An Overview of Fire Protection for Structural Engineers

Part 2: Fire Safety Systems and Features

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Described in Part 1 of this three-part series overviewing fire protection for structural engineers, fire safety objectives dictate the design of fire protection systems and features in a building. From life and property protection to the continuity of services and preservation of heritage sites and the environment, an understanding of the objectives of a project is necessary for the correct design of protection features within a building. Part Two of the series details fire safety systems and features used to fulfill the fire safety objectives chosen for a project.

Building Fire Safety Systems and Features

Fire safety objectives are typically addressed through the design and specification of different fire safety systems and features in buildings. One distinguishing aspect of building fire safety design is the "defense-in-depth" approach that is typically used to contend with the highly transient development of building fires. The "load" imposed by a fire on a building depends on when the fire is detected, when it is suppressed, and how it is confined by fire barriers.

The primary fire safety systems and features installed in buildings include:

- Fire prevention features and controls
- Flammability of building components and contents
- Fire detection, alarm, and communication systems
- Fire suppression systems
- Structural fire protection
- Means of egress
- Smoke management

The design of these systems and features requires coordination to meet the fire safety objectives.

Fire Prevention Features and Controls

Fire prevention features and controls are not always explicitly considered as part of the building fire safety system, but fire prevention is the first line of defense against fire. Standards have been developed for the design and installation of electrical systems, fuel gas systems, heat-producing appliances, and a myriad of other potentially hazardous systems and operations with the implicit purpose of minimizing the potential for these systems and operations to ignite a fire. Fire codes include administrative controls, such as the regulation of smoking and the use of open flames and heat-producing appliances, that are specifically intended to reduce the potential for human activities to cause unwanted fires. However, despite these fire prevention features and controls, the potential for fire cannot be eliminated entirely, so most of the focus of building fire safety design is on systems and features that mitigate the consequences of fires that do occur.

Flammability

The next line of defense against fire is to control the flammability of building components and contents. This is a commonly overlooked aspect of fire safety design, which should be considered because flammability drives the rate of fire hazard development as well as the peak fire intensity and duration and, consequently, the design of fire mitigation systems. Historically, the flammability of construction elements and interior finishes has been regulated more so than the flammability of furnishings, on the basis that it is easier to regulate elements that are part of the building construction than all the contents introduced into the building following construction.

From a construction classification standpoint, construction types are distinguished as either combustible or noncombustible. Type I and II buildings require noncombustible materials for all elements of construction. Type III and IV buildings require noncombustible exterior walls, with other elements allowed to be combustible. Type V buildings can have combustible construction for all building elements. However, there are a few notable exceptions to these requirements.

One of the exceptions has been the introduction of combustible insulation materials into the exterior façades of tall buildings. Motivated by the desire to improve the energy efficiency of these buildings, requirements for noncombustible façades have been relaxed over the past few decades to allow such applications. The recent façade fires at the Grenfell Tower in London and the Torch Tower in Dubai graphically illustrate the need to control the flammability of high-rise façades. In these applications, internal fire safety systems are ineffective and the external reach of the fire department is limited to the lower stories of the building.

The normal load of combustible content in most buildings is sufficient to cause a severe fire if not detected and suppressed relatively early during the growth phase of the fire. For this reason, the design of building fire safety does not typically rely on fuel control as the primary means of achieving fire safety objectives.

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Fire Detection, Alarm, and Communication Systems

Once a fire starts, it must be detected before other mitigation strategies are implemented. Humans are excellent fire detectors because we can sense low concentrations of smoke and are fairly effective at discriminating between nuisance sources of smoke, such as burnt toast, and hazardous sources of smoke, such as an incipient fire. Unfortunately, humans are not the most reliable type of fire detector because we are not always present, we sleep, and our judgment is sometimes impaired. Furthermore, even when we do detect a fire, we may not always respond consistently or effectively. For these reasons, some form of automatic fire detection is common in many buildings.

