High-Rise Building Design Considerations to Limit Property Damage

Richard J. Davis

AVP, FM Global
President, SFPE
Master of Science, Fire Protection,
Worcester Polytechnic Institute (WPI)
Scope
This paper provides general guidance regarding fire-related property protection for high-rise building design. Prescriptive guidance is based on FM Global recommendations and does not necessarily represent the views of the membership of SFPE. This document does not specifically address life-safety issues, though improvements in property protection can also improve life safety.

Introduction
High-rise buildings present a variety of challenges to fire protection. As building heights increase, so do these challenges. The importance of high-rise buildings in terms of the number of occupants, the value of the property, and the impact a catastrophic loss would have on the community all warrant an increased level of protection.

Manual Firefighting
Firefighters make great efforts when they respond to high-rise building fires. There are a number of factors that hamper these efforts:
- Large numbers of people must exit the building, slowing the firefighters’ entrance
- Large numbers of people may require help exiting the building
- Limited vertical access
- Limited capacity of air tanks
- Potential exterior fire spread above the reach of ladder trucks
- Limited water pressure for upper floors

It is unrealistic to rely heavily on firefighters in limiting property damage in high-rise building fires; therefore, it is necessary for building designers to provide an increased level of fire protection for these buildings.

Prescriptive Guidelines
Sprinkler Protection
Providing automatic sprinklers throughout high-rise buildings is of paramount performance, and sprinklers usually are required by code
for high-rise buildings. In some cases, the lower floors may contain occupancies with greater fire loads, such as retail areas. These areas require greater sprinkler design densities than for office areas. Quick response sprinklers should be provided in atriums and under adjacent balconies.

**Emergency Power**

Emergency power capabilities should be provided for:

- emergency lighting
- communication systems
- emergency elevators
- fire pumps
- smoke-control systems

In some cases, building occupants desire emergency power for their business equipment. This situation creates a large demand for emergency generators and thus for diesel fuel, which can increase the need for passive protection (see Structural Fire Protection section below) and active protection.

**Passive Protection**

Automatic sprinkler protection is very reliable and should be provided in all high-rise buildings. While the provision of sprinkler protection is of primary importance for a variety of reasons, sufficient passive protection must also be provided.

The importance of these buildings in terms of the number of occupants, the value of the property, and the impact a catastrophic loss would have on the community may warrant a level of passive protection that does not rely on active (sprinkler) protection. High-rise buildings typically have numerous tenants over the years, and often when tenants change, so do the furnishings and interior finish. Sprinklers may be temporarily impaired during these renovations.

Needed passive protection features include fire-rated floors, beams, trusses, columns, stairway and elevator enclosures, and pipe and cable shafts. The following are prescriptive recommendations from FM Global Property Loss Prevention Data Sheet 1-3, *High-Rise Buildings*¹:
Building Component | Recommended Fire-Resistance Rating
--- | ---
Floor slabs and beams | 2 hours
Columns | 3 hours
Shafts and chases | 2 hours
Stairwell and elevator enclosures | 2 hours

The above guidelines are based on a study of uncontrolled fire losses in high-rise buildings. These were buildings that were not completely sprinklered. Older buildings that were not required to have sprinklers by code, typically had greater fire resistance ratings for components than most more modern, sprinklered high-rise buildings.

**Green Buildings**
Common spray-applied, fire-resistive coatings are cementitious or mineral fiber-based. These formulations usually include filler materials as well. The use of recycled materials within these formulations is encouraged in many countries, including the United States and some countries in Asia, and some of these coatings and boards now contain between 10% and 45% recycled material. Whatever the materials being used, they should be tested and listed for use in a fire-rated assembly or with regard to combustibility by a nationally recognized testing laboratory.

