Sprinkler Protection of Non-storage Occupancies with High Ceiling Clearance

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Background

- New architectural designs create real fire protection challenges to fire engineers. “The Taller” seems to be “The Better”

- Sprinkler performance and effectiveness in buildings with high roofs and non-storage occupancies such as atria, convention centers, casinos auditoriums, theaters, exposition halls and others, is not well understood.
Introduction – Current Situation

- NFPA
- CEN
- China GB 50084
- Singapore CP 52
- FM
# Test Plan

<table>
<thead>
<tr>
<th>FIRE TEST NUMBER</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial ambient temperature, (°C)</td>
<td>15.0</td>
<td>14.8</td>
<td>13.4</td>
<td>14.3</td>
<td>15.0</td>
</tr>
<tr>
<td>Relative humidity, (%)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>Stack height, (m)</td>
<td>1.63</td>
<td>1.63/1.13*</td>
<td>1.63/1.13*</td>
<td>1.63</td>
<td>1.63</td>
</tr>
<tr>
<td>Main array in term of pallet loads (L × W)</td>
<td>8 × 2</td>
<td>8 × 2</td>
<td>8 × 2</td>
<td>6 × 2</td>
<td>6 × 2</td>
</tr>
<tr>
<td>Target array in term of pallet loads (L × W)</td>
<td>6 × 1</td>
<td>6 × 1</td>
<td>6 × 1</td>
<td>4 × 1</td>
<td>4 × 1</td>
</tr>
<tr>
<td>Cardboard moisture content (%)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>5.2</td>
<td>5.5</td>
</tr>
<tr>
<td>Ceiling height, (m)</td>
<td>12</td>
<td>16</td>
<td>16</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Ceiling clearance, (m)</td>
<td>10.4</td>
<td>14.4</td>
<td>14.4</td>
<td>16.4</td>
<td>16.4</td>
</tr>
<tr>
<td>Deflector to ceiling, (mm)</td>
<td>290</td>
<td>290</td>
<td>290</td>
<td>308</td>
<td>308</td>
</tr>
<tr>
<td>Aisle width, (m)</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Ignition location</td>
<td>Under 1</td>
<td>Under 1</td>
<td>Under 1</td>
<td>Under 1</td>
<td>between 4</td>
</tr>
<tr>
<td>Temperature rating, (°C)</td>
<td>68</td>
<td>68</td>
<td>74</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Sprinkler sensitivity (RTI), (m·s)^{1/2}</td>
<td>105</td>
<td>35</td>
<td>138</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>Sprinkler spacing, (m × m)</td>
<td>3 × 3</td>
<td>3 × 3</td>
<td>3 × 3</td>
<td>3 × 3</td>
<td>3 × 3</td>
</tr>
<tr>
<td>Nominal sprinkler K factor, L/min/(bar)^{3/5}</td>
<td>115</td>
<td>115</td>
<td>161</td>
<td>363</td>
<td>363</td>
</tr>
<tr>
<td>Discharge pressure, (MPa)</td>
<td>0.15</td>
<td>0.25</td>
<td>0.15</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Sprinkler Discharge Rate, (L/min)</td>
<td>141</td>
<td>182</td>
<td>209</td>
<td>363</td>
<td>363</td>
</tr>
<tr>
<td>Estimated Relative Drop Diameter</td>
<td>1.00</td>
<td>0.84</td>
<td>1.13</td>
<td>1.69</td>
<td>1.69</td>
</tr>
</tbody>
</table>
Test Fuel and Fuel Array Arrangement
Sprinkler System

- Sprinkler installed within dot line
- Ignition (Test 5)
- Ignition (Test 1-4)

P : Pressure Gage
Full Scale Fire Test 1

- Fuel Arrangement: Group A Plastics
- Ceiling height: 12 m
- Fuel Height: 1.63 m
- Clearance to ceiling: 10.4 m
- Arrangement of fuel package: 8 by 2, solid pile
- Ignition Location: Under 1 sprinkler
- Density: 15 mm/min (0.37 gpm/sq ft)
- Sprinklers: K115, RTI 105 (m-s)^1/2 Standard Response, Pendent
- Spacing: 3.0 m x 3.0 m
# Full Scale Fire Test 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of test, (min)</td>
<td>7.5</td>
</tr>
<tr>
<td>First sprinkler operation, (min:s)</td>
<td>1:53</td>
</tr>
<tr>
<td>Last sprinkler operation, (min:s)</td>
<td>6:01</td>
</tr>
<tr>
<td>Number of operated sprinklers</td>
<td>12</td>
</tr>
<tr>
<td>Time of ignition across aisle, (min:s)</td>
<td>N/A</td>
</tr>
<tr>
<td>Peak gas temperature at ceiling above ignition, (°C)</td>
<td>228.7</td>
</tr>
<tr>
<td>Maximum 1 minute average gas temperature at ceiling above ignition, (°C)</td>
<td>163.3</td>
</tr>
<tr>
<td>Maximum steel temperature, (°C)</td>
<td>62.6</td>
</tr>
<tr>
<td>Fire travel to end of main array</td>
<td>N/A</td>
</tr>
<tr>
<td>Fire spread across aisles</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Full Scale Fire Test 1

