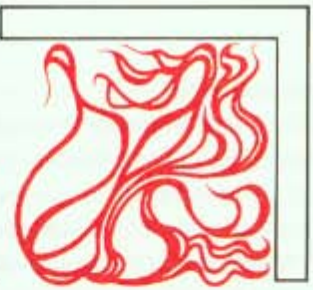


fire protection planning report



BUILDING CONSTRUCTION INFORMATION FROM THE CONCRETE AND MASONRY INDUSTRIES

November 1991

Fundamentals of Firesafety in High-Rise Buildings



From 1970 to 1990, a combined total of 2,273 new construction starts of buildings 8 stories or more have occurred in the major metropolitan areas of New York City, Los Angeles, and Chicago (Source: F.W. Dodge National Information Services).

In general, the model building codes define a high-rise building as a structure with a floor use for human occupancy exceeding 75 feet above the lowest level of fire department vehicle access. Fire in high-rise buildings can mean flame and smoke beyond the reach of firefighters' ladders and hoses. Nevertheless, the number of lives lost in high-rise building fires has historically been lower than for other types of structures. Each year, about 5,000 people perish in building fires in the United States. Over the last 3 decades, however, based on fire incidents reported to the National Fire Protection Association (NFPA), an average of fewer than 28 fire-related deaths per year have occurred in high-rise building fires (excluding those involving grain elevators and silos). If the MGM Grand and DuPont Plaza fires are excluded, the death total is approximately 22 per year. One of the reasons for the excellent safety record through the years is that building codes have traditionally required fire-resistive, noncombustible construction for high-rise buildings.

Compartmentation has also played an important role. Maybe the best evidence of this is illustrated by the extensive damage that can result from high-rise fires where large open areas are present, as witnessed in the First Interstate Bank Building and DuPont Plaza fires. If building codes become less restrictive in their fire protection requirements, poorer performance results can be expected.

Most firesafety professionals agree that the best fire protection scheme is one that utilizes a balanced design combining compartmentation, automatic detection, and automatic suppression elements. This is especially important for high-rise buildings because of the difficulties encountered in manually suppressing the fire and conducting rescue and evacuation operations.

The Concrete and Masonry Industry Firesafety Committee (CMIFC) identifies the following items as fundamentals of firesafety design for high-rise buildings.

1. *The fundamental axiom in firesafety for high-rise buildings is that the building must retain its structural integrity throughout the duration of a fire, and offer safe areas of refuge for the occupants until they can be evacuated. There must be no structural failure in the event of a burn-out in any portion of the building.*

2. *Horizontal and vertical compartmentation should be utilized to limit the spread of fire beyond the area of origin. In order to prevent smoke and hot gases from breaching the compartment boundaries, through-penetrations and openings must be properly fire stopped.*

3. *The use of combustible materials and finish systems (cladding) on exterior walls should be prohibited. This is a prime consideration in preventing a fire from occurring on the building's exterior above the reach of fire department hose streams.*

4. *Active types of fire protection such as automatic detection and alarm systems, and automatic suppression systems are important components of high-rise building design. Because these are mechanical systems, however, it is equally important that they be regularly inspected, tested and maintained as part of an established mainte-*

nance program.

5. Tradeoffs involving the reduction or elimination of fire resistance or other firesafety features should not be permitted. Redundancy in protection is paramount if the firesafety of high-rise buildings is to improve.

6. Protection must be provided to prevent the vertical spread of fire from floor to floor via the building's exterior openings. This phenomenon of fire spread is often referred to as "leap frogging".

7. As fire science and technology continue to improve, code officials must utilize the technological advances available and incorporate changes into the codes based on scientific principles.

The paragraphs that follow expand on each of the above points.

ITEM 1: STRUCTURAL INTEGRITY AND FIRE ENDURANCE

Manual suppression of fires above the reach of fire department aerial ladders must primarily be achieved through an interior attack. When fire occurs in the upper levels of very tall buildings, it takes considerable time for the firefighters to reach the burning area. Additional resources may have to be diverted to search and rescue operations. To offset these factors, high-rise buildings should be designed to withstand the complete burnout of a portion of the building without experiencing structural failure. Occupants must have adequate time to evacuate the building or have access to safe areas of refuge, including the roof, until they can be rescued. Firefighters need sufficient time to fight the fire and carry out search and rescue missions without the fear of collapse. The potential for large-scale property damage and loss of life due to the collapse of a high-rise building is of catastrophic proportion. Damage to surrounding buildings from collapsing construction, coupled with a large unconfined fire as a radiator of heat energy represents a hazard of extreme severity.

