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Lessons Learned From Unsatisfactory Sprinkler Performance: An update on trends and a root cause discussion from the investigating engineer's perspective

Oftentimes, performance is affected by factors not linked to the initial design or installation

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Automatic sprinkler systems are often considered the most significant component of a building fire protection strategy. When properly designed, installed and maintained, an automatic sprinkler system can control a fire and significantly reduce deaths, injuries and property damage. However, sprinkler systems have their limitations, and their performance can be affected by factors not linked to the initial design or installation of the sprinkler system. This article explores automatic sprinkler system failure data to identify and discuss causes of unsatisfactory sprinkler performance.

Historical fire losses provide experiences that shape current fire protection design methodologies, design criteria and defense strategies. Significant lessons learned have been extracted from post-fire investigations of major losses of life and/or property despite protection by an automatic sprinkler system. These post-fire loss investigations revealed not only the cause of the fires, but causes associated with unsatisfactory sprinkler system performance. Unsatisfactory performance includes failure to operate, as well as ineffectiveness to control a fire and limit damages to life and property.

Generally, sprinkler systems are considered reliable1 and effective when properly designed, installed and maintained. Research shows that between 2003 and 2007, sprinklers operated in 93% of all fires large enough to cause actuation and were effective in 97% of the fires in which they operated.2 However, buildings are dynamic, and in the modern era of design flexibility, structures are increasingly subject to changes in characteristics, use and function. Over time, new tenants replace old ones, walls may be removed, added or altered, protected commodities can change, and sprinkler systems may require modification. From its initial installation, the sprinkler system waits patiently through the changes, and perhaps someday in the event of a fire, will have an opportunity to spring into action. What occurs to the protected occupancies and the system after the initial installation, up to the time of a fire, can have a profound impact on sprinkler system effectiveness.

An investigating fire protection engineer may determine why the sprinkler system did not control the fire or otherwise perform as intended, as well as evaluate how these factors affected the outcome of the fire and the overall ineffectiveness of the sprinkler system. This information is of value to the fire protection community, as knowledge of past mistakes can create awareness and possibly help to prevent repeat failures.

This article highlights specific root causes that lead to unsatisfactory performance through the examination of past fire loss data across a broad range of occupancies. Specific examples of fires where sprinkler systems failed to perform as intended are presented.

SPRINKLER SYSTEM PERFORMANCE BY THE NUMBERS

A review of historical sprinkler system statistics reveals common failure modes of sprinkler systems. The National Fire Protection Association (NFPA) publishes data summarizing sprinkler system performance in the United States on a frequent basis. From 1925 through 1969, the top five reasons for unsatisfactory sprinkler performance were:3

1. Water shut off (35.4%)
2. System not adequate for level of hazard in occupancy (13.5%)
3. Inadequate water supplies (9.9%)
4. Inadequate maintenance (8.4%)
5. Obstruction to water distribution (8.2%)

Other reasons for unsatisfactory performance included: partial sprinkler protection (8.1%); faulty building construction (6.0%); system components defective or damaged (5.6 %); exposure fire (1.7 %) ; system frozen (1.4%) and other (1.9%). Examining the most recent statistics,2 similar causes of unsatisfactory sprinkler system performance persist. The top five reasons that sprinkler systems failed to operate or were ineffective during a fire were:

1. System shut off (38%)
2. Inappropriate system for the type of fire (18%)
3. Water discharged did not reach fire (12%)
4. Lack of maintenance (12%)
5. Problem with water supply or not enough water discharged (9%)

Other reasons for unsatisfactory performance included manual intervention defeated system (8%) and system component damaged (3%). Although the categories used to quantify unsatisfactory performance have evolved over time, the common themes remain the same.

Examining the 35 reported large-loss fires in the United States in 2008,4 (large-loss being defined by the NFPA as a fire or explosion event of at least $10 million) large-loss fires caused an estimated $2.34 billion in damages, killing 15 civilians, injuring 60 civilians and 32 firefighters. Of these 35 large loss events, 31 involved structure fires (the other four were wildland fires).

Information regarding automatic suppression equipment was reported for 21 of the 31 structure fires. Eleven of the 21 fires were provided with some type of suppression system. Eight of these 11 systems operated (73%). Six of the eight systems (75%) were not effective in controlling the fire, while the effectiveness of one was not reported and only one system was effective in controlling the fire in its coverage area (see Table 1).

