

National Construction Safety Team Act Annual Report

Fiscal Year 2008

Summary

This annual report to Congress for FY 2008 is required by the National Construction Safety Team Act. NIST completed its federal building and fire safety investigation of the World Trade Center disaster with the release of its final report on WTC 7 on November 20, 2008. Also during 2008, the International Code Council (ICC) membership approved twenty-three major changes to the International Building Code (IBC) and the International Fire Code (IFC) that are consistent with the recommendations of the NIST World Trade Center Investigation report. The ICC Codes are widely adopted and used as the basis for state and local construction codes throughout the United States. In addition, the National Fire Protection Association (NFPA) membership also approved fifteen changes to the NFPA 5000 Building Construction and Safety Code; NFPA 1, Fire Code; and NFPA 101, Life Safety Code. The NFPA codes and standards are also adopted and widely used as the basis for state and local fire codes throughout the United States.

Introduction

In October 2002, the President signed into law the National Construction Safety Team (NCST) Act (P.L. 107-231), which authorized the Director of the National Institute of Standards and Technology (NIST) to establish National Construction Safety Teams for deployment after events causing the failure of a building or buildings that result in substantial loss of life or that pose significant potential for substantial loss of life.

The purpose of these investigations is to improve the safety and structural integrity of buildings in the United States. A team shall:

- (A) establish the likely technical cause or causes of the building failure;
- (B) evaluate the technical aspects of evacuation and emergency response procedures;
- (C) recommend as necessary, specific improvements to building standards, codes, and practices based on the findings made pursuant to subparagraphs (A) and (B); and,
- (D) recommend any research and other appropriate actions needed to improve the structural safety of buildings, and improve the evacuation and emergency response procedures, based on the findings and recommendations of the investigation.

Under Section 10 of the NCST Act, NIST is to provide by February 15 of each year a report that includes:

- (1) a summary of the investigations conducted by Teams during the prior fiscal year;

- (2) a summary of recommendations made by Teams in reports issued under Section 8 during the prior fiscal year and a description of the extent to which those recommendations have been implemented; and,
- (3) a description of the actions taken to improve building safety and structural integrity by the National Institute of Standards and Technology during the prior fiscal year in response to reports issued under Section 8.

This report summarizes NIST's activities under the NCST Act for Fiscal Year 2008.

1. Investigations Conducted by Teams during Fiscal Year 2008

During Fiscal year 2008, NIST completed its federal building and fire safety investigation of the World Trade Center disaster, concluding its extensive, three-year scientific and technical study of the collapse of World Trade Center 7 (WTC 7). NIST released a draft of the final report on the collapse of WTC 7 for public comment on August 21, 2008. The investigation found that the collapse of the 47-story WTC 7 in New York City late in the afternoon of Sept. 11, 2001, was primarily due to fires. This was the first known instance of fire causing the total collapse of a tall building. The WTC 7 investigation report included 13 recommendations for improving building and fire safety; one new recommendation and twelve reiterated from the final report on the WTC Towers.

Technical Approach. To reach the conclusions in its report, NIST complemented its in-house expertise with private-sector technical experts; accumulated an extensive collection of documents, photographs and videos related to the WTC events of 9/11; conducted first-person interviews of WTC 7 occupants and emergency responders; and analyzed the evacuation and emergency response operations in and around WTC 7. NIST also performed the most complex computer simulations ever conducted to model a building's response behavior and determine its collapse sequence due to a combination of debris impact damage, fires and a progression of structural failures from local fire-induced damage to collapse initiation, and, ultimately, to global collapse.

Major Findings. The study found that the fires in WTC 7, which were uncontrolled but otherwise similar to fires experienced in other tall buildings, caused an extraordinary event. Heating of floor beams and girders caused a critical support column to fail, initiating a fire-induced progressive collapse that brought the building down.

Video and photographic evidence combined with detailed computer simulations show that neither explosives nor fuel oil fires played a role in the collapse of WTC 7. The NIST investigation team also determined that other elements of the building's construction—namely trusses, girders and cantilever overhangs that were used to transfer loads from the building superstructure to the columns of the electric substation (over which WTC 7 was constructed) and foundation below—did not play a significant role in the collapse.

