Fire Protection

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The Report on the World Trade Center Incident: A Critique

Subsequent to the collapse of the twin towers of the World Trade Center (WTC) on the morning of September 11, 2001, the Federal Emergency Management Agency (FEMA) in conjunction with the Structural Engineering Institute of the American Society of Civil Engineers (ASCE) investigated the incident. FEMA's report, titled the "World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations," was issued in May, 2002.

The following is intended to be a brief synopsis of the incident, as well as an analysis of some of the report's recommendations relating to fire protection and fire safety. The report in its entirety is available at the FEMA Web site (*www.fema.gov*). The URL of the report is *www.fema.gov/library/wtcstudy.shtm*.

The incident

On the morning of September 11, 2001, American Airlines Flight 11 bound for Los Angeles departed from Logan International Airport in Boston at 7:59 a.m. (EDT). Forty-seven minutes later, at 8:46 a.m., the plane slammed into the north face of the north tower of the World Trade Center in New York. One hour and 43 minutes later, at 10:29 a.m., the north tower collapsed.

On that same morning, United Airlines Flight 175, also bound for Los Angeles, departed from Logan International Airport at 8:14 a.m. (EDT). Forty-nine minutes later, at 9:03 a.m., this airplane slammed into the south face of the south tower of the World Trade Center. Fifty-six minutes later, at 9:59 a.m., the south tower collapsed.

Both airplanes that struck the World Trade Center towers were Boeing 767-200ER aircraft. The American Airlines airplane struck the north tower between floors 94 and 98, while the United Airlines airplane struck the south tower between floors 78 and 84. It was estimated the speed of the plane that struck the north tower was 470 miles per hour at impact, while the speed of the plane that struck the south tower was 590 miles per hour at impact.

The population of the World Trade Center complex, which included the two towers and five other buildings, was estimated to be approximately 58,000 people on the morning of September 11. The death toll from this incident exceeded 3,000 people, including 2,830 building occupants, 157 passengers and crew on the two airplanes and 343 public safety personnel. According to the study, almost all of the occupants of the towers who were located on floors below the airplane impact areas were able to safely evacuate.

Executive summary

The executive summary provided in the report provides an excellent overview of the report. The following excerpts are from the executive summary:

- "... In total, 10 major buildings experienced partial or total collapse and approximately 30 million square feet of commercial office space was removed from service, of which 12 million belong to the WTC Complex.

  "The purpose of this study was to examine the damage caused by these events, collect data, develop an understanding of the response of each affected building, identify the causes of observed behavior, and identify studies that should be performed..."

- "... Recommendations are presented for more detailed engineering studies, to complete the assessments and produce improved guidance and tools for building design and performance evaluation.

  "As each tower was struck, extensive structural damage, including localized collapse, occurred at the several floor levels directly impacted by the aircraft. Despite this massive localized damage, each structure remained standing. However, as each aircraft impacted a building, jet fuel on board ignited. Part of this fuel immediately burned off in the large fireballs that erupted at the impact floors. Remaining fuel flowed across the floors and down elevator and utility shafts, igniting intense fires throughout upper portions of the buildings. As these fires spread, they further weakened the steel-framed structures eventually leading to total collapse.

  "The collapse of the twin towers astonished most observers, including knowledgeable structural engineers, and, in the immediate aftermath, a wide range of explanations were offered in an attempt to help the public understand these tragic events..."

- "...FEMA and ASCE formed a Building Performance Study (BPS) Team consisting of specialists in tall building design, steel and connection technology, fire and

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blast engineering, and structural investigation and analysis."

- "... The fact that the structures were able to sustain this level of damage and remain standing for an extended period of time is remarkable and is the reason that most building occupants were able to evacuate safely."

- "... the structures were subjected to a second, simultaneous severe loading event in the form of the fires caused by the aircraft impacts."

- "... However, as the burning jet fuel spread across several floors of the buildings, it ignited much of the buildings' contents, causing simultaneous fires across several floors of both buildings. The heat output from these fires is estimated to have been comparable to the power produced by a large commercial power generating station."

- "It was not the purpose of this study to assess the code-conformance of the building design and construction, or to judge the adequacy of these features...

  "The study did not reveal any specific structural features that would be regarded as substandard, and, in fact, many structural and fire protection features of the design and construction were found to be superior to the minimum code requirements."

- "During the course of this study, the question of whether building codes should be changed in some way to make future buildings more resistant to such attacks was frequently explored. Depending on the size of the aircraft, it may not be technically feasible to develop design provisions that would enable all structures to be designed and constructed to resist the effects of impacts by rapidly moving aircraft, and the ensuing fires, without collapse. In addition, the cost of constructing such structures might be so large as to make this type of design intent practically infeasible.

  "Although the attacks on the World Trade Center are a reason to question design philosophies, the BPS Team believes there are insufficient data to determine whether there is a reasonable threat of attacks on specific buildings to recommend inclusion of such requirements in building codes...

  "... Future building code revisions may be considered after the technical details of the collapses and other building responses to damage are better understood."