Concrete and masonry construction provides high-rise buildings with excellent structural fire endurance. In an actual fire, concrete floors and concrete or masonry walls are likely to remain in place for a longer duration than reflected by their ASTM E119⁽¹⁾ fire ratings. This normally holds true because the fire resistance rating period of these members is typically determined by the heat transmission end point of the ASTM E119 test. In most cases, just how long the walls and floors will continue to perform their structural function is not known because the tests are routinely terminated prior to structural failure.

Concrete columns in high-rise buildings also offer a factor of safety or degree of conservatism with respect to fire endurance. This occurs because structural design requirements control the size of the member, and the

additional expense of changing formwork as the building becomes taller exceeds the material savings that would be realized by reducing the column dimensions. In most instances, concrete beams controlled by structural considerations will also be conservatively designed for firesafety concerns. Specifically, concrete beams with nonprestressed reinforcing steel will offer conservative fire resistance for rating requirements of up to 3 hours; provided that the beams are 10 inches or greater in width.

In a testing program that recently concluded at the National Research Council of Canada (NRCC), columns that were designed as 4-hour columns according to current building code provisions were able to withstand the ASTM E119 exposure for several hours beyond 4 hours. Most fire tests, however, are not conducted beyond 4 hours due to the extra cost involved and because a 4-hour rated assembly is usually the maximum that is required by building codes. In a high-rise environment, the extra minutes of protection afforded by concrete and masonry may make the critical difference between life and death. It could also mean the difference between containing the fire to the area of origin versus a total building loss. Due to the difficult challenges that a high-rise building fire presents, and the amount of risk involved, the CMIFC advocates that a *minimum* of 3-hour fire resistance rated columns and 2-hour floors and roof be required in high-rise construction.

ITEM 2: COMPARTMENTATION

It is the function of structural fire resistance to keep a building from collapsing during a fire. The purpose of compartmentation is to contain the spread of fire to a limited area, and provide a safe haven for occupants outside the compartment of fire origin. There are numerous cases where dwelling units in apartment buildings constructed of concrete and masonry were able to withstand the complete burnout of the unit without the fire spreading beyond the compartment.

Concrete and masonry make excellent materials for compartmentation because they do not burn. They do not contribute fuel to the fire, nor do they release toxic fumes in a fire as do combustible materials. Concrete and masonry compartmentation, properly fire stopped, is an effective deterrent to the spread of smoke and fire. It protects those outside the unit of origin from the careless actions of their neighbors, and retards the spread of smoke and fire allowing additional time for evacuation. When properly constructed, compartmentation should prevent the spread of fire (and smoke) both vertically as well as horizontally. The CMIFC recommends a *minimum* of 2-hour fire resistance rated concrete or masonry construction for floors, and for dwelling unit and tenant separation walls. Provisions for calculating the fire resistance of concrete and masonry



Although the contents of this dwelling unit were destroyed by fire, the concrete walls and ceiling prevented the fire from spreading beyond the unit of origin.

members to meet this criterion are published in Chapter 31 of the *Standard Building Code (SBC)*,⁽²⁾ *Uniform Building Code (UBC) Standard No. 43-9*,⁽³⁾ and in the *1992 Accumulative Supplement* to the 1990 *BOCA National Building Code (BNBC)*.⁽⁴⁾ This information is also contained in the CMIFC's *Fire Protection Planning Report No. 13*.⁽⁵⁾

ITEM 3: REGULATION OF COMBUSTIBLE BUILDING VENEERS

Just as the combustibility of contents can increase the fuel load within a building, combustible construction, both interior and exterior, can also impact the fire safety of the building. While building codes may not be well suited for controlling the use of combustible contents within a building, they can still effectively regulate the installation of combustible building elements in high-rise construction.

Since none of the model codes^(2,4,6) permit wood veneers or vinyl siding on high-rise buildings, the prohibition of all combustible exterior veneers or finish systems on high-rise buildings seems justified. This is not the case however, as there are some finish systems that are insufficiently regulated. Exterior insulation and finish systems (EIFS) represent a group of such products.

In the United States, EIFS is almost unrestricted in its use. The *National Building Code of Canada*,⁽⁷⁾ however, limits the use of combustible cladding to unsprinklered buildings of no more than 3 stories in height, or to buildings of no more than 6 stories in height when sprinklers are provided. Although these provisions prohibit combustible cladding and EIFS from high-rise use, the allowance for

increased height with the installation of sprinklers is not warranted. Interior sprinkler installations are not designed to protect against fires of exterior origin, and sprinklers are not 100% effective.

