Fire Protection

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The NIST WTC Investigation Draft Final Report

On April 5, 2005, the National Institute of Standards and Technology (NIST) released a portion of a draft of the final report on its investigation into the collapse of the World Trade Center (WTC) towers. The portion of the report released includes a 25-page executive summary for the Design, Construction and Maintenance of Structural and Life Safety Systems (NCSTAR 1-1) section of the report. Section E.11 in the executive summary includes 26 findings of the investigation.

While most of the findings are of interest, Findings 22 through 25, titled *Compartmentation and Sprinklers*, should be of particular interest to building design professionals. If the concepts outlined in these four findings are eventually incorporated into building codes, they could very well have a significant impact on the way that future buildings are designed. The following are excerpts from these findings.

Finding 22. *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 fire 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.

Compartmentation of spaces is a key building fire-safety requirement to limit fire spread.

Finding 23. *Building codes typically require one-hour 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.*

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.*

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 that 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 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.*

It is important to note that, although the issue of building design for terrorist attacks is not explicitly addressed in the portion of the draft final report released in April, Dr. Shyam Sunder, the lead investigator for the NIST study of the WTC collapse, indicated in a presentation at the American Institute of Architects' convention on May 20, 2005, that NIST will not be recommending that provisions to mitigate the consequences of terrorist attacks be included in building codes. Hence, it can be concluded that the concepts outlined in Findings 22 through 25 of the NIST report are not intended to address the terrorist attacks that occurred on Sept. 11, or any future terrorist attacks. In other words, the issues and concepts incorporated in these findings are only intended to address the hazards that have traditionally been addressed in building codes.

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History of Sprinkler "Trade-Offs"

Prior to the early 1970s, the issue of occupant fire safety in buildings was addressed in building codes through the use of a combination of egress facilities and passive fire protection (building compartmentation and structural fire resistance). Up until that time, it was generally accepted that the role of sprinkler protection in building fire safety was limited to property protection. In the 1960s (and perhaps even earlier), the commonly held belief that sprinklers were of little benefit to the safety of building occupants in a fire was challenged by a group of engineers who referred to themselves as fire protection engineers.

This group of professionals, along with some in the fire service, advocated that sprinkler protection could be used to protect building occupants in a fire. There was, however, one significant hurdle to the installation of sprinkler protection in buildings – cost.

The cost of installing sprinkler protection in storage, industrial and mercantile buildings was offset by large reductions in fire insurance premiums. No significant reductions in insurance premiums were available, however, for the installation of sprinkler protection in fire-resistive buildings containing light-hazard occupancies, as defined by National Fire Protection Association (NFPA) 13, such as office buildings, hotels and apartment buildings, simply because property losses due to fire in these types of buildings were low. Hence, the challenge to those who advocated the installation of sprinkler protection in buildings for occupant fire safety purposes was to somehow reduce the cost of sprinkler installations so that sprinkler protection could actually be utilized as a tool to protect building occupants in light-hazard buildings.

Contrary to what many fire protection professionals would like to believe, life safety isn't just limited to building fire safety.

Several means of reducing the cost of installing sprinkler protection in buildings were adopted in the late 1960s and 1970s. These included hydraulically designed sprinkler systems (as an alternative to systems designed per the pipe schedule), grooved piping systems (as an alternative to screwed piping systems) and the approval of extended coverage sidewall sprinklers (as an alternative to using standard sprinklers to protect residential occupancies).

The cost of installing sprinkler protection in light-hazard buildings has been nearly constant (at between $1 and $2 per square foot) over a 30-year period. This means that, when inflation is considered, the actual cost of installing sprinkler protection in buildings has plummeted.

Another means to further reduce the (net) cost of sprinkler installations and encourage the installation of sprinkler protection was also developed – reductions ("trade-offs") in the requirements for compartmentation and structural fire resistance when sprinkler protection is provided throughout a building. Sprinklers operate when a fire is in its incipient stage. Sprinkler operation limits fire spread and also prevents flashover. (Typically, sprinkler protection limits the area involved in a fire to 100 square feet or less in light-hazard occupancies with relatively low ceilings.) In addition, sprinkler operation also rapidly reduces the temperatures to which structural members are exposed prior to the operation of sprinklers. (Sprinklers protecting light-hazard occupancies with relatively low ceilings typically operate prior to ceiling temperatures reaching 800°F and, within two minutes of operation of the first sprinkler, ceiling temperatures are typically reduced to 200°F or less.) Hence, it can be said that sprinkler protection performs functions that are equivalent to that performed by building compartmentation and structural fire protection. In addition, it can be stated that sprinkler protection is capable of preventing flashover, while neither building compartmentation nor structural fire protection can perform this function.

