The goal of this project is to support the National Fire Protection Association (NFPA) 13 [1] Technical Committee in the development of new protection requirements addressing sprinkler installation under sloped ceilings. The present study has been conducted in partnership with the Fire Protection Research Foundation (FPRF) and the Property Insurance Research Group (PIRG). The study was conducted in three phases with the current Phase 3 aiming to develop fire protection guidelines by conducting sprinklered, large-scale fire tests.

In the first two phases of the project, numerical modeling using the computational fluid dynamics (CFD) code FireFOAM [2] [3] identified the sensitivity of sprinkler activation times and spray dynamics affected by ceiling slope, sprinkler orientation (deflector parallel-to-floor or parallel-to-ceiling), and obstructed ceiling construction (e.g., purlins and girders). As input to the large-scale test planning, the modeling studies identified a maximum ceiling inclination angle of 18° or a slope of 0.333 (4 in 12), and acceptable purlin depth in the range of 150-610 mm (6-24 in.). Modeling also showed that the parallel-to-floor sprinkler deflector orientation provides better water distribution on top of the stored commodity compared to the parallel-to-ceiling orientation. Recent cold-flow measurements have also demonstrated that a parallel-to-floor sprinkler deflector orientation provides superior water distribution within the area located below the sprinkler with negligible impact on the distribution pattern due to spray impingement onto the sloped ceiling [4]. Based on the numerical modeling results [5] [6], a testing proposal was developed in Phase 2 of the project [7].

Large-scale, sprinklered fire tests were conducted in Phase 3 to evaluate the performance of ceiling sprinklers using the FM Global standard Cartoned Unexpanded Plastic (CUP)* commodity stored in a rack-storage arrangement under sloped ceilings. All the tests were conducted in the Large Burn Laboratory (LBL) at the FM Global Research Campus in West Glocester, RI. Obstructed ceiling construction (see definition in the FM Global Loss Prevention Data Sheet (DS) 2-0, Installation Guidelines for Automatic Sprinklers [8]) in the form of purlins and girders were included. In Fig. 1(a), the image shows a test being conducted under an unobstructed ceiling inclined at 18° (slope of 4 in 12) and Fig. 1(b) shows a test being conducted under the same ceiling in presence of obstructed construction (purlins and girders). Obstructed construction tends to keep the flow of hot combustion products originating from fires confined in the purlin channels, possibly causing delays in sprinkler activations.

* FM Global standard CUP commodity is equivalent to the NFPA Group A plastic commodity.
From the range of conditions explored in large-scale testing and from numerical modeling [5] [6], and spray test [4] results, major trends involving the principal parameters are summarized below.

- Compared to the three sprinkler activations in the CUP baseline test with a non-sloped, unobstructed ceiling, one–four additional sprinkler activations occurred when the ceiling was inclined at 10° and four–seven additional activations occurred when the ceiling was inclined at 18°. In these tests, fire spread was successfully controlled. The 18° tests were found to be more challenging from a sprinkler protection standpoint, especially the unobstructed ceiling test in which ten sprinklers activated.

- Presence of obstructed construction (purlins and girders) was generally found to cause early activation of sprinklers and mitigated the biased ceiling jet flow caused by the ceiling slope (the ceiling jet tends to move toward the upslope). However, it was found that deeper purlins could cause the ceiling jet to confine within the purlin channels causing several sprinklers to activate far away from the fire source. Closing the purlin channels at the girder locations (the gap above the girders) was found to mitigate the ceiling jet channeling effect, reducing the unwanted activation of sprinklers along the purlin channels. Closing the channels was found to be effective for purlin depths of 460 mm (18 in.) at 10° inclination and 300 mm (12 in.) at 18° inclination.

- At 10° ceiling inclination, current tests showed limited effect of sprinkler deflector orientation on suppression effectiveness; however, for parallel-to-ceiling orientation, the sprinkler spray cores moved away from the ignition region and a larger amount of commodity was consumed during the test. For other storage scenarios besides the tested configuration (four-tier CUP arrays, 10 ft ceiling clearance), sprinkler suppression performance may be adversely affected when deflectors are kept parallel-to-ceiling. Spray tests [4] and numerical modeling [5] [6] have shown inferior spray distribution for the parallel-to-ceiling orientation for ceilings inclined at 18°.
Fig. 1: Large-scale fire suppression tests conducted under a sloped ceiling at 18° inclination: (a) unobstructed ceiling, and (b) ceiling with obstructed construction (purlins and girders).
References