Impact of Elevated Walkways on Sprinkler Protection Phase II

Noah L. Ryder, PhD, PE

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Outline

• Background
• Project Goals & Tasks
• Project Progress
• Questions & Discussion
Background

Solid and open metal grates are often installed in aisles as walkways or are also used as mezzanine levels above storage. Minimal information on how these walkway and mezzanine installations impact current storage protection requirements as typical large-scale testing does not include them.

• When is this type of installation considered a problem from a sprinkler protection standpoint (ie water is not delivered to the intended surface)?

• At what point do walkways interfere with pre-wetting of adjacent arrays?
Background: Example Layout
Background: Rack/Mezzanine Configurations

Solid Shelf/Walkway

Solid Shelving

Perforated Shelf/Walkway

Perforated Shelf/Walkway
Project Goals

The objective of this Phase II project is to execute the research plan developed in Phase I in order to develop guidance on protection of storage when solid or open metal grate walkways are present.
Project Tasks

**Task 1: Survey of existing conditions.** FRA will develop a survey and collect information on current warehouse configurations to gain insight into the status quo and to attempt to ascertain how storage protection may be changing.

**Task 2: Sprinkler characterization and modeling of spray/walkways/rack interactions.** This will include baseline scenarios for comparison of the spray pattern development and water delivery and will help determine the range of scenarios to be examined experimentally.

**Task 3: Cold flow experiments** to examine the sprinkler spray characteristics and determination of delivered density to fuel surfaces and storage array faces in a mock storage rack/walkway environment.

**Task 4: CFD modeling of anticipated fire test scenarios** to examine activation and spray distribution; and

**Task 5: Development of a large-scale fire test plan** to fill the identified knowledge gaps in order to complete the development of technical guidance.
Conduct survey to try and gain information about installed storage configurations. Distribute to insurers, owners, etc. Details to include:

• storage configuration;
• stored commodity;
• details of mezzanine/walkway configuration (using definition);
• sprinkler system details;
• loss history (if any);
• and photographs.
Research Plan: Survey Results

- 210 individual respondents

<table>
<thead>
<tr>
<th>ANSWER CHOICES</th>
<th>RESPONSES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Insurer</td>
<td>21.90%</td>
<td>46</td>
</tr>
<tr>
<td>Owner</td>
<td>6.67%</td>
<td>14</td>
</tr>
<tr>
<td>AHJ</td>
<td>21.90%</td>
<td>46</td>
</tr>
<tr>
<td>Designer</td>
<td>30.95%</td>
<td>65</td>
</tr>
<tr>
<td>Contractor/Installer</td>
<td>14.76%</td>
<td>31</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>16.67%</td>
<td>35</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>237</strong></td>
<td></td>
</tr>
</tbody>
</table>
Q3: Storage commodity classification(s) where elevated walkways were encountered. Please select all that apply.

- Class I-IV
- Group A Plastics
- Flammable & Combustible Liquids
- Aerosols
- Unavailable
- Other (please specify)
Q4: Were any of the systems Automated Storage and Retrieval Systems (ASRS)?
Q7: What was the approximate building area encountered containing an elevated walkway? Select all that apply, including from multiple locations.

- 0-20,000 sq. ft.
- 20,000-40,000 sq. ft.
- 40,000-100,000 sq. ft.
- Above 100,000 sq. ft.
- Unknown
Q8: Please identify the storage configuration(s) present when elevated walkways were used. Select all that apply, including from multiple locations.

- Unknown
- Rack
- Palletized
- Solid Piled
- Bin Box
- Shelves
- Back-to-back shelves
- Other (please specify)
Research Plan: Modeling & Testing

4S Characterization

Modeling (CFD)
- Cold Flow
  - Activation
  - ADD
- Hot Flow (fire)
  - Activation
  - Suppression

Testing
- Cold Flow
  - Activation
  - ADD
- Hot Flow (fire)
  - Activation
  - Suppression

Cold Flow informs Hot Flow

* With and Without Obstructions
Research Plan: Mezzanine/Grating Definition
# Research Plan: Modeling & Cold Flow Experiments