- [Referring to buildings other than the towers] "... the collapse of these [other] structures is particularly significant in that, prior to these events, no protected steel-frame structure, the most common form of large commercial construction in the United States, had ever experienced a fire-induced collapse. Thus, these events may highlight new building vulnerabilities, not previously believed to exist."

- "The issues identified from this study of damaged buildings in or near the WTC site have been summarized into the following points:
  "a. ...
  "b. Fireproofing needs to adhere under impact and fire conditions that deform steel members, so that the coatings remain on the steel and provide the intended protection.
  "c. Connection performance under impact loads and during fire loads needs to be analytically understood and quantified for improved design capabilities and performance as critical components in structural steel frames.
  "d. Fire protection ratings that include the use of sprinklers in buildings require a reliable and redundant water supply. If the water supply is interrupted, the assumed fire protection is greatly reduced.
  "e. Egress systems currently in use should be evaluated for redundancy and robustness in providing egress when building damage occurs, including the issues of transfer floors, stair spacing and locations, and stairwell enclosure impact resistance.
  "f. Fire protection ratings and safety factors for structural transfer systems should be evaluated for their adequacy relative to the role of transfer systems in building stability."

"**Interaction of Structural Elements and Fire.** The existing prescriptive fire resistance rating method (ASTM E119) does not provide sufficient information to determine how long a building component in a structural system can be expected to perform in an actual fire. A method of assessing performance of structural members and connections as part of a structural system in building fires is needed for designers and emergency personnel.

"The behavior of the structural system under fire conditions should be considered as an integral part of the structural design. Recommendations are to:

- "Develop design tools, including an integrated model that predicts heating conditions produced by the fire, temperature rise of the structural component, and structural response.
- "Provide interdisciplinary training in structures and fire protection for both structural engineers and fire protection engineers.

"Performance criteria and test methods for fireproofing materials relative to their durability, adhesion, and cohesion when exposed to abrasion, shock, vibration, rapid temperature rise, and high-temperature exposures need further study."

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"**Fire Protection Engineering Discipline.** The continued development of a system for performance-based design is encouraged. Recommendations are to:

- "Improve the existing models that simulate fire and spread in structures, as well as the impact of fire and smoke on structures and people.
- "Improve the database on material burning behavior."

"**Building Evacuation.** The following topics were not explicitly examined during this study, but are recognized as important aspects of designing buildings for impact and fire events. Recommendations for further study are to:

- "Perform an analysis of occupant behavior during evacuation of the buildings at WTC to improve the design of fire alarm and egress systems in high-rise buildings.
- "Perform an analysis of the design basis of evacuation systems in high-rise buildings to assess the adequacy of the current design practice, which relies on phased evacuation.
- "Evaluate the use of elevators as part of the means of egress for mobility-impaired people as well as the general building population for the evacuation of high-rise buildings. In addition, the use of elevators for access by emergency personnel needs to be evaluated."

Analysis

While the FEMA report does an excellent job of documenting and explaining the events surrounding the destruction of the World Trade Center towers and the adjacent buildings, the report fails to provide an in-depth perspective on the event itself. Obviously, with an event of this magnitude (with the collapse of the towers shown repeatedly on television), and the wave of patriotism sweeping the country, it is easy to understand why FEMA shied away from including such a perspective.

The attack on the World Trade Center and the collapse of the towers was an event that is unique in history. While a study documenting the event is of general interest to the structural engineering and fire protection engineering fields, as well as to the public at large, the question which begs not only to be asked, but also answered, is whether or not this one event should affect the design and engineering of buildings, particularly tall buildings. While the FEMA report briefly addresses this question (and concludes that there is insufficient data available to make a recommendation), an in-depth discussion of this issue is crucial and should have been included in the report.

Should building codes be modified to address building safety in the event of a terrorist attack on a building? If the answer to this question is yes, then the follow-up to this ques-

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tion is rather obvious: what should the design basis be for making buildings "terrorist-resistant"?

The structural loads that would be applied to a building in an incident similar to the attack on the World Trade Center towers would depend upon the size of plane that would strike the building, as well as the speed of the plane at impact. In addition to these two parameters, the location of the impact, as well as the quantity of fuel onboard the aircraft would have an effect on the potential damage to the structural system of a building. Simply because we design a building to resist collapse under the conditions which occurred in the attack on the World Trade Center does not mean that a building could not be destroyed by using a larger airplane or by striking the building at a higher speed. In addition, why limit the damage to a building to a strike by a single plane? The potential "what if" scenarios involving only airplanes are infinite, and why limit the "what if" terrorist attack scenarios to building impacts to airplanes?

The fact is that if terrorists want to accomplish the destruction of a building, there will always be a means to accomplish their goal, regardless of how "hardened" we design and construct our buildings. In other words, there is no building that can be constructed now, or in the future, that will be immune to every form of attack. Given this fact, is it really worth the resources to discuss how to make our building structures "terrorist-resistant," and then incorporate these concepts into building codes? Or would the public be better served by focusing all of our resources on preventing such attacks instead? The answer to that question seems obvious. To be fair, the report suggests that our first line of defense against attacks similar to the attack on the World Trade Center should be airline security. But by providing recommendations for further study of certain engineering issues, the FEMA report tacitly endorses the concept that buildings can be made "terrorist-resistant" by better (and, of course, more costly) building construction.

