Early Suppression Fast Response Sprinklers and Obstructions

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The objective of the Phase 2 research effort was to explore the threshold and tolerance of the early suppression fast response (ESFR) sprinklers to obstructions. This research utilized both intermediate scale testing and full-scale testing.

ESFR sprinklers were developed to meet the demands of high challenge storage fire scenarios and are a common choice to protect warehouses. 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.

Actual delivered density (ADD) testing was utilized to identify the obstruction parameters for the full-scale testing. The variation in the performance of the various ESFR sprinkler models was established so that the results of the testing program would not be product specific. ADD testing was conducted, both with and without obstructions, to evaluate this issue.

Five large-scale fire tests were conducted to gather data to establish the acceptable threshold the ESFR sprinkler could be obstructed until the obstruction prevented the ESFR sprinkler from meeting its performance objectives. Each test was conducted using a nominal storage height of 30 feet and a ceiling height of 40 feet. The main storage array consisted of double-row rack storage and two single-row racks target arrays separated with four-foot aisles on both sides. Standard cartoned unexpanded Group A plastic test commodity was used in the testing. The ignition was located at the base of the storage array and horizontally offset approximately 2 feet from the obstructed sprinkler in the transverse flue space.

Due to a recent change to NFPA 13 regarding the use of K-14 ESFR sprinklers, the K-17 ESFR sprinkler was selected for this test series. Two full-scale tests were performed with bar joist obstructions and three tests were performed with a combination of bar joist and bridging member obstructions. Tables 1 and 2 outline the summary of these tests and their respective results.

Table 1. Test Parameters

Fire Test Number	Test 1	Test 2	Test 3	Test 4	Test 5
Test Date	April 14, 2015	April 16, 2015	April 20, 2015	April 22, 2015	April 24, 2015
Storage Type	Double Row Rack				
Commodity Type	Cartoned Unexpanded Group A Plastic (Plastic Cups in Corrugated Boxes on Hardwood Pallets)				
Pallet Type	2 way entry, stringer, hardwood				
Nominal Storage Height (feet)	30				
Ceiling Height (feet)	40				
Nominal Clearance (feet)	10				
Aisle Width (feet)	4				
Ignition Location	Under One Sprinkler (offset)				
Sprinkler Systems	Ceiling Only (no in-rack sprinklers)				
Sprinkler Orientation	Pendent				
Deflector to Ceiling (inch)	14				
Sprinkler Spacing, sprinkler by branchline,	10 feet by 10 feet				
Temperature Rating (°F)	165				
Sprinkler Type	ESFR				
Nominal Sprinkler Discharge Coefficient K (gpm/psig $^{0.5}$)	16.8				
Nominal Discharge Density (gpm/ft^2)	1.21				
Nominal Discharge Pressure (psig)	52				
Primary Obstruction	36 inch deep steel joist, edge of lower chord 6 inches from centerline of sprinkler	30 inch deep steel joist, edge of lower chord 3 inches from centerline of sprinkler	36 inch deep steel joist, edge of lower chord 6 inches from centerline of sprinkler	36 inch deep steel joist, edge of lower chord 6 inches from centerline of sprinkler	22 inch deep steel joist, edge of lower chord 6 inches from centerline of sprinkler
Secondary Obstruction	None	None	1-1/2 inch by 1-1/2 inch bridging member; 1-1/2 inch away from sprinkler	1-1/2 inch by 1-1/2 inch bridging member; Centered below sprinkler	1-1/2 inch by 1-1/2 inch bridging member; Centered below sprinkler

Table 2. Test Results

Test Results					
Fire Test Number	Test 1	Test 2	Test 3	Test 4	Test 5
Test Date	April 14, 2015	April 16, 2015	April 20, 2015	April 22, 2015	April 24, 2015
Primary Obstruction	36 inch deep steel joist, edge of lower chord 6 inches from centerline of sprinkler	30 inch deep steel joist, edge of lower chord 3 inches from centerline of sprinkler	36 inch deep steel joist, edge of lower chord 6 inches from centerline of sprinkler	36 inch deep steel joist, edge of lower chord 6 inches from centerline of sprinkler	22 inch deep steel joist, edge of lower chord 6 inches from centerline of sprinkler
Secondary Obstruction	None	None	1-1/2 inch by 1-1/2 inch bridging member; 1-1/2 inch away from sprinkler	1-1/2 inch by 1-1/2 inch bridging member; Centered below sprinkler	1-1/2 inch by 1-1/2 inch bridging member; Centered below sprinkler
Length of Test (minutes)	31	32	32	32	32
First Sprinkler Operation Time (min: sec)	0:56	1:42	1:19	1:11	1:01
Last Sprinkler Operation Time (min: sec)	6:08	7:37	1:19	1:11	6:42
Number of Operated Sprinklers	3	12	1	1	23
Peak Gas Temperature at Ceiling Above Ignition (°F)	294	406[1]	238	250	1264
Maximum 1 minute Average Gas Temperature at Ceiling Above Ignition (°F)	129	256*	114	115	979
Peak Steel Temperature at Ceiling Above	128	157*	86	84	248
Maximum 1 minute Average Steel Temperature at Ceiling Above Ignition (°F)	126	157*	85	83	246
Ignition Time of Target Array (min: sec)	3:36 (North Target)	3:24 (North Target)	N/A	N/A	2:26 (North Target)
Fire Travel to Extremities of Test Array	No	No	No	No	Yes (North Target)

[1] Due to a data system issue, data was taken at 20 second intervals during Test 2. The values reported are the peak and one minute maximum recorded values and likely not the true peak and time average maximum values.

From the full-scale fire tests that were conducted, the following conclusions can be made:

- A K-17 ESFR sprinkler obstructed by a bar joist with a 6-inch offset from the closest edge of the obstruction and without a horizontal bridging member produced acceptable results.

- A K-17 ESFR sprinkler obstructed by a bar joist with a 3-inch offset from the closest edge of the obstruction and without a horizontal bridging member controlled the fire with 12 sprinklers activating.

- Tests 3 and 4 showed that regardless of horizontal offset a bridging member with a vertical separation of 19.5 inches on a 36-inch deep bar joist with a 6-inch offset provides acceptable results.

- The failure of Test 5 can be attributed to the vertical proximity of the bridging member to the sprinkler. This test illustrated that a bridging member directly underneath the sprinkler with a vertical separation of 6 inches produced unacceptable results.

- The fire growth rates discussed in Report Section 8.3 show that the fire in Test 2 was not comparable to the other four fires and should be repeated.

The following additional testing is recommended:

- Testing of bridging members on different bar joist depths to increase the understanding of the vertical distance effects of the obstructions

- A K-14 ESFR sprinkler test with the worst-case successful obstruction arrangement found during the K-17 ESFR testing.

- ADD testing to evaluate various obstructions scenarios prior to full-scale testing.

- Evaluate the results of Test 2 by retesting the obstruction scenario at full-scale or by other means such as intermediate scale testing methods.

- Miscellaneous obstruction tests