Discussion of NIST's findings

Given NIST's statements in Findings 22 through 25, it seems apparent that NIST believes that sprinkler protection is not sufficiently reliable to act as a substitute for building compartmentation and structural fire resistance. However, NIST has yet to offer any evidence to support this conclusion, other than the discussion of theory included in the findings. The theoretical basis for allowing sprinkler protection to be used as at least a partial substitute for building compartmentation and structural fire resistance was established more than 35 years ago and "trade-offs" have been included in the building codes used in the United States for more than 30 years. Hence, the fire record in the United States over the last three decades should tell us whether or not the theory behind reductions in code requirements for compartmentation and structural fire resistance works in the real world. Given this, let's examine some facts and statistics:

- In the last 30 years, no major high-rise building fires (excluding the fires that resulted from the terrorist attacks on 9/11) have occurred in U.S. high-rise buildings protected throughout by a sprinkler system.
- In the last 30 years, no large life-loss fires (excluding the fires that resulted from the terrorist attacks on 9/11) have occurred in any U.S. building protected throughout by a sprinkler system.
- A number of major fires have occurred in unsprinklered or partially sprinklered high- rise buildings in the United States in the last 30 years. These include the following fires: the World Trade Center Tower 1 in New York (1975), the MGM Grand Hotel in Las Vegas (1980), the Hilton Hotel in Las Vegas (1981), the First Interstate Bank Building in Los Angeles (1988), the One Meridian Plaza Building in Philadelphia (1991) and the Cook County Administration Building in Chicago (2003).

Note that the fire in the Cook County Administration Building would not actually be classified as a major fire since it was confined to a relatively small tenant space and did not spread to adjacent floors. However, six occupants died as a result of the fire in the building.

- Since 1975, the Building Officials and Code Administrators (BOCA) National Building Code has permitted high-rise office and residential buildings protected by a sprinkler system to be constructed with a two-hour structural frame and two-hour floor construction. Since that time, there have been no collapses of high-rise buildings protected throughout by a sprinkler system constructed to comply with the high-rise provisions contained in the BOCA Code.

• All three regional model building codes, the Life Safety Code, the International Building Code (IBC) and NFPA 5000, permit atriums to be provided in buildings that are protected throughout by a sprinkler system. An atrium is a violation of the most basic compartmentation required by these building codes - floor-to-floor compartmentation. In the last 25 years, there has not been a major fire in a building that contains an atrium and is protected throughout by a sprinkler system.

• NFPA statistics indicate that no fire deaths occurred in any U.S. hotel (both high rise and low rise) protected throughout by a sprinkler system in the five-year period between 1994 and 1998, even though many hotels were protected by defective sprinklers during this time period.

• NFPA statistics indicate that there were a total of only seven fire deaths in U.S. high- rise office buildings in the 14-year period between 1985 and 1998.

Given the excellent fire record of light-hazard buildings protected throughout by a sprinkler system over the last 25 to 30 years, it would be difficult to make the case that sprinkler systems protecting light-hazard occupancies are unreliable. This is not to say that failures of sprinkler systems protecting light-hazard occupancies do not occur. Sprinkler protection failure, however, will not necessarily result in a major fire or in fatalities. Each of the reductions in passive fire protection permitted by our present building codes has been well thought out, and no model building code used in the United States has ever permitted the elimination of all egress provisions and passive fire protection features in buildings protected by sprinklers. Obviously, if the reliability of sprinkler protection is an issue, one alternative to mandating both sprinkler protection and multiple forms of passive fire protection would be to simply make sprinkler installations more reliable. Yet, the reliability of sprinkler protection for light-hazard occupancies and the alternative of more reliable sprinkler installations are not mentioned in Findings 22 through 25.

Contrary to NIST's assertion that the package of reductions ("trade-offs") in the requirements for passive fire protection when sprinkler protection is provided has not been reviewed in depth in the United States, this issue was debated at length in the late 1990s during the development of the IBC and continues to be debated during each code change cycle. Of course, the reductions in passive fire protection permitted for sprinklered buildings in the high-rise provisions included in the three regional model codes, the

IBC and NFPA 5000 were discussed and debated for years in the early 1970s. The fact that NIST is seemingly unaware of these facts calls into question NIST's awareness of the building code development process.

