Full-Scale Fire Testing for Storage Protection under Sloped Ceilings

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• Minimal options for slopes greater than 2:12 (10°) in storage applications
• NFPA 13 guidance for storage applications limited to <2:12
• FM Global Data Sheet 2-0 – <2:12
  • For >2:12
    • Install drop ceiling
    • Install in-racks for up to 4:12 (18°)

• What should guidance be?
Collaborative Effort

Property Insurance Research Group
Project Phases

Phase I
- Numerical modeling
- Survey
- Unobstructed, sloped ceilings
- Spray simulations

Phase II
- Numerical modeling
- Obstructed construction
- Ridges
- Additional sprinklers

Phase III
- Large-scale testing
- Baseline suppression test
- Cold flow spray tests
- Sloped ceiling tests
Sloped Ceiling Setup

- Ceiling
- Main and Target Arrays

- 10°, 18°
- 60 ft
- 10 ft
- 20 ft
Ceiling Inclination

- Inclination causes ceiling jet to travel in upslope direction
  - Biased sprinkler activation pattern
  - Modeling predicted limited extent of ceiling jet in downslope region
    - Particularly for inclinations ≤18° (4:12)
Obstructed Construction

- Purlins can promote early sprinkler operations
  - Confine ceiling jet
- For deeper purlins
  - Flow channeling effect
  - Closing purlin channels possible remedy
Sprinkler Deflector Orientation

- Critical for ceiling inclinations ≥18°

parallel-to-floor

parallel-to-ceiling
Sprinkler Deflector Orientation

- Spray testing
Testing Parameters

- Ceiling inclinations of 10° and 18°
- Obstructed construction
  - Max purlin depth of 18 in.
- Sprinkler deflectors parallel-to-floor
Baseline Large-Scale Test

- Compare sloped ceiling test results
  - Number of sprinkler operations
  - Extent of fire spread

Baseline Test: 0°

Four tier arrays
- 3 sprinkler operations
- Limited damage

Sloped Ceiling: 18°
Ceiling Structure

Video
Large-Scale Tests

- Seven large-scale tests
  - Four tests at 10°
  - Three tests at 18°
- Obstructed construction
  - Sheet-metal purlins and girders
Large-Scale Test Setup

- Sprinklers
  - K-16.8 ESFR
  - Pendent QR, 165°F
  - 35 psig (100 gpm)
  - 10 ft x 10 ft on ceiling
Large-Scale Test Setup

- Main array offset
  - Rack centered among four sprinklers
  - Offset ignition
0°, Ceiling Jet Channeling
18°, 12 in. Purlins, Open Channels

- Purlin channels open at girder locations
- Sprinkler orientation parallel-to-floor
18°, 12 in. Purlins, Open Channels

Test Video
18°, 12 in. Purlins, Open Channels

- 13 sprinkler operations
  - Perimeter sprinklers
- Flow channeling
- Water demand!
- Fire damage around the ignition region
  - Targets ignited but flames were rapidly suppressed
18°, 12 in. Purlins, Closed Channels

- Purlin channels closed at girder locations
- Sprinkler orientation parallel-to-floor
18°, 12 in. Purlins, Closed Channels

Test Video
18°, 12 in. Purlins, Closed Channels

- 7 operations
- Prevented ceiling jet channeling
- Fire damage around the ignition region
  - Limited damage
18°, Unobstructed Ceiling
18°, Unobstructed Ceiling

Test Video
18°, Unobstructed Ceiling

- **10 sprinkler operations**
  - Perimeter sprinklers
    - None on the elevated side
  - Fire damage around the ignition region
    - Limited damage
  - West target ignited but fire was suppressed
## Comparison with Baseline Test

<table>
<thead>
<tr>
<th></th>
<th>0°</th>
<th>10°</th>
<th>10°</th>
<th>10°</th>
<th>10°</th>
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<tbody>
<tr>
<td>Purlin depth (in.)</td>
<td>–</td>
<td>12</td>
<td>12</td>
<td>18</td>
<td>18</td>
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<tr>
<td>Purlin channels</td>
<td>–</td>
<td>Open</td>
<td>Open</td>
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<td>Closed</td>
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<tr>
<td>Deflector parallel to</td>
<td>Floor</td>
<td>Floor</td>
<td>Ceiling</td>
<td>Floor</td>
<td>Floor</td>
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<tr>
<td>First/last sprinkler (min:s)</td>
<td>1:22/1:25</td>
<td>1:22/1:41</td>
<td>1:16/2:32</td>
<td>1:37/10:47</td>
<td>1:23/1:34</td>
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<tr>
<td>Total sprinkler operations</td>
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<td>6</td>
<td>4</td>
<td>9</td>
<td>7</td>
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<tr>
<td>Perimeter operations</td>
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<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Fire spread to array end</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
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<td>1:22/1:25</td>
<td>1:18/3:30</td>
<td>1:14/3:06</td>
<td>1:08/3:48</td>
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<td><strong>Total sprinkler operations</strong></td>
<td>3</td>
<td>10</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td><strong>Perimeter operations</strong></td>
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<td>Yes (?)</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td><strong>Fire spread to array end</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
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Conclusions: Ceiling Inclination

- **10° (2:12 slope)**
  - 1-4 additional sprinkler operations compared to baseline test
  - Non-sloped, unobstructed ceiling protection designs

- **18° (4:12 slope)**
  - 4-7 additional sprinkler operations
  - More challenging protection scenario (unobstructed ceiling)
  - Increase total number of permitted sprinkler operations
Conclusions: Obstructed Construction

- Presence of obstructed construction can be beneficial
  - Mitigating the effect of ceiling slope
  - Deeper purlins can cause ceiling jet channeling
- Closing purlin channels reduces channeling effect
  - 18 in. purlins at 10° (2:12 slope)
  - 12 in. purlins at 18° (4:12 slope)
10° (2:12 slope)
- Current tests showed limited effect of orientation
- For parallel-to-ceiling orientation, core spray moved away from ignition region

18° (4:12 slope), parallel-to-ceiling orientation
- Spray tests conclusively demonstrated spray-core moves toward upslope direction
- Spray modeling showed a 25% reduction in water flux over the fire region compared to parallel-to-floor orientation
**Recommendations**

**Ceiling Inclination**
- Deflector orientation
  - $>0^\circ \& \leq 10^\circ$
    - Parallel-to-floor preferred
  - $>10^\circ \& \leq 18^\circ$
    - Parallel-to-floor

**Purlin Depth**
- $\leq 12 \text{ in.}$
- $>12 \text{ in.} \& \leq 18 \text{ in.}$
- Unobstructed
- $\leq 12 \text{ in.}$

**Recommendation**
- Consider as non-sloped, unobstructed ceiling
- Close purlin channels
- Increase sprinklers in protection design
  - +
- Close purlin channels