<table>
<thead>
<tr>
<th>Sprinkler</th>
<th>Time (min:s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>1:53</td>
</tr>
<tr>
<td>55</td>
<td>3:22</td>
</tr>
<tr>
<td>35</td>
<td>3:27</td>
</tr>
<tr>
<td>36</td>
<td>3:29</td>
</tr>
<tr>
<td>37</td>
<td>3:32</td>
</tr>
<tr>
<td>56</td>
<td>3:34</td>
</tr>
<tr>
<td>54</td>
<td>3:37</td>
</tr>
<tr>
<td>43</td>
<td>4:05</td>
</tr>
<tr>
<td>34</td>
<td>4:21</td>
</tr>
<tr>
<td>57</td>
<td>4:46</td>
</tr>
<tr>
<td>66</td>
<td>5:47</td>
</tr>
<tr>
<td>47</td>
<td>6:01</td>
</tr>
</tbody>
</table>
Full Scale Fire Test 1

Test 1 - Ceiling gas temperature at Sprinkler 45
Full Scale Fire Test 2

- Fuel Arrangement: Group A Plastics
- Ceiling Height: 16 m
- Fuel Height: 1.63 / 1.13 m
- Clearance to ceiling: 14.4 m
- Arrangement of fuel package: 8 by 2, solid pile
- Ignition Location: Under 1 sprinkler
- Density: 20 mm/min (0.50 gpm/ sq ft)
- Sprinklers: K115, RTI 35 (m-s)^{1/2} Quick Response, Pendent
- Spacing: 3.0 m x 3.0 m
## Full Scale Fire Test 2

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length of test, (min)</strong></td>
<td>7.5</td>
</tr>
<tr>
<td><strong>First sprinkler operation, (min:s)</strong></td>
<td>2:00</td>
</tr>
<tr>
<td><strong>Last sprinkler operation, (min:s)</strong></td>
<td>5:44</td>
</tr>
<tr>
<td><strong>Number of operated sprinklers</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Time of ignition across aisle, (min:s)</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Peak gas temperature at ceiling above Ignition, (°C)</strong></td>
<td>99.5</td>
</tr>
<tr>
<td><strong>Maximum 1 minute average gas temperature at ceiling above ignition, (°C)</strong></td>
<td>62.9</td>
</tr>
<tr>
<td><strong>Maximum steel temperature, (°C)</strong></td>
<td>60.9</td>
</tr>
<tr>
<td><strong>Fire travel to end of main array</strong></td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Fire spread across aisles</strong></td>
<td>Yes</td>
</tr>
</tbody>
</table>
Full Scale Fire Test 2

Figure 7. Sprinkler opening sequence of Test 2.
Full Scale Fire Test 2

Figure 6, Test 2 – Ceiling gas temperatures at Sprinklers 25, 33 and 45.
Full Scale Fire Test 3

- Fuel Arrangement: Group A Plastics
- Ceiling Height: 16 m
- Fuel Height: 1.63 / 1.13 m
- Clearance to ceiling: 14.4 m
- Arrangement of fuel package: 8 by 2, solid pile
- Ignition Location: Under 1 sprinkler
- Density: 23 mm/min (0.58 gpm/sq ft)
- Sprinklers: K161, RTI 138 (m-s)\(^{1/2}\) Standard Response, Pendent
- Spacing: 3.0 m x 3.0 m
# Full Scale Fire Test 3