<table>
<thead>
<tr>
<th>Modeling Parameters</th>
<th>K-Factor</th>
<th>Sprinkler</th>
<th>Pressure (psi)</th>
<th>$W_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline No Mezzanine</td>
<td>11.2</td>
<td>1</td>
<td>7, 20, 50</td>
<td>NA</td>
</tr>
<tr>
<td>D (in) = 1/4, 3/8, 1/2, 3/4, 1.0</td>
<td>17</td>
<td>2</td>
<td>7, 20, 50</td>
<td>36, 44, 52, 60</td>
</tr>
<tr>
<td>L (in) = 1, 1.5, 2, 3, 4, 5, 6</td>
<td>22</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$W_1$ (in) = 1/8, 1/4, 3/8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$W_S$ (in) = 1/2, 3/4, 1, 1.25, 1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Sprinkler Characterizations

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended Coverage</td>
<td>11.2</td>
</tr>
<tr>
<td>Extended Coverage</td>
<td>11.2</td>
</tr>
<tr>
<td>Storage</td>
<td>14.0</td>
</tr>
<tr>
<td>Storage</td>
<td>16.8</td>
</tr>
<tr>
<td>Storage</td>
<td>16.8</td>
</tr>
<tr>
<td>Storage</td>
<td>19.6</td>
</tr>
<tr>
<td>Storage</td>
<td>22.4</td>
</tr>
<tr>
<td>Storage</td>
<td>25.2</td>
</tr>
</tbody>
</table>
Spray Characterizations: K14 ESFR (35 psi)
Spray Characterizations: K16.8 ESFR (35 psi)
Sprinkler Characterizations: K16.8 (35 psi)

Sprinkler A

Sprinkler B
The simulation uses measured velocity and droplet size to discretely calculate a drop's position in space. At each time step from the original measured velocity, the acceleration is calculated and updates the velocity and position.

The grating is assigned ranges of coordinates based on its specification, if a drop and the grating occupy the same space that drop is removed from the calculation.

\[ \Delta t = \text{time step} \]
\[ X = 0 \]
\[ Y = \text{Height} \]
\[ V_x = \text{Measured velocity} \]
\[ V_y = \text{Measured velocity} \]
\[ a_x = \frac{\frac{1}{2} \rho V_x^2 C_D A}{m} \]
\[ a_y = \frac{\frac{1}{2} \rho V_y^2 C_D A}{m} + G \]
\[ \rho = \text{Density of Air} \]
\[ C_D = 0.47 \text{ for sphere} \]
\[ A = \text{Cross sectional area of drop} \]
\[ m = \text{mass of drop} \]
\[ G = \text{Acceleration due to gravity} \]
```python
# -*- coding: utf-8 -*-

""
Created on Wed Jun 15 12:28:10 2022
""

@Author: Ryan Hutchens

import pandas as pd
import matplotlib.pyplot as plt
import os
import math
import numpy as np

sprinkler_data_path = r'C:\Users\Ryan\Documents\GitHub\Lab-scripts\4S\Elevated Walkways\Sprinkler Data'

sprinkler_list = os.listdir(sprinkler_data_path)

# Distance from sprinkler velocity and DV50 are measured
optical_radius = .6

# Time step resolution for simulation
delt_t = .01 # (sec)

# Height of sprinkler from grate
height = 8 # (ft)

# Grate specifications
depth = 6 # (in)
bearing_bar_thickness = .1875 # (in)
grate_spacing = 1 # (in)
```
Simulation Visualization

Spray visualization represents a 5° wedge of full 360° sprinkler characterization.