As evidenced by the most recent large-loss fire data, sprinkler system problems can be a significant contributing factor to large-loss fires.

REASONS SPRINKLER SYSTEMS FAIL TO CONTROL THE HAZARD

As described in the data above, the NFPA has catalogued a number of reasons that commonly contribute to unsatisfactory sprinkler system performance. The following is a list of major categories that summarize why sprinkler systems are ineffective in controlling fires and the root causes for unsatisfactory sprinkler system performance.3

1. Failure to maintain operational status of the system. The foundation of achieving satisfactory sprinkler performance is regular inspection, testing and maintenance of the sprinkler system and providing a system that is 100% operational before and during a fire event. This category includes instances where the water supply is shut off for any number of reasons prior to or during the fire event (i.e., manual intervention during firefighting activities), inadequate maintenance (including installation deficiencies not captured during acceptance testing or subsequent inspection, testing and maintenance procedures), component mechanical or corrosion failures, and obstructions to water distribution.

2. Failure to assure adequacy of system and/or for the complete coverage of current hazard. The effectiveness of a sprinkler system starts with proper design and installation of the system for the given hazard. This category encompasses instances where the unsatisfactory performance of the sprinkler system was caused by the inability of the sprinkler system to apply enough water to control the hazard it protects, and includes initial design errors, partial system installations, installation mistakes, changes to the commodity (i.e., type, configuration or quantity), and/or changes to the building (i.e., its configuration, use or occupancy).

3. Defects affecting, but not involving, the sprinkler system. By design, the proper operation of a sprinkler system during a fire may depend on the function of other building systems and features. This category captures instances where unsatisfactory performance of the sprinkler system during a fire event was caused by conditions or elements that are peripheral to, but not distinctly a part of, the sprinkler system. Examples of causes include reductions in available water supply to the protected building, faulty building construction and lack of compartmentation.

4. Inadequate performance by the sprinkler system itself. The proper operation of a sprinkler system during a fire depends on proper operation of the components. Although considered reliable, sprinkler system components can fail and adversely affect the operation of the entire system. Data has shown that these types of failures are a very small fraction of the overall reasons for failure.

Other causes that contribute to unsatisfactory performance of sprinkler systems include: exposure fires starting on the exterior of the building; delays associated with manual fire suppression efforts; general delays in notifying the fire department of a small incipient fire that rapidly grows to a catastrophic size; and other unknown causes. These causes are a relatively small fraction of the reported reasons for unsatisfactory sprinkler system performance.

FAILURES TO MAINTAIN OPERATIONAL STATUS OF THE SYSTEM (#1)

Maintaining the water supply is the fundamental key to overall sprinkler system performance. A sprinkler system without adequate water supply (water pressure, flow and duration) is not likely to provide satisfactory performance. Data has shown that lack of an adequate water supply is a primary contributing factor to unsatisfactory sprinkler system performance. Water supplies can be shut off for any number of reasons, including maintenance, vacant structures, to allow for firefighting operations, building construction or demolition, and system impairments such as leaks, pipe obstructions, obstructions to sprinkler distribution, closed valves, etc. A closed water supply valve is the most common cause of system impairment.

Case study: A July 2007 fire in Massachusetts caused approximately $26 million in damages. The fire occurred within a three-story former mill building of unprotected construction that was used by 56 mercantile businesses and covered 350,000 square feet (33,000 square meters). The fire was believed to have started after welding was completed in the basement the day before. The building was closed at the time of the fire. A full-coverage combination wet- and dry-pipe sprinkler system was provided and was located in the area of fire origin. However, a sprinkler valve in the area of origin was closed and padlocked. With the water supply shut off, the fire was able to spread and quickly overwhelm the rest of the sprinkler system. No notice of the system shutdown had been provided to the fire department.6

Even if an adequate water supply is provided, manual interruption of the water supply during a fire event can have catastrophic results. Fire department interruption of a sprinkler system removes the sprinkler system from the protection equation and renders the system ineffective. Turning off a sprinkler system will allow the fire to grow and cause the activation of additional sprinklers. If the system is restored later in the fire, it is possible that sprinklers outside of the design area will have opened, reducing the delivered density from the sprinkler system and increasing the likelihood that the sprinkler system will be overwhelmed by the fire.