**Collapse History of Multi-Story Buildings from Fire Exposure**
There is some history of multi-story buildings collapsing due to fire. A study was done in 2002 for the U. S. National Institute of Standards and Technology (NIST), following the collapse of the World Trade Center towers in New York City. Besides the twin towers, there were a number of other tall buildings (that were not impacted by aircraft) that collapsed (in whole or part) due to fire. Since then, two other high-rises are known to have partially collapsed—one in Spain in 2005 (see Fig. 1) and one in 2008 at Delft University in the Netherlands.
Structural Fire Protection

The NIST report on the collapse of the World Trade Center towers went into great detail and included several recommendations for the enhanced fire resistance of structures and new methods for the fire-resistant design of structures. Recommendation 4, in part, proposed the increase of fire-resistance ratings for very tall buildings (more than 20 stories). Over the last decade, the minimum required fire-resistance ratings of columns, bearing walls, and beams, girders, trusses and arches supporting more than one floor have effectively been increased from 2 to 3 hours in the International Building Code (IBC) and NFPA 5000 for buildings over 180 ft (55 m) and 420 ft (128 m) in height, respectively.

Recommendation 4 also advised studying the impact of spaces containing “unusually large fuel concentrations.” One major change in the United States in recent years is the size of the fire load found in some areas of high-rise buildings that will challenge passive fire protection. Supplies of diesel fuel are no longer limited to 660 gal
(2.5 m³); enough to power emergency lights, etc. Now, thousands of gallons of diesel fuel can be found in tank storage vaults; enough to provide full back-up power for normal business operations. Often, this fuel is pumped to generator rooms on upper floors. Oversized pipes (pipe headers) are located in emergency generator rooms and can contain much more fuel than is normally allowed in day tanks. Furthermore, the fire rating provided for the structural framing often is based on the standard time temperature (STT) curve rather than the much more stringent hydrocarbon fire exposure. Based on comparative heat fluxes, and depending on the actual required rating, this could considerably reduce the fire resistance provided—in other words, an assembly tested for 3 hours per the STT curve may only resist about 2 hours in a hydrocarbon fire exposure test.

Recommendation 5 was to improve fire-resistance testing and extrapolation of results, including the relationship between actual beam length and the limited length that fits in the test furnace. Such furnaces are currently limited to 17 ft (5.2 m) in length. As described in one of the supplemental NIST reports, limited fire-resistance tests comparing the performance of 17 ft (5.2 m) trusses and 35 ft (11 m) trusses implied that, all else being equal, the performance of the longer truss was considerably reduced. While testing the full length of fire-rated horizontal structural members may not be practical, and the tests performed by NIST were too limited to draw any definite conclusions, the development of a correlation that allows the determination of increased coating thickness for increased length in relation to the tested sample may be needed.

In addition, there are several effects the fire has on structural framing that cannot be properly quantified in a relatively small furnace. Considerable expansion occurs due to increased temperatures of structural steel, despite the presence of a fire-resistive covering. The expansion is directly proportional to the length. Connections between columns and beams or trusses must be capable of accommodating this expansion and resisting lateral and torsional forces that develop from it. The science of structural fire protection is still developing, but there are several references available on the subject (see Recommended Reading section below).
Another recommendation in the NIST report called for increased durability and impact resistance of fire-resistant materials. In most cases, as the density of a material increases, its impact resistance does as well. Some of the most common sprayed fire-resistant materials (SFRMs) have a low density of only 15 pcf (240 kg/m³). While normal-weight concrete and light-weight structural concrete are at the high end of the scale (145 pcf [2300 kg/m³] and 120 pcf [1900 kg/m³] respectively), they still can be used for this purpose. There are some newer, denser versions of proprietary products that offer increased impact resistance. For example, some cementitious products are available in medium, high and ultra-high densities.

**Exterior Wall Construction**

Many high-rise buildings do not have frequent full-height partitions throughout individual floor areas. Ceiling height is relatively limited and the quantity and distribution of combustibles may be significant, making flashover within a given floor likely in an uncontrolled fire. Flames and hot gases will exit the upper, approximate two-thirds of the window, allowing combustion air to flow in beneath the flames. Flames may potentially impinge on the window of the floor immediately above. The taller the window opening, the higher flames will be that could impinge on the floor above, cause window cracking and allow a direct path for flames to ignite drapes and other combustibles on the floor immediately above. Limiting the height of windows can reduce the probability of exterior vertical fire spread (see Fig. 2), particularly in a post-flashover fire. This has not been a concept that has been embraced by building owners, and might only be considered for very tall, very important or very expensive buildings.

