The Effect of Obstructions on ESFR Sprinkler Performance

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Abstract

Early Suppression Fast Response (ESFR) sprinklers were developed to meet the demands of high challenge storage fires and are a common choice for warehouse fire protection. Many aspects of ESFR sprinklers are unique in comparison 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 can greatly affect the ability of the ESFR sprinkler to achieve fire suppression.

This paper presents the results of recent testing which explored the relationship between ESFR performance and various obstruction scenarios. Eight full-scale and approximately 40 Actual Delivered Density (ADD) tests have been completed to date. Both the ADD and full-scale testing was completed at Underwriter's Laboratory in Northbrook, IL. The goal of this ongoing project is to ultimately develop a tool which could be used to provide the reliable analysis of the impact of obstructions on ESFR sprinkler performance. In addition, the results of the project will be submitted to the National Fire Protection Association for code changes.

Keywords: Early Suppression Fast Response Sprinklers, Actual Delivered Density, Obstruction.

Introduction

ESFR sprinkler obstruction requirements have for the most part, remained unaltered since the early development of the sprinkler. The requirements outlined in the 2016 Edition of National Fire Protection Association, "Standard for Installation of Sprinkler Systems" (NFPA 13), are intended to limit obstructions 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.

Currently ESFR sprinklers are required to be located 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 required 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. Figure 1 shows a typical bar joist, sprinkler, and bridging member arrangement.

Figure 1. 22-inch Deep Bar Joist with Bridging Member.

The absence of full-scale testing results complicates one's ability to interpret these requirements. The potential to improve the current ESFR sprinkler obstruction requirements provided the motivation for the Fire Protection Research Foundation to commission this research project.

Actual Delivered Density (ADD) Testing

ADD testing was used to select various obstruction scenarios to be tested in full-scale. Figure 2 shows a typical sprinkler vs obstruction condition used in the testing. The ADD apparatus used can be described are 48 water collection pans and 12 heptane nozzles. The water collection pans are separated into groups of four. A group of four collection pans simulates the top surface of one pallet load of stored commodity. Eight groups of four collection pans are placed in the main array. In addition, two satellite collector arrays are placed adjacent to the main array to investigate pre-wetting of sprinkler spray on a multiple-row storage array. A 6-inch flue space was maintained between the two adjacent simulated commodities. The complete ADD apparatus simulates a 4 x 4 array of stored pallet loads of commodity.

The apparatus was arranged to simulate the planned full-scale fire test configuration. The center of the ADD apparatus was located directly below the sprinkler and the top of the apparatus (representing the top surface of stored commodity) was located 10 feet from the ceiling. The apparatus was calibrated to produce a heat release rate of 2.5 MW, which is the heat release rate expected from a fire occurring within rack storage of cartoned, unexpanded Group A plastic commodity to a height 30 feet. Figure 3 shows the east view of the ADD apparatus during one of the bar joist obstruction tests.

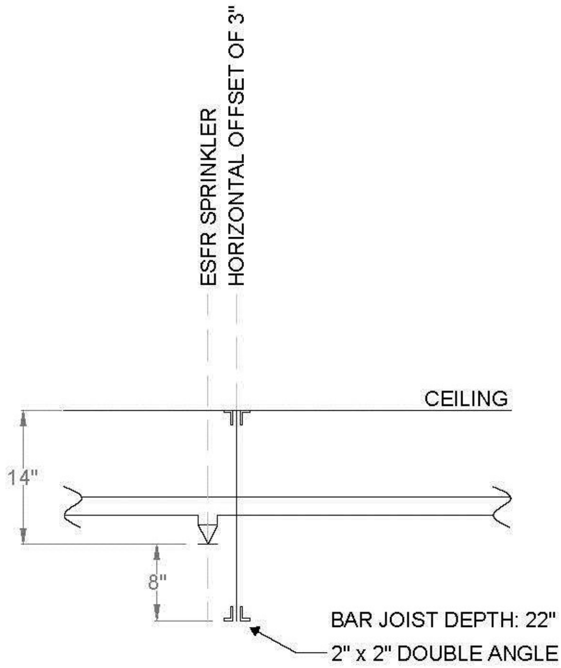

Figure 2. Typical Sprinkler Obstruction Arrangement.

ADD testing was used to compare the change in water flux delivered to the top of the simulated commodity with various obstruction arrangements. Coordination of bridging members was identified as the most problematic obstruction issue. The initial focus of the experimentation was to understand the reduction in ADD caused by bar joist and bridging member location.

Figure 3. ADD Testing Apparatus With Obstruction.

Various arrangements of obstruction widths and shapes were tested to measure the change in ADD from the baseline condition (unobstructed sprinkler). The obstructions ranged in width from 3 to 12 inches. Both round and flat shapes were used. To better understand the results of the ADD work, the obstruction scenarios were plotted against ESFR sprinkler discharge patterns. This analysis showed that for obstructions located directly below the sprinkler the ADD decreases as the vertical distance between the sprinkler and the obstruction decreases. For obstructions horizontally offset from the sprinkler, the inverse is true, the ADD decreases as the vertically distance between the sprinkler and the obstruction increases. This relationship is shown Figure 4.