A key factor leading to the eventual collapse of WTC 7 was thermal expansion of long-span floor systems at temperatures hundreds of degrees below those typically considered

in current practice for fire resistance ratings determined by use of the ASTM E-119 standard test. Floors 7 through 45 of WTC 7 used a structural system design in widespread use. Typical floor framing consisted of wide flange beams and girders and connections were generally either a single shear plate or double angle connection, although in several locations, seated connections were used. Floors 46 and 47 were reinforced to support the additional loads of cooling towers and water tanks for fire suppression. The lowest four floors housed two-story lobbies, one each on the center of the south side of the 1st and 3rd floors. Floors 5 and 6 were mechanical spaces and also housed the transfer trusses that distributed the load of the upper floors to the structural frame of the Consolidated Edison (ConEd) substation and the structure of the lowest four floors of WTC 7.

The investigators also reported that if the city water main had not been cut by the collapse of World Trade Center towers 1 and 2 (WTC 1 and WTC 2), operating sprinklers in WTC 7 would likely have prevented its collapse. Nevertheless, NIST recommended that building standards and codes be strengthened beyond their current intent to achieve life safety by preventing structural collapse even during severe fires like this one, when sprinklers do not function, do not exist or are overwhelmed by fire.

The investigation team found that the design of WTC 7 was generally consistent with the New York City building code in effect at the time. The estimated 4,000 occupants of WTC 7 on the morning of September 11 were evacuated without any fatalities or serious injuries.

Reducing Future Risks. NIST identified several existing, emerging or even anticipated capabilities that could have helped prevent WTC 7's collapse. The degree to which these capabilities improve performance remains to be evaluated. Possible options for developing cost-effective fixes include:

- More robust connections and framing systems to better resist effects of thermal expansion on the structural system.
- Structural systems expressly designed to prevent progressive collapse, which is the spread of local damage from a single initiating event, from element to element, eventually resulting in the collapse of an entire structure or a disproportionately large part of it. Current model building codes do not require that buildings be designed to resist progressive collapse. The 2009 IBC contains a provision addressing structural integrity which was developed in response to NIST's WTC recommendations. ASCE 7-05 also contains a provision on general structural integrity stating that buildings shall be designed to sustain local damage with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage.¹ The ASCE 7-05 standard does not provide specific design criteria to minimize risk of progressive collapse.

¹ Minimum Design Loads for Buildings and Other Structures, ASCE 7-05, American Society of Civil Engineers, 2005.

- Better thermal insulation (i.e., reduced conductivity and/or increased thickness) to limit heating of structural steel and to minimize both thermal expansion and weakening effects. Insulation has been used to protect steel strength, but insulation also could be used to maintain a lower temperature in the steel framing to limit thermal expansion.
- Improved compartmentation in tenant areas to limit the spread of fires.
- Thermally resistant window assemblies to limit breakage, reduce air supply, and retard fire growth.

Response to Public Comments. Following a four-week public comment period, NIST released its final report on the collapse of WTC 7 on November 20, 2008. The final report was strengthened by clarifications and supplemental text suggested by organizations and individuals worldwide in response to the draft WTC 7 report, released for public comment on August 21, but the revisions did not alter the investigation team's major findings and recommendations, which include identification of fire as the primary cause for the building's failure.

In response to comments from the building community, NIST conducted an additional computer analysis. The goal was to see if the loss of WTC 7's Column 79 – the structural component identified as the one whose failure on 9/11 started the progressive collapse – would still have led to a complete loss of the building if fire or damage from the falling debris of the nearby WTC 1 tower were not factors. The investigation team concluded that the column's failure under any circumstance would have initiated the destructive sequence of events.

Other revisions to the WTC 7 final report included:

- Expanding the discussion of firestopping, the material placed between floors to prevent floor-to-floor fire spread;
- Clarifying the description of thermal expansion as it related to WTC 7's shear studs and floor beams; and
- Expanding in greater detail the computer modeling approach used to define where and when the fire in WTC 7 started and the extent of window breakage as a result of fire.

Completion of the Investigation. With the release of the final WTC 7 report, NIST completed its federal building and fire safety investigation of the WTC disaster that began in August 2002. The complete text of the WTC 7 final report, a video describing the WTC 7 Investigation findings, all comments received on the draft WTC 7 report, and other materials are available on the NIST WTC website: <http://wtc.nist.gov>.