The type of fire detection system employed depends on the fire safety objective(s) for the application. At the sensitive end, there are incipient fire detectors and flame detectors that can detect a fire almost immediately after ignition, and in some cases even before ignition occurs. However, these applications are relatively expensive and not suitable for some environments, so their use has been limited. In commercial buildings, smoke detectors provide relatively early detection of fire and are typically required for applications where occupants may be sleeping, such as hotels, apartment buildings, and hospitals. The most common form of fire detector used in commercial buildings in the United States is the automatic sprinkler, which combines automatic heat detection with automatic fire suppression.

Once an automatic fire detector activates, it transmits a signal to a fire alarm control panel. The control panel may then initiate a number of responses including activation of the fire alarm system in the building, notification of the fire department, elevator capture and recall, reconfiguration of HVAC system operation, closure of fire doors and dampers, as well as other functions. In large buildings, the number of inputs and outputs can become quite complicated, requiring careful specification of the sequence of operations logic during design, comprehensive commissioning, and periodic testing.

One of the problems with traditional tonal fire alarm signals is that they do not communicate clear instructions or information to building occupants. Where phased evacuation is used instead of general evacuation, such as in high-rise buildings, Emergency Voice Communication Systems (EVACS) are typically used to permit selective or general verbal communication from the emergency control center to building occupants during an emergency.

Fire Suppression Systems

Once a fire is detected, the next fire safety strategy is to suppress it. The vast majority of fires are not even reported because they are detected quickly by people and manually suppressed before causing any injury or significant damage. However, humans are not always reliable, so automatic sprinkler systems are commonly deployed as the primary engineered fire suppression strategy.

Each sprinkler in an automatic sprinkler system has a heat-sensitive element that activates the sprinkler when it reaches its activation temperature. Once activated, each sprinkler discharges water in a relatively uniform discharge density over the area protected by that sprinkler. The specific water discharge density is designed to reduce the heat release rate from the maximum potential and to control the fire (*Figure 1*). The design discharge density is based on the hazard classification of the space or commodity being protected. Sprinkler systems are typically designed for approximately 10 to 20 sprinklers to operate over an area of approximately 1000 to 2500 square feet to control a fire and prevent it from growing larger. Once the fire is controlled, the fire department can complete its suppression when it arrives.

In the absence of an automatic fire suppression system, the fire department must respond and suppress the fire. However, it takes a relatively long time for the fire department to be notified, to respond to the fire scene, and ultimately to discharge water on a fire. Consequently, it is not unusual for a fire to have "flashed over" and be "fully developed" by the time the fire department starts to suppress it. A fully developed fire is characterized by ignition of the entire contents of a room resulting in maximum compartment temperatures upwards of 1000°C. Under these conditions, fire represents a serious risk to the building, to any occupants remaining in the building, and to the responding firefighters. Structural fire protection is the next strategy in the sequence of protection methods to address these risks.

Structural Fire Protection

The primary means of controlling the hazard of a "post-flashover" fire is with compartmentation of the building into separate fire areas with fire barriers and fire-resistive structural elements. The traditional approach to structural fire protection has remained virtually unchanged for the past century. Buildings are classified into one of nine different construction types (IA, IB, IIA, IIB, IIIA, IIIB, IV, VA and VB) based on the combustibility and fire resistance rating of the construction elements. Type I buildings are the most "fire resistive," while Type V buildings are the least.

The required type of construction is based on several factors, including the height and floor area of the building, the occupancy of the building, the street frontage of the building, and the presence or absence of automatic sprinkler protection. The required type of construction is typically determined by the architect and the fire protection engineer on a project; structural engineers are not typically involved in this determination.