Inadequate sprinkler system inspection, testing and maintenance can render a properly designed and installed system ineffective. NFPA 258 provides required inspection, testing and maintenance for a sprinkler system. If systems are not periodically inspected for mechanical deficiencies, proper function, valve actuation, water flow, sprinkler clearances, etc., the system may not be effective during a fire.

Case Study: A fire in a Georgia textile recycling plant in January 2007 caused $7.5 million in damages and killed one civilian, despite the presence and operation of the installed sprinkler system. The plant was 245,000 ft2 (23,000 m2), three-stories high and was built of heavy-timber construction. Due to an unknown cause, a fire broke out in a machinery room of the plant and spread to the rest of the plant, activating over 75 sprinklers. The sprinkler system was ineffective in controlling the fire, as it had not been maintained for quite some time. Maintenance deficiencies included improper sprinkler clearance, sprinkler risers modified to allow the use of garden-type hoses, and valves not fully open.7

Fire protection codes and standards provide multiple ways to verify the open status of valves, including tags and electronic valve supervision systems connected to the building fire alarm system. Training as to what precautions should be taken in off-normal conditions, as well as communicating impairment protocols, is part of maintaining the system in an operational status. In general, a flowing sprinkler system in an emergency situation will provide better protection than a sprinkler system that is turned off or otherwise manipulated. Fire suppression efforts should work in conjunction with automatic sprinkler systems. Firefighting professionals should confirm that the fire is extinguished and there is no threat of a fire spreading before shutting off automatic sprinkler systems.

FAILURES TO ASSURE ADEQUACY OF SYSTEM AND/OR THE COMPLETE COVERAGE OF CURRENT HAZARD (#2)

A sprinkler system's effectiveness during a fire event is bound by the design criteria of the original installation. The design criteria must be consistent with the protected hazard. A common cause of unsatisfactory sprinkler system performance is inappropriate design for the hazard protected. The inadequacy of a sprinkler system could stem from a number of reasons, including initial design errors, installation deficiencies, partial system designs, changes to the protected commodity in its configuration/quantity, and building changes in use or occupancy.

Case Study: In 2008, a fire ignited accidentally by roofers occurred in an outdoor film studio consisting of unprotected wood frame facades constructed to mimic the narrow streetscape of New York City. The facades were in close proximity to one another and were protected with a deluge sprinkler system. The system operated during the fire; however, it was unable to control the fire due to the amount, distribution and orientation of available fuels. The fire quickly spread through the facades and involved adjacent buildings and structures. As the fire spread, the facades collapsed and deluge riser failed, reducing the effectiveness of the deluge system. The deluge sprinkler system's inability to control the fire and the large fuel load, among other factors, was a factor in the fire's rapid spread and estimated $38 million in damage.4, 7

Changes in the protected hazard, the sprinkler system or the structure itself can occur throughout the life of a building and may not be evaluated with respect to the existing sprinkler system capabilities. Whether intentional or performed out of ignorance, the result can be catastrophic. As structures change (e.g., change in tenant, ownership, operation; change in walls, ceilings or floors; change in storage), the sprinkler system, as initially designed and installed, may be inappropriate for the protected hazard. The annual inspection required by NFPA 258 includes a review of the hazard(s) to verify the system design remains appropriate for the hazards and use of the building. This is an important item needed for successful performance.

Seemingly minor changes in the protected hazard can significantly impact the sprinkler system's ability to effectively control a fire. Sprinkler systems that are not adequate to protect the stored commodities or where the fire load is too large for the system design have contributed to large losses in several instances. These include a 1999 Georgia warehouse fire (damages $7.3 million); a 1998 North Carolina warehouse fire (damages $32 million); and a 1996 Michigan rolled paper and chemical warehouse (damages $14 million).9

Case Study: A March 1998 fire at a bulk retail store in Tempe, AZ, resulted in more than $6 million in damage to the building and contents. The store, originally built in 1988, was a one-story masonry structure with a footprint of 400 x 250 ft (120 x 76 meters) and a height of 24 to 29 feet (7.3 to 8.8 meters). It was equipped with a partial in-rack sprinkler system not involved in the fire and had a ceiling-level automatic sprinkler system designed to protect a Class IV commodity throughout. At the time of the fire, the store primarily housed Class A expanded and unexpanded plastics, a hazard that does not match the level of protection provided. Although the sprinkler system did play some role in slowing the fire spread, it activated 2.5 times more sprinklers than the system was designed to supply, and did not stop flames from spreading across 10 foot (3 meter) aisles. Among other contributing factors, the change in the commodity without reevaluating the installed sprinkler system played a large role in the fire spread and damage to the building.10

