Obstructions and ESFR Sprinklers

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Early Suppression Fast Response (ESFR) sprinklers were developed to meet the demands of high challenge storage fire scenarios and are a common choice to protect warehouses. The added benefit to the use of this technology is in most cases, the requirement for rack sprinklers can be circumvented. Many aspects of ESFR sprinklers are unique compared to standard spray sprinklers. Paramount to ESFR sprinkler performance is the ability of the sprinkler to provide large amounts of water, in a specific discharge pattern, to the fire source in the incipient phase of fire development. Obstruction of the sprinkler discharge pattern could greatly affect the ability of the ESFR sprinkler to achieve fire suppression.

ESFR sprinkler obstructions requirements have for the most part, remained unaltered since the early development of the sprinkler. The requirements outlined in the 2013 Edition of NFPA 13, "Standard for Installation of Sprinkler Systems" (NFPA 13), are intended to limit the obstruction from inhibiting the spray pattern of the ESFR sprinkler. These requirements are based on a limited number of tests with conservative assumptions in addition to safety factors.

Current ESFR obstruction requirements are to locate the sprinklers a minimum of 12 inches horizontally from the nearest edge of any bottom chord or bar joist. A bridging member of 2 inches or less in width is to be located a minimum of 24 inches below the elevation of the sprinkler deflector or positioned a minimum of 12 inches horizontally from the sprinkler deflector. The ESFR design standards also limit the height of storage from being within 36 inches of the sprinkler deflector.

The absence of small and full-scale tests to understand and validate the obstruction requirements complicates one's ability to interpret these requirements. The possibility to improve the current ESFR sprinkler obstruction requirements provided the motivation for the Fire Protection Research Foundation to commission this research project, "Obstructions and ESFR Sprinklers – Phase 1."

The initial phase of this study reviewed relevant literature and sources made available to the team from the advising panel or through publically accessible sources. The background of the ESFR sprinkler development was also reviewed to better understand the possible effects obstructions have on ESFR sprinkler performance.

A fire-testing program was also outlined to establish a direction forward to explore the ESFR sprinkler obstruction issue.

A literature review was completed to compile and analyze available resources that evaluate the performance of an ESFR sprinkler with obstructions or literature that covers the development of the ESFR sprinkler standards.

The ESFR sprinkler relies on three important factors: the sprinkler response (response time index), the Actual Delivered Density (ADD), and the Required Delivered Density (RDD). ADD is defined as the water flux delivered to the top surface of a burning rack-storage array after penetrating the fire plume. RDD is defined as the water flux required to be delivered at the top of the burning storage array to achieve suppression.

The ESFR sprinkler is based on the concept of early suppression, whereby the activation of the sprinkler occurs during the early stages of a fire while the RDD is minimal. During the early stages of the fire, the ADD will exceed the RDD and thus provide an adequate density to suppress the fire[1].

The performance of a fire sprinkler can be measured by fire plume penetration, which is the ability of the sprinkler to deliver water droplets through the fire plume to the burning surface of the storage array. The penetration ratio is determined by the ADD divided by the Locally Applied Density (LAD) under a no fire condition[2]. The penetration ratio of an ESFR sprinkler does not change significantly with fire size (penetration ratio approaching 1.0), which highlights the superior performance of ESFR sprinklers.

Obstructions located near the sprinkler may redirect water or change the characteristics of the water droplet to the point that suppression of the fire would not be achieved (i.e., ADD<RDD). Additionally, water droplets may ricochet off the obstruction causing adjacent sprinklers to be wetted and thus not activate properly; a phenomenon termed cold soldering. This can lead to the operation of an excessive number of sprinklers or prevent the operation of sprinklers that are required for suppression.

The ESFR sprinkler has a specific and deliberately designed spray pattern much different from that of a standard spray or control mode sprinkler. The water density of ESFR sprinklers decreases with radial distance from the sprinkler axis. The area within the 2-foot radial distance has a significantly higher density than the measurements at 4, 6, 8, and 10 feet. The pattern was developed to suppress a fire located directly below the sprinkler with a high sprinkler to storage clearance (10 feet or greater), which is generally considered the most challenging fire location for ESFR sprinklers[3]. This discharge characteristic underscores the importance of not significantly obstructing the sprinkler in this critical region.

As part of the literature review, actual field obstruction conditions were identified. Obstructions relating to the commonly used structural roof system, open web steel joists, were evaluated. Dimensional parameters for the joists were reviewed to establish size generalities and trends. This information was used both to evaluate the practicality of the obstruction testing reviewed and to establish boundary conditions for the fire-testing program.

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[1] Yao, C. (1988). The Development of the ESFR Sprinkler System. Fire Safety Journal, 14, 66 - 73.

[2] Yao, C. (1997). Overview of Sprinkler Technology Research. Fire Safety Science - Proceeding of the Fifth International Symposium (pp. 93 - 110). Melbourne, Australia: International Association for Fire Science.

[3] Chan, T.-S. (1994). Measurements of Water Density and Drop Size Distributions of Selected ESFR Sprinklers. Journal of Fire Protection Engineering, 79 - 87.

The size of the joists depends on three main factors: the required spans, design loads, and available space. The most common joist depth is 30 inches. The depth of the joist is related to the span of the joist and can be assumed equal to one-half of the span in inches[4]. For spans exceeding 60 feet, it was determined the joist depth of 35 inches is most common. For scenarios that have small spans or limited room joists, depths of 22 inches are commonly used.

The bottom chord of the joist consists of two double angles with equal length sides and is either welded or bolted together. The double angles can also vary in size depending on the application. For the most common scenario, 2-inch by 2-inch double angles are used for 30-inch deep joists. For joist exceeding this depth, the double angles are increased to 2½ inches by 2½ inches.

Obstructions are also caused by structural elements such as bridging used to provide support against lateral and other loads. The bridging members consist of a single angle. Size can also vary depending on the required loading. The most commonly found bridging member was determined to be a 1½-inch by 1½-inch angle.

Ten full-scale tests were identified as relevant to the study of ESFR sprinkler obstruction: seven tests containing obstruction scenarios and three containing plugged sprinklers. Out of the seven obstruction tests, only two failed, both due to the operation of an excess number of sprinklers (greater than 12).

A series of ADD testing was completed by Mammoser & McCormick to analyze the effect of a bar joist or a bridging member on the ESFR sprinkler spray pattern. The testing consisted of over one hundred ADD tests using K-14 ESFR pendent sprinklers with different size bar joist and bridging members in various horizontal and vertical offsets.

These test results were used as the basis for the testing phase of the project, which will include additional ADD testing, and several full-scale tests. It is hoped this testing effort will provide the data needed to establish more practical and useable requirements for ESFR sprinkler and obstruction interaction.

[4] Braggs, L. (2014, June 25). Sales Engineer, Vulcraft. (W. Fletcher, Interviewer)