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of test, (min)</td>
<td>10</td>
</tr>
<tr>
<td>First sprinkler operation, (min:s)</td>
<td>2:44</td>
</tr>
<tr>
<td>Last sprinkler operation, (min:s)</td>
<td>/</td>
</tr>
<tr>
<td>Number of operated sprinklers</td>
<td>1</td>
</tr>
<tr>
<td>Time of ignition across aisle, (min:s)</td>
<td>5:47</td>
</tr>
<tr>
<td>Peak gas temperature at ceiling above Ignition, (°C)</td>
<td>158.7</td>
</tr>
<tr>
<td>Maximum 1 minute average gas temperature at ceiling above ignition, (°C)</td>
<td>103.3</td>
</tr>
<tr>
<td>Maximum steel temperature, (°C)</td>
<td>92.1</td>
</tr>
<tr>
<td>Fire travel to end of main array</td>
<td>No</td>
</tr>
<tr>
<td>Fire spread across aisles</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Full Scale Fire Test 3

Figure 8, Test 3 – Ceiling gas temperatures at Sprinklers 25, 33 and 45.
Full Scale Fire Test 4

- Fuel Arrangement: Group A Plastics
- Ceiling Height: 18 m
- Fuel Height: 1.63 m
- Clearance to ceiling: 16.4 m
- Arrangement of Fuel Package: 6 by 2, solid pile
- Ignition Location: Under 1 sprinkler
- Density: 40 mm/min (1.0 gpm / sq ft)
- Sprinklers: K363, RTI 130 (m-s)\(^{1/2}\) Standard Response, Pendent
- Spacing: 3.0 m x 3.0 m
# Full Scale Fire Test 4

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of test, (min)</td>
<td>30</td>
</tr>
<tr>
<td>First sprinkler operation, (min:s)</td>
<td>3:34</td>
</tr>
<tr>
<td>Last sprinkler operation, (min:s)</td>
<td>/</td>
</tr>
<tr>
<td>Number of operated sprinklers</td>
<td>1</td>
</tr>
<tr>
<td>Time of ignition across aisle, (min:s)</td>
<td>5:17</td>
</tr>
<tr>
<td>Peak gas temperature at ceiling above Ignition, (°C)</td>
<td>120.7</td>
</tr>
<tr>
<td>Maximum 1 minute average gas temperature at ceiling above ignition, (°C)</td>
<td>94.9</td>
</tr>
<tr>
<td>Maximum steel temperature, (°C)</td>
<td>42.2</td>
</tr>
<tr>
<td>Fire travel to end of main array</td>
<td>No</td>
</tr>
<tr>
<td>Fire spread across aisles</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Full Scale Fire Test 4

Figure 9, Test 4 – Ceiling gas temperatures at Sprinklers 44, 45, and 46.
Full Scale Fire Test 5

- Fuel Arrangement: Group A Plastics
- Ceiling Height: 18 m
- Fuel Height: 1.63
- Clearance to Ceiling: 16.4 m
- Arrangement of Fuel package: 6 by 2, solid pile
- Ignition Location: Between 4 sprinklers
- Density: 40 mm/min (1.0 gpm/ sq ft)
- Sprinklers: K363, RTI 130 (m-s)\(^{1/2}\) Standard Response, Pendent
- Spacing: 3.0 m x 3.0 m
# Full Scale Fire Test 5

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of test, (min)</td>
<td>15</td>
</tr>
<tr>
<td>First sprinkler operation, (min:s)</td>
<td>3:11</td>
</tr>
<tr>
<td>Last sprinkler operation, (min:s)</td>
<td>3:15</td>
</tr>
<tr>
<td>Number of operated sprinklers</td>
<td>3</td>
</tr>
<tr>
<td>Time of ignition across aisle, (min:s)</td>
<td>No</td>
</tr>
<tr>
<td>Peak gas temperature at ceiling above Ignition, (°C)</td>
<td>98.4**</td>
</tr>
<tr>
<td>Maximum 1 minute average gas temperature at ceiling above ignition, (°C)</td>
<td>70.0</td>
</tr>
<tr>
<td>Maximum steel temperature, (°C)</td>
<td>31.5</td>
</tr>
<tr>
<td>Fire travel to end of main array</td>
<td>No</td>
</tr>
<tr>
<td>Fire spread across aisles</td>
<td>No</td>
</tr>
</tbody>
</table>
Full Scale Fire Test 5

Figure 10, Test 5 – Ceiling gas temperatures at Sprinklers 45, 46, 55, and 56.
Conclusion

- Effectiveness of sprinkler to control depends on delivered density
- Under 12 m ceiling, K 115 sprinkler at 1.5 bar did not control the fire.
- Under 16 m ceiling, K115 sprinkler at 2.5 bar did not control the fire. A K160 sprinkler marginally controlled the fire at discharge pressure of 1.5 bar.
- Under 18 m ceiling, K363 sprinkler at 1.0 bar generates significantly larger drops and effectively controlled the fire.