One of the recommendations included in the report is that "fire protection ratings that include the use of sprinklers in buildings require a reliable and redundant water supply." Essentially this recommendation indicates that reductions in fire ratings for the structural system of high rise buildings should not be permitted when a sprinkler system is installed in the building, unless the standard water supply typically provided for a sprinkler system is modified to increase the water supply reliability. The unstated assumption in this recommendation is that the standard water supply provided for sprinkler systems is unreliable, however, our real world experience with sprinkler installations in high rise buildings indicates that this is not the case. Of course, the sprinkler system failed in the World Trade Center incident, hence this recommendation seems to be logical. However, can anyone imagine the design of a sprinkler system that would not have failed at the World Trade Center? Obviously, there is no piping system that can be installed economically which would resist the impact of a large airplane traveling at a high rate of speed. Just exactly what is a reliable water supply for a sprinkler system in the context of the World Trade Center incident?

From a theoretical standpoint, a requirement for redundant water supplies for a sprinkler installation seems logical in order to reduce the required fire ratings of the structural frame of a building. Again, our real world experience over the past 25 years indicates that providing a redundant water supply is unnecessary. Asingle tragic event, where providing a redundant water supply wouldn't have made any difference anyway, shouldn't change what our real world experience tells us.

The report also states that "the existing prescriptive fire resistance rating method (ASTM E119) does not provide sufficient information to determine how long a building component in a structural system can be expected to perform in an actual fire." The report goes on to recommend that "a method of assessing performance of structural members and connections as part of a structural system in building fires is needed

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for designers and emergency personnel." The statement that the ASTM E119 fire test does not provide information on how a structural system will perform in an actual fire is correct, however, is it absolutely imperative that we have this information? Obviously, the performance of a structural system under fire conditions depends upon the fire conditions. No one could have anticipated the fire conditions to which the World Trade Center towers would be exposed to on September 11 prior to that date. Even if we had the capability to determine the actual fire performance of the structural system of these buildings under fire conditions, who would have modeled the fire exposure to the World Trade Center towers assuming the structural damage which occurred prior to the fire exposure? Again, our real world experience with fires in steel structures indicates that our depth of knowledge at present is adequate. The report, in essence, acknowledges this fact with the statement that "the collapse of these structures is particularly significant in that, prior to these events, no protected steel-frame structure, the most common form of large commercial construction in the United States, had ever experienced a fire-induced collapse" until September 11.

The report also includes a recommendation that "egress systems currently in use should be evaluated for redundancy and robustness in providing egress when building damage occurs, including the issues of transfer floors, stair spacing and locations, and stairwell enclosure impact resistance." Again, our real world experience with building fires indicates that the egress system design practices presently in use are adequate in all but the most extreme cases. The FEMA report,

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in effect, acknowledges this with the statement that "almost everyone in WTC 1 and WTC 2 [the towers] who was below the [airplane] impact areas was able to safely evacuate the buildings, due to the length of time between the impact and collapse of the individual towers." Most who observed the events would agree that this fact is pretty remarkable, but what about the building occupants located above the impact? The recommendation regarding "stairwell enclosure impact resistance" is intended to address this problem. However, it is hard to imagine the stair enclosure construction which would be capable of protecting the integrity of the exit stair enclosures from the impact of a Boeing 767 aircraft flying at 470 miles per hour, subsequently followed by an exposure to an enormous flammable liquids fire. Certainly, the practicality of a recommendation regarding further study of the impact resistance of exit stair enclosures is questionable.

The incident at the World Trade Center on September 11 was an emotional event, but government policy on funding research should not be based upon emotion.

Overall, the recommendations for further fire engineering studies seem more grounded in abstract research than in practicality. This is not unexpected given the makeup of the study group, which included fire protection engineering professors from both the University of Maryland and Worcester Polytechnic Institute and engineers from leading East Coast fire engineering consulting firms that specialize in research. Given the circumstances surrounding the incident, it certainly understandable that the group be composed of engineers located on the East Coast. But after air travel restrictions were lifted, fire safety experts from other parts of the country could have been included in the study team. Including experts outside of academia and outside of research fields would likely have produced more practical ("down-to-earth," as we say in the Midwest) recommendations.

Should the recommendations in the FEMA report be implemented? Speaking as an American taxpayer, as well as an expert in the field of fire protection, it is my opinion that we have far more pressing problems in this country, and in the world, and that our tax dollars can be put to far better use than by implementing the many research-oriented recommendations included in the FEMAreport. The incident at the World Trade Center on September 11 was an emotional event, but government policy on funding research should not be based upon emotion. Clearly, any proposed research projects which will be funded using taxpayers' money should have application to problems which will likely occur again. It is highly unlikely that an event similar to the September 11 incident will ever be staged again. September 11 was a tragic day in New York, but it's now time for some common sense regarding the incident to prevail. □

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