Finally, the issue of the "maximum credible fire scenario" mentioned in Finding 22 needs to be addressed. Research conducted by the National Bureau of Standards (NBS) in the 1920s determined that there is a relatively simple relationship between fire loading measured in pounds per square foot (psf) of wood equivalent and fire severity expressed in terms of exposure time to the ASTM E119 time - temperature curve. (Wood is assumed to have a heat content of 8,000 Btu/pound. Wood equivalent is determined by dividing the heat content of the building contents by 8,000 Btu/pound.) The NBS research indicated the following relationships.

Fire Loading	Fire Severity
Wood Equivalent	*ASTM E119 Exposure*
5 psf	1/2 hour
10 psf	1 hour
20 psf	2 hours
30 psf	3 hours

Later research conducted by the NBS determined that the fire loading of office and residential occupancies was between five and 10 psf of wood equivalent. Hence, based upon this research, it would be expected that the maximum severity of a fire occurring in an office or residential occupancy would be equivalent to between a 30-minute and a one-hour exposure to the ASTM E119 time - temperature curve.

The investigation into the collapse of the World Trade Center towers appears to have confirmed this relationship. According to NIST, the fire load on the floors where the aircraft struck was between four and five pounds (of wood equivalent) per square foot, and fires on these floors typically burned for approximately 20 minutes in one location before moving to unburned fuel in another location. The fires did not burn in multiple locations on each floor simultaneously because of the limited quantity of air (oxygen) available.

In other words, the fires in the WTC towers were "ventilation-controlled" fires. Given this, it can be concluded that the provisions included in the 1975 and subsequent editions of the BOCA Code, which permitted high-rise office and residential buildings to be constructed with a two-hour structural frame and two-hour floor construction, provide for more-than-adequate structural fire resistance and floor-to-floor compartmentation in the (improbable) event of a failure of the sprinkler system.

Conclusions

It seems apparent from the findings discussed above that, when NIST releases its recommendations for proposed changes to building codes, it will be proposing that at least some of the reductions in both building compartmentation and structural fire resistance requirements in sprinklered buildings, which have been incorporated into the model building codes in the United States since the 1970s, be eliminated from the codes.

The incorporation of the concepts outlined in Findings 22 through 25 into building codes used in the United States could very well have a major impact on the design of new buildings. Perhaps there will be no more atriums and, perhaps, codes will require large open spaces (i.e. exhibit halls, retail stores, covered malls, arenas, casinos, storage and industrial buildings) to be subdivided into small compartments. And how will this have come about?

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As a result of an investigation into the collapse of the World Trade Center towers caused, not by the typical fires that occur in office buildings, but by terrorist attacks.

Will the incorporation of the concepts that NIST outlines in Findings 22 through 25 into building codes really make sprinklered buildings "safer", or simply make buildings more costly to construct, without actually significantly improving the level of safety provided? With all due respect to the researchers at NIST, my opinion is that sprinklered buildings designed to comply with the IBC, NFPA 5000 or any edition of the BOCA Code from 1975 to 1999 provide more than an adequate level of fire safety for both occupants and firefighters. Incorporating the concepts outlined in Findings 22 through 25 into building codes used in the United States would simply be a waste of capital that could be used for other far more important purposes.

Contrary to what many fire protection professionals would like to believe, life safety isn't just limited to building fire safety. In fact, if we spent tens, or even hundreds, of millions of dollars more on high-rise office building fire safety and cut the number of fire fatalities that occur in those buildings in half, this might reduce the number of Americans who die in such fires by one person every one or two years. Are the benefits of implementing the concepts outlined in NIST's Findings 22 through 25 really worth the cost? All you need to answer this question are the fire fatality statistics for high-rise buildings published by the NFPA in September 2001. ■

About the Author

Richard Schulte is a 1976 graduate of the fire protection engineering program at the Illinois Institute of Technology. After working in various positions within the fire protection field, he formed Schulte & Associates in 1988. His consulting experience includes work on the Sears Tower and numerous other notable structures. He has also acted as an expert witness in the litigation involving the fire at the New Orleans Distribution Center. He can be contacted by sending email to rschulte@plumbingengineer.com.

Several of Mr. Schulte's previous columns comprising a series on the World Trade Center collapse can be downloaded (in PDF format) from the ***Plumbing Engineer*** *Web site, www.plumbingengineer.com. They are located in the "PE Archives" section.*