As a more appropriate solution, the CMIFC recommends that standardized testing procedures be developed to test combustible veneers for their ignition characteristics. The test results can then be compared to the pilot ignition value of wood for purposes of establishing appropriate set-back requirements. For the time being, codes should be changed to regulate all combustible veneers the same way as wood until more information can be obtained about the ignition and fire spread performance characteristics of these products through testing. Provisions contained in the *1992 Accumulative Supplement* to the 1990 *BNBC* already address this issue.

ITEM 4: ACTIVE SYSTEMS - ALARMS, DETECTION, AND SUPPRESSION

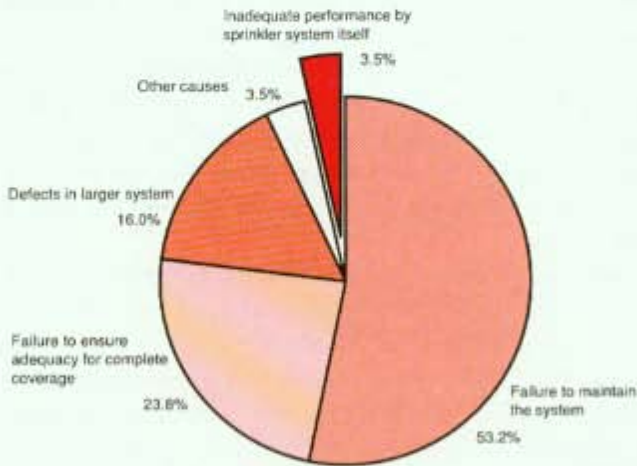
A detailed discussion on this subject would be too lengthy to include in this report. Nevertheless, sprinkler, alarm, and detection systems are all important components of a balanced fire protection scheme for high-rise building construction. Again, it is emphasized that regularly scheduled testing and routine maintenance, as part of a comprehensive maintenance program, are vital to the performance of these systems. Appropriate sections of building codes should be referenced for requirements pertinent to each of these elements of protection.

ITEM 5: REDUNDANCY IN PROTECTION WITHOUT TRADEOFFS

Although model codes typically permit tradeoffs in fire resistance, compartmentation, travel distance to exits, fire alarm pull stations, etc., when sprinklers are installed, no acceptable equivalency has been proven between sprinklers and other components of fire protection. The issue is highly emotional and centers around philosophical differences between the effectiveness of passive versus active types of protection. Until a scientific basis of equivalency is established, however, these sprinkler tradeoffs, as they are commonly known, should not be permitted.

Sprinklers have had a good track record but like other mechanical systems they are not 100% effective. Statistics from a number of sources through the years have indicated that sprinklers perform successfully 80-99% of the time. It is interesting to note from a study conducted by the NFIPA (Source: April 1991 *Operation Lifesafety Newsletter*) on sprinkler performance during a 45-year period from 1925 to 1969, that 96.5% of all reported sprinkler malfunctions were the result of human neglect. The remainder were due to inadequate performance of the sprinkler system itself.

Judging from these results, it would appear that many of these types of failures could have been eliminated through regular inspection and maintenance programs. However, one of the major shortcomings of this solution is the lack of enforceability in the implementation of such programs.



A National Fire Protection Association study of unsatisfactory sprinkler system performances from 1925 to 1969 reports that all but 3.5% were attributed to human neglect. The NFPA has categorized the malfunctions into the 5 major groups shown above.

Anytime systems are dependent on human intervention, there is a susceptibility to failure due to human error. The argument against tradeoffs is especially pertinent for high-rise construction because of the time factor involving the mobilization of people in a fire situation. Redundancy in protection is essential to compensate for this. Investigations of severe high-rise fires that have resulted in large loss of life and/or extensive property damage have shown that the severity of losses could not be blamed on any single element. Information assembled from a number of sources on the following case studies reinforce this point.

Case 1: DuPont Plaza Hotel & Casino - San Juan, Puerto Rico, December 1986. The fire resulted in 96 fatalities and was deliberately set. Some of the contributing factors to the severity of the loss were: large quantities of combustible furniture stored in a temporary storage area; large open floor areas without compartmentation; no automatic detection systems, which caused a delay in the discovery of fire until its advanced stages; lack of automatic sprinklers in the room of fire origin; spread of heat, smoke, and toxic gases to remote areas of the building via vertical and horizontal penetrations and unprotected openings; rapid penetration of fire through the combustible partition wall in the room of fire origin; insufficient fire exit capacity for the casino; and an improperly functioning exit door. Authorities investigating the fire reported that the death toll could

have been worse had it not been for guest room exterior balconies.