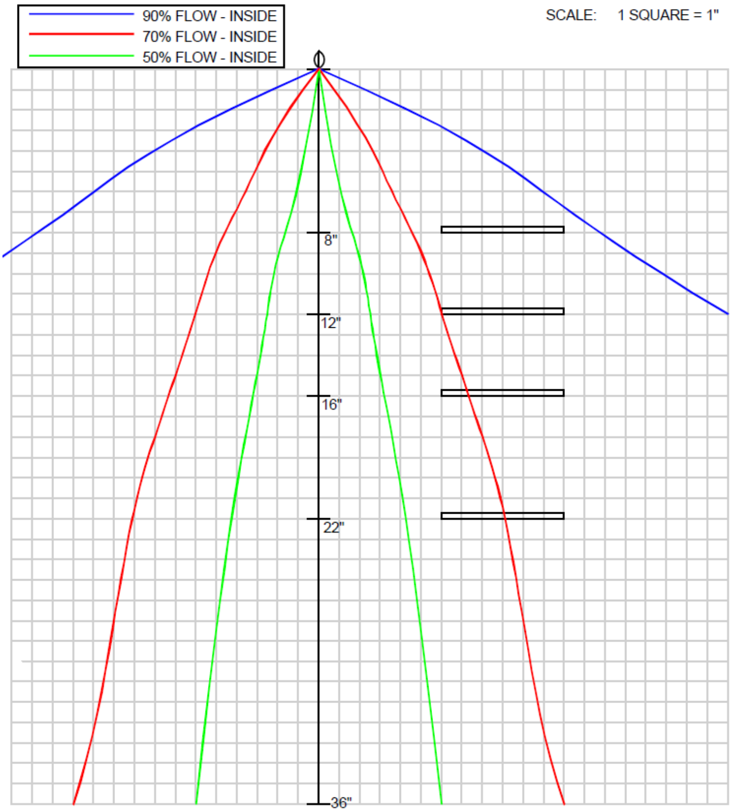

Figure 4 . ESFR K17 Sprinkler Spray Pattern with 6-Inch Wide Flat Obstruction Horizontally Offset 6 Inches

Full-scale Fire Testing

Various obstruction arrangements were tested in full-scale based upon the information gathered in the ADD testing and sprinkler discharge pattern analysis. The test array consisted of the following (see Figures 5 and 6):

- Standard Group A plastic commodity
- 30 feet of double-row rack storage and 40-foot high ceiling
- Standard 4-foot aisles with 6-inch transverse and longitudinal flue spaces provided at rack uprights and between unit loads.
- K17 ESFR sprinklers operating at 52 psi and positioned at the ceiling with 14-inch clearance between the ceiling and the deflector.
- Sprinkler spacing 10 feet x 10 feet
- Two - half igniters positioned at the base of the commodity offset on the center of the transverse flue space in the main array.

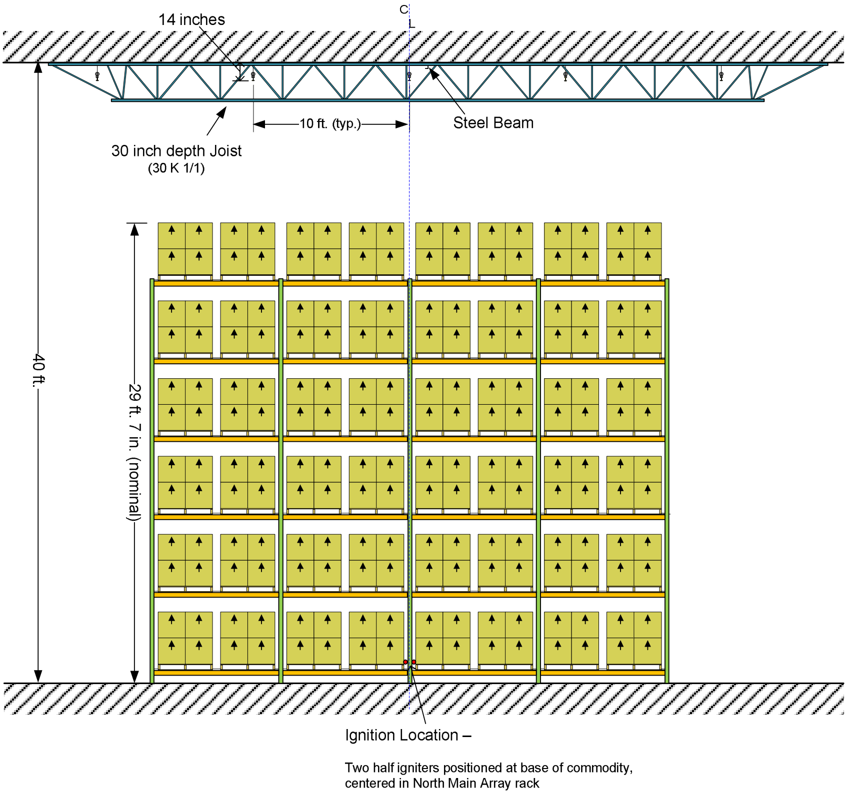

Figure 5. Typical Full-scale Test Section View

The results of the testing are summarized below:

- K17 ESFR sprinklers obstructed by a 1.5-inch x 1.5-inch bridging member located 12 inches directly below the sprinkler produced acceptable results. It can be said that bar joists 26-36-inches deep, 6 inches horizontally offset from the sprinkler with a 1.5-inch x 1.5-inch bridging member located directly under the sprinkler will not significantly decrease the performance of the ESFR sprinkler.
- K17 ESFR sprinklers obstructed by a 6-inch wide flat obstruction located 6 inches horizontally offset and 20 inches below the sprinkler produced acceptable results.
- K17 ESFR sprinklers obstructed by a 12-inch wide flat obstruction located 6 inches horizontally offset and 20 inches below the sprinkler activated 10 sprinklers, 2 sprinklers more than that stated in the pass/fail criteria (reduction in safety factor from 1.5 to 1.2 based upon 12 sprinkler design). The fire damage was acceptable, as were the ceiling temperatures.

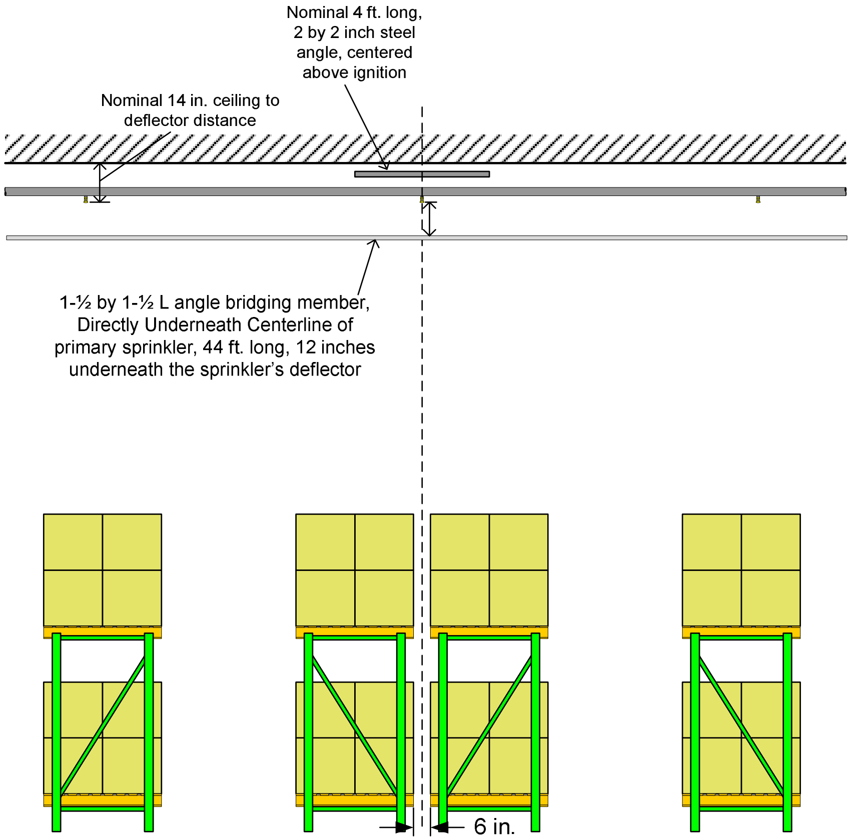

Figure 6. Typical Full Scale test Arrangement, Elevation View Near Ceiling

Conclusion

This research project has made much progress in the understanding of the effect obstructions have on ESFR sprinkler preformance. This data will provide opportunity to adjust the current design standards to scientifically based parmeters. Additional testing is needed to widen the knowledge base.

From this work, it is hypothesized that although ADD testing may be used to gain insight into full-scale fire test performance, other variables are involved. For example, two flat obstructions, 6 and 12-inches wide, located 6 inches horizontally from the sprinkler and 20 inches below have very similar ADD testing results. One might even suggest that the ADD for the 6-inch-wide obstruction is worst. However, when both scenarios were tested in full-scale, only one sprinkler activated in the 6-inch-wide obstruction test and 10 sprinklers activated in the 12-inch-wide obstruction test.

The test results of the 12-inch-wide obstruction showed at least three sprinklers skipped (did not operate). One explanation is that the larger width of the 12-inch-wide obstruction caused a larger disruption of sprinkler droplets and thus allowed the fire plume to transport the droplets to adjacent sprinklers, cooling the sprinkler such that operation did not occur. Without examination of this variable, the understanding of the effect miscellaneous obstructions has on ESFR sprinkler performance will be limited.

Future Work

One additional phase of testing is anticipated to occur in late 2017 or early 2018. This phase will include additional study of sprinkler skipping phenomena and testing of additional obstruction scenarios.

Regarding the development of the obstruction prediction tool discussed in the project objective, much thought has been given to this concept. Given this is a three-dimensional problem, the presentation of the tool in a two-dimensional format, such as in a hard copy version of NFPA 13, is challenging. However, it is thought a diagram showing various zones within which will be obstruction restrictions can be created. More work on this concept is underway now.

Acknowledgements

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