Background: Details of the Probable Collapse Sequence for WTC 7. NIST found that the impact of debris from the collapse of WTC 1 ignited fires on at least 10 floors of WTC 7, and the fires burned out of control on six lower floors. The heat from these uncontrolled fires caused thermal expansion of the steel beams on the lower floors of the east side of WTC 7, damaging the floor framing on multiple floors. Eventually, a girder

on Floor 13 lost its connection to a critical interior column that provided support for the long floor spans on the east side of the building. The displaced girder and other local fire-induced damage caused Floor 13 to collapse, beginning a cascade of floor failures down to the fifth floor. Many of these floors had already been at least partially weakened by the fires in the vicinity of the critical column. This collapse of floors left the critical column unsupported over nine stories.

When this critical column buckled due to lack of floor supports, what followed in rapid succession was a progression of structural failures. Failure first occurred all the way to the roof line—involving all three interior columns on the most eastern side of the building. Then, progressing from east to west across WTC 7, all of the columns in the core of the building failed. Finally, the entire façade collapsed.

The investigation team considered the possibility of other factors playing a role in the collapse of WTC 7, including the possible use of explosives, fires fed by the fuel supply tanks in and under the building, and damage from the falling debris of WTC 1.

The team said that the smallest blast event capable of crippling the critical column would have produced a “sound level of 130 to 140 decibels at a distance of half a mile,” yet no noise this loud was reported by witnesses or recorded on videos.

As for fuel fires, the team found that they could not have been sustained long enough, could not have generated sufficient heat to fail a critical column, and/or would have produced “large amounts of visible smoke” from Floors 5 and 6, which was not observed.

Finally, the report notes that “while debris impact from the collapse of WTC 1 initiated fires in WTC 7, the resulting structural damage had little effect in causing the collapse of WTC 7.”

2. Recommendations Made by Teams and the Extent of Implementation

As a part of its report on the collapse of WTC 7, NIST issued one new recommendation and reiterated 12 from the previously completed investigation of the World Trade Center towers, WTC 1 and WTC 2. While the partial or total collapse of a tall building due to fires is a rare event, NIST strongly urged building owners, operators and designers to evaluate buildings to ensure the adequate fire performance of the structural system. Of particular concern are the effects of thermal expansion in buildings with one or more of the following features: long-span floor systems, connections not designed for thermal effects, asymmetric floor framing and/or composite floor systems. Engineers should be able to design cost-effective fixes to address any areas of concern identified by such evaluations.

The 12 recommendations reiterated from the WTC towers investigation address several areas, including specific improvements to building standards, codes and practices; changes to, or the establishment of, evacuation and emergency response procedures; and research and other appropriate actions needed to help prevent future building failures.

3. Actions Taken to Improve Building Safety and Structural Integrity

The International Code Council (ICC), at the ICC hearings held September 15-21, 2008, in Minneapolis, Minn., adopted 23 changes to be incorporated into the 2009 edition of the ICC's I-Codes (specifically the International Building Code, or IBC, and the International Fire Code, or IFC). These changes responded directly to the recommendations made by NIST as a part of its final report on the collapses of the WTC Towers. The new code provisions will lead to future buildings—especially tall structures—that will be increasingly resistant to fire, more easily evacuated in emergencies, and safer overall. The I-Codes are state-of-the-art model codes used as the basis for building and fire regulations promulgated and enforced by U.S. state and local jurisdictions.

The lessons learned from the tragic events of 9/11 have yielded stronger building and fire codes for a new generation of safer, more robust buildings across the nation. These changes are the result of a strong commitment to public safety by the nation's building and fire safety officials, private sector professionals, and the fire service. The improvements that they ensure will be of lasting value to our society.

The new codes address areas such as increasing structural resistance to building collapse from fire and other incidents; requiring a third exit stairway for tall buildings; increasing the width of all stairways by 50 percent in new high-rises; strengthening criteria for the bonding, proper installation and inspection of sprayed fire-resistive materials (commonly known as "fireproofing"); improving the reliability of active fire protection systems (such as automatic sprinklers); requiring a new class of robust elevators for access by emergency responders in lieu of an additional stairway; making exit path markings more prevalent and more visible; and ensuring effective coverage throughout a building for emergency responder radio communications.

Summaries of the approved changes follow below while detailed lists, along with a chart tracking the progress toward implementing all of the NIST WTC recommendations, may be found at <http://wtc.nist.gov>.