Case 2: Schomburg Plaza Apartment Complex - Manhattan, N.Y., March 1987. This fire originated in a garbage chute and resulted in 7 fatalities, 3 burned out apartments, 48 uninhabitable units, and the forced evacuation of about 700 people. Contributing factors included: lack of smoke detectors where residents died; breach of horizontal and vertical compartmentation due to poor construction workmanship and inadequate fire stopping; operational failure of sprinklers in the trash chute due to clogged sprinkler lines, discontinuity of piping, and shut valves; poor inspection and maintenance program as evidenced by numerous outstanding maintenance deficiencies; lack of smoke control; miscommunication between fire department personnel; fire fighting operations hampered by locked entrance doors and damaged standpipe connections; delay in notification of the fire department; and questionable code practices which allowed electrical outlets to be installed in a 2-hour rated fire wall.

Case 3: First Interstate Bank Building - Los Angeles, May 1988. One fatality occurred as a result of this fire, with the estimated damage exceeding \$50 million. Contributing factors included: delay in notification of fire department; shut sprinkler system control valves; initial water supply shortage; failed automatic fuel supply to diesel fire pump which had to be manually operated on a continuous basis; failed automatic fill valve to the fire pump's water supply reservoir, which had to be manually overridden; moderate to heavy fuel load on fire floor; lack of significant barriers or compartmentation of large open floor areas on the fire floor; failure of all elevators to return to the ground floor when called, necessitating firefighters to climb stairs in order to fight the 12th floor blaze; vertical spread of fire through gaps at the curtain wall/floor junction, and also due to fire "leap frogging" from window to window on adjacent floors; inadequate smoke control; locked stairwell doors on several floors that led into the building areas, hampering firefighting operations; and a blocked fire door on the fire floor. Consequences of the 4-hour blaze could have been much worse were it not for the building having 3-hour columns and 2-hour floors as required by the UBC.

A number of high-rise fires have since occurred, but those mentioned above have probably been more publicized than others. The similarity of the problems in the cases described is fairly evident. In general, many things had to go wrong for the fires to have been as disastrous as they were. With the additional fire safety challenges and complexities that high-rise buildings present, redundancy in protection is the only rational answer. Individuals can

argue their opinions as to what they feel is adequate protection, but what cannot be argued is that balanced design consisting of compartmentation, automatic detection, and automatic suppression offers the best protection for high-rise buildings. With the total annual cost of fire exceeding \$115 billion, (Source: *Engineering Times*, July 1991) there is potentially a large sum of money that can be saved and utilized to provide an even greater level of protection than that currently specified in the model codes. Recommendations are summarized later in this report.

ITEM 6: VERTICAL EXTERIOR FIRE SPREAD

All of the model codes contain provisions to protect against the vertical spread of fire via the leap-frog effect. For unprotected openings (windows) on adjacent floors that are within 5 ft horizontally of each other, the codes have attempted to address this issue with the following requirement. In the BNBC, openings must be separated vertically by at least 3 ft with 1-hour fire resistance rated wall construction, or have flame barriers of not less than 1-hour that project at least 30 inches horizontally beyond the exterior wall. In the UBC, the requirement is identical, except that the fire resistance rating of these assemblies need only be 3/4 of an hour. SBC provisions are similar to the BNBC and UBC, except that they specify noncombustible construction for vertical separation or noncombustible flame barriers. No minimum requirement is made with respect to fire resistance. The common element of all three codes, however, is that these provisions are waived with the installation of sprinklers. As with any other tradeoff, this practice is fundamentally wrong!

Research conducted at the NRCC over the last couple of years has shown that horizontal projections are effective in protecting the wall and windows above the fire plume (source: Nov. 1990 issue of *Fire Technology*⁽⁶⁾). It is important that these horizontal barriers, or "eyebrows" as they are sometimes referred to, be of sufficient depth (projection from the wall) to function properly.