Fires originating in unprotected areas, such as concealed spaces, voids or areas beyond the protection area of sprinklers can be catastrophic. A fire originating in an unprotected space can grow unchecked, eliminating the opportunity for the sprinkler system to operate and protect the hazard while the fire is still relatively small. Consequently, once the fire spreads into the protected area, the sprinkler system can be overwhelmed by the fire's size and is unable to control the fire.

Case Study: In November 2008, a fire occurred in a 114-unit, one- and two-story unprotected wood-framed motel and overwhelmed the wet-pipe sprinkler system. The fire originated in an unprotected (i.e., non-sprinklered) attic space and spread across the attic and down into the protected motel lobby and guest rooms. The sprinkler system was unable to control the fire once it spread into the protected area, and ultimately the ceiling and roof collapsed, further complicating fire suppression efforts. The fire caused an estimated $10 million in damages.4

The hazard protected must be within the designed capability of the sprinkler system. If changes to the protected hazard are made after the original installation of the sprinkler system, an evaluation of the potential effects must be considered. Incomplete coverage by a sprinkler system can result in vulnerability of the system effectiveness. The absence of sprinklers may allow for a fire to grow to a size that can overwhelm the systems installed in protected areas. Although some sprinkler system installation standards may allow for exclusion of sprinkler protection in particular locations, a comprehensive risk analysis can be used to weigh the potential consequences for incomplete sprinkler system coverage.

DEFECTS AFFECTING, BUT NOT INVOLVING THE SPRINKLER SYSTEM (#3)

Sprinkler system designs are premised on the principle that the strength of the water distribution system available at the time of construction will remain within the original design buffer. However, the water supply strength can degrade over time. Increased nominal demand from new developments utilizing the same water infrastructure, closing of water infrastructure isolation valves and seasonal effects can result in diminished flow and/or pressure available to sprinkler systems. Water authorities may reduce water infrastructure working pressure to conserve water that is wasted due to leakage.

Defective building construction can render a sprinkler system inoperable. A common occurrence is the collapse of a building element used for support of sprinkler system components during a fire. The failure of a joist, beam, roof section or floor during a fire can rupture sprinkler system pipes, causing a loss of water pressure to the system and unsatisfactory performance of the sprinkler system.

Case Study: In July 2002, a 61,600 ft2 (5,700 m2), 110 foot (34 meter) high Wisconsin magazine printing plant suffered a building collapse and subsequent fire, causing approximately $17 million in damage. The plant, built of unprotected non-combustible construction and protected by a complete coverage wet-pipe sprinkler system, was in full operation when the building collapsed and the fire started. During the building collapse, the sprinkler system and sprinkler risers were damaged and rendered useless; the subsequent fire burned through the remainder of the plant rapidly.2

Compartmentation of hazards through the use of fire barriers and walls is a fire protection strategy in itself, but physical separations can play a role in the effectiveness of the sprinkler system. Higher hazard areas in buildings can be segregated by fire-resistance-rated construction. The concept is to contain the fire in the compartment and prevent spread outward.

Defects associated with building elements or other protection features can have an impact on sprinkler system performance. The attachment of sprinkler system components to building elements for support and restraint should be selected with care during the design and construction process. Vigilance is necessary in maintaining passive fire protection compartmentation, not only to prevent the spread of fire, but to also improve the effectiveness of the sprinkler system in the area of fire involvement.

INADEQUATE PERFORMANCE BY THE SPRINKLER SYSTEM ITSELF (#4)

Although rare, components of the sprinkler system itself (sprinklers, piping, valves, etc.) can either fail to activate, delay activation or decrease the available water supply needed to effectively control the fire. System component damage is the least frequently cited reason for unsatisfactory sprinkler system performance. This is consistent with the earlier statements that overall sprinkler system components are reliable. The data presented involving component damage of sprinkler equipment included incidents where the damage was a consequence of the fire, rather than a root cause of sprinkler system failure.2

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