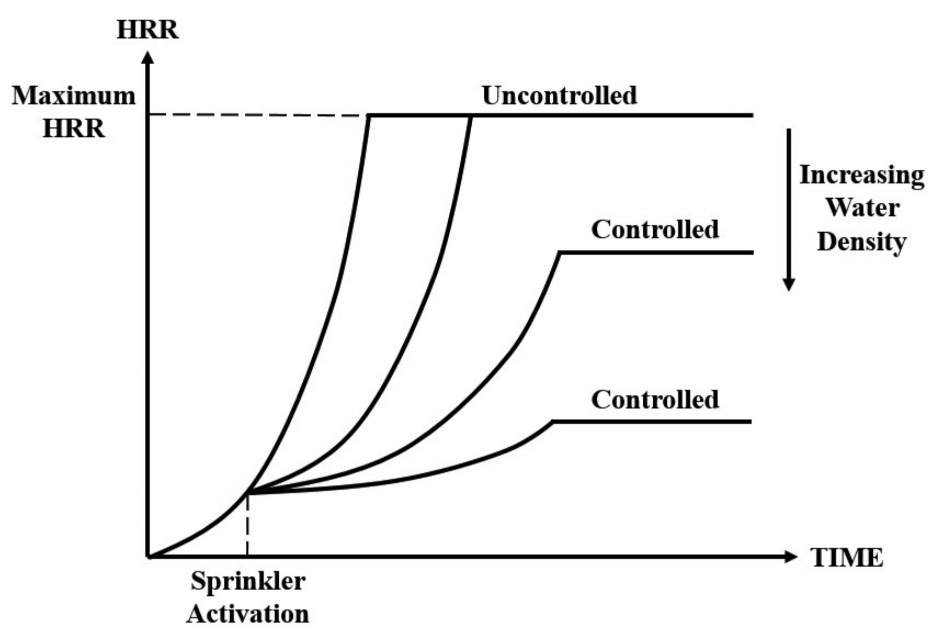

Figure 1. Example of sprinkler activation and control of the HRR of a fire based on water discharge density.

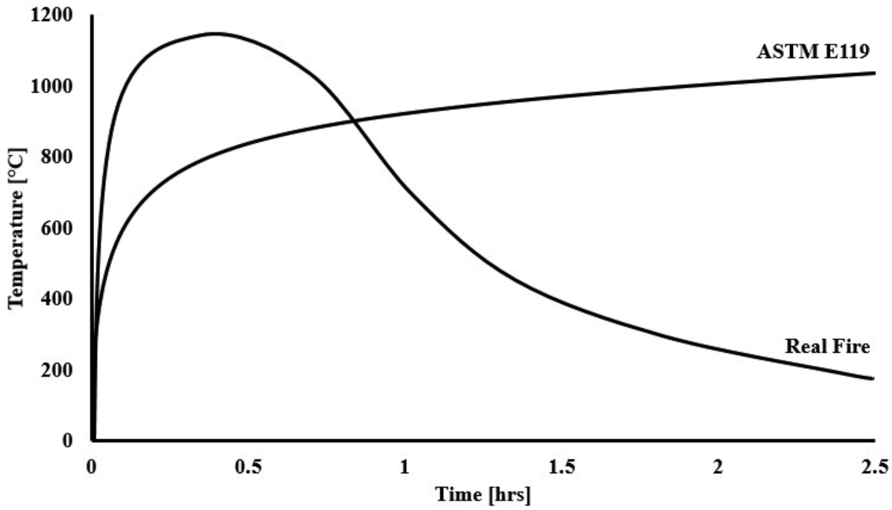

Figure 2. Time-temperature curves for ASTM E119 and an example real fire.

The required fire resistance ratings for different construction elements are based on the type of construction selected for the building. Fire resistance ratings are determined from the fire testing of relatively large-scale assemblies in a furnace, in accordance with the ASTM E119 fire test specification. The fire test conditions are intended to be representative of exposure to post-flashover fire conditions. The fire test results are expressed in terms of hourly ratings, e.g., 1-hour, 2-hour, and 3-hour, based on how long a test specimen is subjected to post-flashover conditions while meeting the performance criteria specified in the ASTM E119 test standard. Because results are expressed in hourly ratings, it is a common misconception to expect that the actual period of performance in the field will be the same as the hourly rating achieved in a fire test. This will not be true because the exposure conditions will not be identical in actual fires and because field assemblies will not be identical to the test assemblies (*Figure 2*).