For example, in the Las Vegas Hilton fire on February 10, 1981, the building eyebrows were only 18 in. deep and triangular in shape. As unburned gases vented out of broken windows, it is likely that the turbulent flow produced by these eyebrows contributed to direct flame impingement on the windows above, resulting in an accelerated vertical fire spread. Firefighters on the scene reported that after the initial involvement of the elevator lobby on the 8th floor, it took only 20 to 25 minutes for the fire to reach the top of the 30-story building by successive involvement of each intervening floor. In contrast, 3-ft eyebrows present on the Union Bank Building in Los Angeles were instrumental in containing a July 18, 1988 fire to the floor of origin (the 34th floor).

Despite the proven effectiveness of eyebrow construction of sufficient depth, the model codes permit this important protection feature to be omitted when sprinklers are provided. The probable reason is to permit curtain wall construction, because of its popularity for high-rise use. These types of wall systems, however, have experienced other problems in preventing vertical fire spread. Openings between the wall panels at the edge of floor slabs was one of the contributing factors to the vertical spread of fire in Los Angeles' First Interstate Bank Building. Concern over this issue has prompted the American Society for Testing and Materials (ASTM) to form a task group that will likely be charged with developing a standard to address this type of flame spread.

Curtain wall construction will continue to remain popular. However, the protection of high-rise structures with sprinklers alone is not sufficient to offset the risk of vertical fire spread. The CMIFC recommends that automatic sprinkler protection be provided in addition to vertical or horizontal flame barriers along the building's exterior, in lieu of trading off one form of protection for another.

ITEM 7: KEEPING CODES CURRENT WITH CHANGING TECHNOLOGY

As fire technology advances, so too must building codes adapt to a more scientific approach. Office furnishings have changed drastically from years ago. Increasing amounts of plastics, including high-density and expanded varieties are typical of office and residential environments today. Expanded foam rubber products such as polyurethane foam are used extensively in upholstered furniture. Computer work stations in office buildings can also greatly add to the combustible loading. The presence of these products creates a much higher wood-equivalent fuel load than in previous years when wood was the most prevalent combustible. Code requirements that are based on obsolete or inappropriate methodologies must be revised to reflect changing conditions.

An example of this is contained in the 1991 Supplement to the 1990 BNBC. Prompted by increasing concern of exposure fires and the ignition of buildings having combustible exterior walls, or walls with combustible veneers, a code change was approved that regulates set-back distance of a building's exterior wall surface based on the material's ability to withstand an incident radiant heat exposure without pilot ignition.

Future code requirements might involve fire resistant design based on calculated fuel loads and heat release rates of a building's contents. The challenge will be to examine how various fuel loads respond under real world fire conditions and to determine what is considered an adequate level of protection. Continued testing of products

according to standard testing procedures based on an increasing knowledge of fire science will be an important link in having codes reflect state-of-the-art technology.

SUMMARY

For high-rise building construction, the CMIFC recommends the following.

- Fire resistance rated construction of not less than 3 hours for columns, and not less than 2 hours for floors and roofs is recommended to reduce the risk of structural failure, should there be a burnout in any part of the building. Concrete and masonry are excellent materials for providing structural fire resistance because the duration of their structural performance in an actual fire should exceed the fire resistance rating period of the elements based on the ASTM E119 standard fire test condition.⁽¹⁾
- Two-hour fire resistance rated, horizontal and vertical compartmentation is recommended to contain the spread of fire, and provide areas of refuge for occupants beyond the room of fire origin until they can be safely evacuated. All through-penetrations should be properly fire stopped to maintain the integrity of the compartment's function as a fire barrier.
- Since wood veneers are prohibited for high-rise use, all other combustible veneers should also be prohibited.
- Active systems such as automatic detection and alarm, and automatic suppression systems, should be installed in conjunction with concrete and masonry construction rather than using these systems as economic incentives for trading off fire resistance or other fire protection features. If one or more of these mechanical systems fails to operate during a fire, as has been common in several severe high-rise fires, the only thing that is left to protect against collapse is the fire resistance inherent in the structure.
- To protect against vertical fire spread due to a leap-frog effect, exterior wall openings must be protected with

vertical or horizontal flame barriers. Trading off this form of protection by installing sprinklers should not be permitted.

- Building codes must continue to be updated to utilize the technological advances that are made in the principles of fire science.

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Organizations represented on the Concrete and Masonry Industry Firesafety Committee

BIA	Brick Institute of America
CRSI	Concrete Reinforcing Steel Institute
ESCSI	Expanded Shale Clay and Slate Institute
NCMA	National Concrete Masonry Association
NRMCA	National Ready Mixed Concrete Association
PCA	Portland Cement Association
PCI	Precast/Prestressed Concrete Institute

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