Tempered glass (fully heat treated) can withstand considerably higher heat fluxes than ordinary glass before cracking. Tempered glass can also be more safely broken by firefighters to facilitate manual smoke removal. When broken, it also presents less of a hazard to firefighters and hose lines at street level.
The International Seminar on Risk Management · 9

High-Rise Building Design Considerations to Limit Property Damage

Fig. 2. Recommended window height limitations to prevent vertical exterior fire spread

A report by the National Research Council of Canada notes that the presence of continuous 3 to 4 ft (0.9 to 1.2 m) wide, noncombustible balconies can also help prevent vertical, exterior fire spread to upper floors. While the flame length is not altered, the balcony redirects it away from the windows and considerably reduces radiant heat exposure to the windows and wall above.

Noncombustible Wall Insulation

The presence of combustible insulation within the exterior wall assembly will contribute fuel to the exposure fire at the building periphery, thus further increasing the exterior flame height and chance for vertical exterior fire spread. In the United States, there has been increased use of exterior walls constructed of exterior insulation and finish systems (EIFS). These assemblies typically use 2 to 4 in. (50 to 100 mm) of expanded or extruded polystyrene insulation (EPS or XPS). EPS and XPS are thermoplastic materials, which melt and drip as they burn. They also have a high heat of combustion (17,000 BTU/lb, 40,000 kJ/kg). Testing done at FM Global has shown that for some of these assemblies and configurations, current code required fire tests may not be stringent enough to properly assess the potential for vertical fire spread. A high-rise building fire in the U.S. in 2008 involved EIFS construction (see Fig. 3).
Penetration Seals and Spandrel Protection

Penetration seals should be provided throughout the floor area to help prevent vertical flame spread directly through the floor. In the United States, such assemblies are tested in accordance with ASTM E 814\textsuperscript{15} and listed assemblies can be found in the Approval Guide\textsuperscript{16}.

Fire-safing around the floor perimeter at its junction with walls is also recommended (see Fig. 4). Such assemblies may be tested according to ASTM E 1966\textsuperscript{17}.
Smoke Control
The use of smoke control systems and stairwell pressurization systems for enclosed stairwells can provide life safety, property protection, and firefighter protection, and can facilitate efforts by firefighters. Stairwell pressure must be properly balanced to limit smoke spread into the stairwell and other floors, yet allow doors to be opened into the stairwell with reasonable force. Excessive pressure will make opening stairwell doors difficult, if not impossible. Consideration must be given to the resistance of the door closer.

Enabling smoke exhaust on fire floors, as well as pressurization of adjacent floors, can limit the extent of smoke and other nonthermal damage throughout the building.

Performance-Based Design
Performance-based design (PBD) can be a valuable tool when designing high-rise buildings, particularly with regard to egress. Appropriate assumptions must be made in the design, and the design
scenario should at least meet the goals intended by the prescriptive code, if available. It is important that all stakeholders in the building design be satisfied with the design objectives. That includes the building owner, the authority having jurisdiction (AHJ) or code official, and the insurance carrier.

PBD typically involves the use of multiple design scenarios. The building owner and designer should consider possible future changes to the building occupancy or construction that may have an adverse effect on the design scenario in order to avoid costly expenses in the future. If the design scenario is not conservative enough, it may limit the insurance carrier’s ability to insure the building, or may limit the amount of insurance capacity that they can provide at a given location. Changes to the facility should be managed throughout its life cycle to ensure the design criteria is adhered to. Recommended reading on this subject is referenced below.

**Recommended Reading**

**The science of structural fire protection :**
- Performance-Based Design of Structural Steel for Fire Conditions, American Society of Civil Engineers Manuals and Reports on Engineering Practice No. 114, Reston, VA., 2009.

**Smoke control :**
- Standard for Smoke Control Systems Using Barriers and Pressure

The International Seminar on Risk Management · 12

**Performance-based design:**


**Note:** The *SFPE Handbook of Fire Protection Engineering* and the NFPA fire codes are available in Korean through KFPA.
References