The term "fire resistance" has two traditional connotations. This term is used to describe the ability of a fire barrier to prevent the spread of fire from one side of the barrier to the other. This term is also used to describe how long a structural element will maintain its load-bearing capacity under fire conditions. The level of fire resistance depends on the fire safety objective. For some situations, the fire safety objective may be to prevent fire spread and to maintain structural integrity for a limited period, e.g., to allow for occupant egress. For other situations, the objective may be to confine a fire and maintain structural integrity until the available fuel load has burned out, e.g., in high-rise buildings.

The traditional approach to structural fire protection requires designers to select fire-resistive elements and assemblies that have been tested and rated in accordance with the ASTM E119 fire test standard. This approach does not consider the connections between elements, the response of an assembly to non-standard fire conditions, or the performance of assemblies with different dimensions than the tested assembly. The emerging practice of structural fire engineering, discussed in Part 3 of this series, allows these interactions to be analyzed in terms of the structural mechanics involved.

Means of Egress

The means of egress in a building includes exit access, the exits, and the exit discharge. The exit is separated from other parts of the building by fire-resistive construction with the intent of providing a safe passageway once occupants reach the exit enclosure. In tall buildings, exit enclosures are also pressurized to prevent smoke infiltration and to maintain a safe environment. Exits must ultimately discharge to a public way to prevent occupants from being trapped in a confined space within or outside a building.

In a prescriptive design environment, the exit capacity must be greater than the occupant load served and the travel distance to exits is limited; the implicit objective of these requirements is to limit the evacuation time. Two or more exits are required, in most buildings, to provide a secondary means of escape in case one of the exits cannot be used during an evacuation.

In a performance-based design environment, the evacuation time is calculated explicitly, with the objective of demonstrating that the required safe egress time (RSET) is less than the available safe egress time (ASET). The ASET is calculated based on the rate of hazard development for the fire scenarios selected for analysis. The ASET depends on the fire safety systems and features installed in the building, as well as on their reliabilities.

Smoke Management

The last building fire safety system addressed here is smoke management. Both passive and active smoke management systems are used to control smoke spread in buildings. Smoke spread is controlled passively through the use of smoke and fire barriers, and by shutting down ventilation systems upon detection of smoke within these systems. Smoke spread is controlled actively by designing ventilation systems either to pressurize adjacent spaces to prevent smoke infiltration or to exhaust smoke directly from the fire zone. The pressurization concept is commonly used in tall buildings, while the exhaust concept is commonly used in atria, sports stadia, and other large open areas.

One of the most effective ways to control smoke spread is to control smoke production and buoyancy forces through automatic fire suppression. By limiting fire size with automatic suppression, both the amount of smoke and the fire-induced forces that drive smoke spread are reduced, in many cases to the point where active smoke management may not be necessary to achieve the fire safety objectives.

Summary

Much as it is with the structural performance of buildings, the fire safety of buildings is often taken for granted, until a disaster occurs. Following a disastrous fire such as at the Grenfell Tower, shortcomings become apparent because fire has a way of finding and exploiting the weakest aspects of building fire safety design. In modern buildings, multiple fire safety systems and features are typically part of the design, so multiple failures are generally needed for a catastrophic fire to occur. However, as discussed here, building fire safety does not just happen by chance or good fortune; it requires the careful consideration of fire safety objectives, the coordination of many fire safety systems and features, and effective fire safety management over the lifespan of a building.

Based on the discussion presented in this article, it should be apparent that the traditional role of the structural engineer in building fire safety has been limited. However, this has been changing over the past two decades or so with the emergence of structural fire engineering as a distinct design discipline. This new role for structural engineers in the design of building fire safety will be discussed in more detail in Part 3 of this series.▪