Resistance of Structures

- Validated and verified tools are needed 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.
- 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 had to further develop and validate existing tools to investigate the fire performance of the WTC towers and WTC 7.

# Compartmentation to Mitigate Fire Spread

- 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<sup>2</sup>.
  - Compartmentation mitigates the horizontal spread of more severe but less frequent fires and typically requires fire-rated partitions for areas of about 12,000 ft<sup>2</sup>. Active firefighting measures also cover up to about 5,000 ft<sup>2</sup> to 7,500 ft<sup>2</sup>.
  - 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 to Mitigate Fire Spread (2)

- The NYC Building Code and PANYNJ 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.
- 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 hour fire separations into spaces or compartments not to exceed 7,500 ft<sup>2</sup>. Floor areas could be increased up to 15,000 ft<sup>2</sup> if protected by 2 hour fire resistive construction and smoke detectors.**
- 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 the time.
- **Following the 1975 fire** a fire safety consultant report recommended to 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 the buildings left the arrangement again with **only partitions separating tenant spaces from each other and from exit access corridors or common spaces in the core, and with shaft enclosures.**

## Compartmentation to Mitigate Fire Spread (3)

- **Building codes typically require 1 h fire-rated tenant separations but do not impose minimum compartmentation requirements (e.g., 12,000 ft<sup>2</sup>) for buildings with large open floor plans to mitigate the horizontal spread of fire.** This was 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.
- **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 fire-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.**

# Tenant Separation Walls

- 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 hr, and shall **continue through any concealed spaces of the floor or roof construction above.**”
- The PANYNJ 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 **assure that this remediation process occurs as quickly as possible.**”



## Tenant Separation Walls (2)

- **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 consistency with the 1968 code.**
- The PANYNJ commissioned a due diligence study in 1996 which indicated that the issue of tenant demising walls not running slab-to-slab included some of the corridor separation walls. This was a more critical requirement since the corridor walls were required to meet a 2 hour fire rating while the demising walls were required to be 1 hour fire rated.
- 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.

# Sprinkler Systems

- **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 from most common building fires and can 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 sky lobbies was still underway at that time.
- The sprinkler system in the WTC towers 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, consistent 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.

## Sprinkler Systems (2)

- 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:**
  - **the complementary functions of sprinklers and fire-protected structural elements,**
  - **the different fire scenarios for which each system is designed to provide protection,**  
and
  - **the need for redundancy should one system fail.**
- **The British Standards Institution (BSI) 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 trade-off 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

- With a few special exceptions, building codes in the United States do not permit 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 elevator use by emergency 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, emergency responders carrying between 50 to 100 pounds of gear required about 1.4 minutes to 2 minutes per floor when using the stairs in WTC 1.
  - While it is difficult to maintain this pace for more than about the first 20 stories, it would take an emergency responder between 1-1/2 to 2 hours 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 emergency 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. All but one of the elevators were damaged in each WTC tower 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.

## Selected Findings on Codes and Practices

- The 1968 New York City Building Code was comparable to other codes of the era (1964 New York State, 1967 Chicago, and 1965 BOCA/BBC national model code).
- **Documents suggest that the WTC towers generally were designed and maintained consistent with the requirements of the 1968 New York City Building Code. Areas of concern included fireproofing of WTC floor system, height of tenant separation walls, and egress requirements for the assembly use space for the Windows of the World in WTC 1 and Top of the World observation deck in WTC 2.**
- The PANYNJ developed and periodically updated a Tenant Alteration Review Manual that contained the technical criteria, standards, and requirements used to guide modifications and alterations over the life of the buildings.
- The PANYNJ developed and implemented a formal facility condition survey and structural integrity inspection program. The buildings generally were found to be in good condition. Frequent recommendations were made to repair or replace missing fireproofing at different locations, particularly in elevator shafts and floors below the plaza level.

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