The leadership provided by the ICC's Ad Hoc Committee on Terrorism Resistant Buildings, its Code Technology Committee and the U.S. General Services Administration were key to achieving the code changes. The proposals were developed and refined on the basis of feedback provided by building and fire code experts convened by the National Institute of Building Sciences (NIBS) with support from NIST.

In addition to the code changes approved by the International Code Council, the National Fire Protection Association (NFPA), at its annual meeting in July 2008, approved fifteen changes to the NFPA 1 Fire Code, NFPA 101 Life Safety Code, and NFPA 5000 Building Construction and Safety Code. Summaries of the changes approved by the NFPA follow below and also appear in the chart tracking the progress of implementation of the recommendations on the NIST WTC website.

NIST remains strongly committed to continuing its work with these groups toward implementing additional changes to codes and standards based on the recommendations contained in our report of the WTC towers investigation. That effort also will include the recommendations from the recently completed NIST investigation of the collapse of WTC Building 7, as well as amending the unapproved proposals based on recommendations from the NIST WTC towers investigation for possible approval during the next ICC and NFPA code development cycles.

**Changes to ICC Building and Fire Codes
Consistent with Recommendations from NIST's WTC Towers Investigation**

**Approved at the Final Action Hearings of the International Code Council
Minneapolis, Minn., September 15-21, 2008**

The following are the 23 model building and fire code changes consistent with the NIST WTC investigation recommendations now required by the I-Codes (changes displayed in italics are ones that were approved at previous ICC hearings and incorporated at the Minneapolis hearing into the 2009 I-Codes):

- An additional (third) exit stairway for buildings more than 420 feet high.
- An increase of 50 percent in the width of exit stairways in new sprinklered buildings.
- Permitting the use of elevators for occupant evacuation in fires and other emergencies for all buildings, and as an alternative to the required additional exit stairway for buildings more than 420 feet high. Passenger elevators must meet specific criteria to be used for evacuation purposes.
- Hardening of exit stairway and passageway enclosures, and elevator shaft enclosures, in buildings—for all buildings more than 420 feet high, for buildings 75-420 feet high where failure of the enclosure would substantially jeopardize human life, and in essential facilities such as hospitals.
- Separating exit stairway enclosures by a distance not less than 30 feet or not less than one-fourth of the maximum building diagonal, whichever is less. For example, a building with a 50-foot by 50-foot floor plan would have a diagonal of about 70 feet. One-fourth of 70 is 17.5 feet, which would be the minimum distance required between exits (since it is less than 30 feet).
- *A minimum of one fire service access elevator for buildings more than 120 feet high.*
- Fire service access elevator lobby sizes that are a minimum of 150 square feet in area with sides at least 8 feet long.
- Keeping fire service access elevator lobbies free of storage.
- Greater reliability of sprinklers with a minimum of two water supply risers for each sprinkler zone in buildings more than 420 feet high. Each riser is required to supply sprinklers on alternate floors and will be placed in remotely located stair enclosures.
- Providing minimum structural integrity for framed and bearing wall structures

- *A one-hour increase in the fire-resistance rating of structural components and assemblies in buildings more than 420 feet high.*
- *Explicit adoption of the "structural frame" approach to fire resistance ratings that requires all members of the primary structural frame to have the higher fire resistance rating commonly required for columns. The primary structural frame includes the columns; other structural members including the girders, beams, trusses and spandrels having direct connections to the columns; and bracing members designed to carry gravity loads.*
- *Broadening the definition of the primary structural frame to include bracing members essential to vertical stability (such as floor systems or cross bracing) whether or not they carry gravity loads.*
- *Increasing bond strength for fireproofing to nearly three times greater than currently required for buildings 75-420 feet high and seven times greater for buildings more than 420 feet high.*
- *Field installation requirements for fireproofing to ensure that:*
 - *installation complies with the manufacturer's instructions;*
 - *the substrates (surfaces being fireproofed) are clean and free of any condition that prevents adhesion;*
 - *testing is conducted to demonstrate that required adhesion is maintained for primed, painted or encapsulated steel surfaces; and*
 - *the finished condition of the installed fireproofing, upon complete drying or curing, does not exhibit cracks, voids, spalls, delamination or any exposure of the substrate.*
- *Special field inspections of fireproofing to ensure that its as-installed thickness, density and bond strength meet specified requirements and that a bonding agent is applied when the bond strength is less than required due to the effect of a primed, painted or encapsulated steel surface. The inspections are to be performed after the rough installation of mechanical, electrical, plumbing, sprinkler and ceiling systems.*
- *Luminous markings delineating the exit path (including vertical exit enclosures and passageways) in buildings more than 75 feet high to facilitate rapid egress and full building evacuation.*
- *Broadening the use of luminous markings to identify obstacles, exit doors, exit signs and floor numbers in the exit path in buildings more than 75 feet high.*
- *Luminous exit path markings in existing buildings more than 75 feet high with the exception of open, unenclosed stairs in historic buildings.*

- Increasing the area of the Fire Command Center (the area from which all fire department operations are directed and usually housing the control panel for alarms, sprinklers, etc.) from 96 square feet to 200 square feet with at least one side 10 feet long in buildings more than 75 feet high.
- Approved radio coverage for all buildings for emergency responders within the building based upon the existing coverage level of public safety communications systems at the exterior of the building. Approved coverage includes specific requirements for signal strength, system design, installation and maintenance.
- Installing an emergency responder radio communications system to provide the required level of radio coverage throughout a building. Typical hardwired communications systems would be replaced.

Changes to the NFPA Building and Fire Codes
Consistent with Recommendations from NIST's WTC Investigation
Approved at the NFPA Annual Meeting and Standards Council Action on 2009 Documents, July
2008

The following are the code changes consistent with the NIST WTC recommendations now required by the NFPA Codes.

- Full building evacuation (use of elevators). Permits elevators to remain in service (prior to FEO Phase I recall) and to be used by occupants for self-evacuation. Requires a package of protection measures including protected lobbies on every floor with direct access to a stair, real time monitoring and communication, secondary power, protection of wiring and cables, water protection, and full building sprinklers. Requirements contained in an adoptable annex; no thresholds or mandates, and no credit against egress requirements.
- Fire service access elevator (use of elevators). Requires a minimum of one fire service access elevator for buildings more than 120 ft in height. Includes a package of protection including protected lobbies on every floor, direct access to a stair with a standpipe, secondary power, protection of wires and cables, real time monitoring, and communications.
- Surviving burnout without collapse. Establishes a required performance-based design scenario that evaluates a high rise building for performance under a fully-developed fire event where the building must resist both local and global collapse.
- Supplemental evacuation equipment. Establishes a series of performance requirements to recognize (but not mandate nor give credit for) supplemental egress systems such as controlled descent devices and platform lifts; with references to ASTM standards.
- Situational awareness. Requirement establishes situational awareness as a fundamental requirement of egress planning and design.
- Managed evacuation. Provides advisory text on managed and unmanaged evacuations as well as partial, total, and protect-in-place strategies.
- Evacuation diagrams. Establishes a menu of provisions that can be mandated by occupancy chapters to require evacuation diagrams that reflect actual floor arrangements and exit locations.
- Luminescent exit stair markings (new buildings). Establishes a menu of provisions that can be mandated by occupancy chapters to deal with markings on stair treads, landings and handrails; perimeter demarcation, obstacles, door frames, and signage.

- Exit signage. Requires directional signage within horizontal components of exit enclosures (transfer corridors).
- Minimum width of transfer corridors. Establishes a minimum width of transfer corridors as $\frac{2}{3}$ the width of the stair.
- Remoteness of stairways. Remoteness changed from walking path to direct line measurement with the criterion remaining at $\frac{1}{3}$ the diagonal if sprinklered and $\frac{1}{2}$ the diagonal if not.
- Remoteness applied to exit discharge. Applies remoteness criteria to exit discharge as well as exit access and the exits themselves.
- Risk assessment for buildings with substantial hazard. Annex note suggesting the conduct of a risk assessment for buildings greater than 420 ft or with more than 10,000 occupants that evaluates performance under extreme events.
- Field inspections of fireproofing. Requires special inspections of fireproofing for integrity where accessible, every 5 years, and a written report provided.
- Emergency responder radio communications in buildings (radio coverage requirements). Requires approved radio coverage in all buildings including requirements for signal strength and signal to noise ratio, by the installation of repeaters monitored by the fire alarm system. Includes requirements for commissioning and regular testing. Alternatively, the fire department can specify wired phones.