Input parameters are supplied by the characterization conducted with the 4S.
### Grate Specifications

<table>
<thead>
<tr>
<th></th>
<th>Height (ft)</th>
<th>Bar Depth (in)</th>
<th>Bar Thickness (in)</th>
<th>Bar Spacing (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>5</td>
<td>1</td>
<td>.25</td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>5</td>
<td>1</td>
<td>.25</td>
<td>2</td>
</tr>
<tr>
<td>c</td>
<td>5</td>
<td>4</td>
<td>.25</td>
<td>1</td>
</tr>
<tr>
<td>d</td>
<td>10</td>
<td>4</td>
<td>.25</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Simulation Visualization

- **a**
- **b**
- **c**
- **d**
$V_x \rightarrow$ Zero, Impact of Drop Size and Velocity

- Velocity from 5-25 m/s
- Drop sizes from 0.5-3mm
Simulation Output

- Each simulation represents a single row of the output. By running the simulation for each azimuthal angle section, a percentage of drops that pass through on their original trajectory is calculated for the entire characterization.

- Using the fraction of water that makes it through the elevated walkway we can scale the volume flux from the original sprinkler characterization.

<table>
<thead>
<tr>
<th>Azimuthal Angle</th>
<th>Elevation Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.87 0.98 0.87 0.92 0.88 0.78 0.79 0.81</td>
</tr>
<tr>
<td>5</td>
<td>0.87 0.98 0.85 0.92 0.86 0.79 0.8 0.75</td>
</tr>
<tr>
<td>10</td>
<td>0.87 0.98 0.83 0.92 0.81 0.87 0.76 0.81</td>
</tr>
<tr>
<td>15</td>
<td>0.87 0.98 0.85 0.86 0.84 0.83 0.77 0.85</td>
</tr>
<tr>
<td>20</td>
<td>0.87 0.96 0.87 0.85 0.81 0.79 0.75 0.8</td>
</tr>
<tr>
<td>25</td>
<td>0.87 0.96 0.91 0.85 0.87 0.76 0.77 0.8</td>
</tr>
<tr>
<td>30</td>
<td>0.87 0.96 0.91 0.87 0.86 0.79 0.7 0.75</td>
</tr>
<tr>
<td>35</td>
<td>0.87 0.96 0.91 0.92 0.85 0.85 0.77 0.8</td>
</tr>
<tr>
<td>40</td>
<td>0.87 0.96 0.91 0.92 0.81 0.87 0.75 0.8</td>
</tr>
<tr>
<td>45</td>
<td>0.87 0.94 0.91 0.86 0.84 0.82 0.78 0.8</td>
</tr>
<tr>
<td>50</td>
<td>0.87 0.94 0.86 0.86 0.85 0.87 0.74 0.8</td>
</tr>
<tr>
<td>55</td>
<td>0.87 0.94 0.91 0.86 0.81 0.79 0.8 0.81</td>
</tr>
<tr>
<td>60</td>
<td>0.87 0.96 0.91 0.85 0.86 0.73 0.71 0.8</td>
</tr>
<tr>
<td>65</td>
<td>0.87 0.96 0.87 0.92 0.86 0.78 0.8 0.85</td>
</tr>
<tr>
<td>70</td>
<td>0.87 0.96 0.87 0.92 0.8 0.86 0.75 0.85</td>
</tr>
<tr>
<td>75</td>
<td>0.87 0.96 0.91 0.91 0.81 0.86 0.79 0.75</td>
</tr>
<tr>
<td>80</td>
<td>0.87 0.96 0.86 0.86 0.87 0.86 0.8 0.81</td>
</tr>
<tr>
<td>85</td>
<td>0.87 0.96 0.86 0.85 0.87 0.78 0.74 0.84</td>
</tr>
<tr>
<td>90</td>
<td>0.87 0.96 0.91 0.84 0.86 0.79 0.79 0.87 0.68</td>
</tr>
</tbody>
</table>
Effect on Volume Flux: K16.8 (35 psi)

**Original Pattern**

<table>
<thead>
<tr>
<th>Height (ft)</th>
<th>Bar Depth (in)</th>
<th>Bar Thickness (in)</th>
<th>Bar Spacing (in)</th>
<th>Volume Passed</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>8</td>
<td>1</td>
<td>0.1875</td>
<td>94.8%</td>
</tr>
<tr>
<td>b</td>
<td>8</td>
<td>6</td>
<td>0.1875</td>
<td>72.0%</td>
</tr>
<tr>
<td>c</td>
<td>20</td>
<td>1</td>
<td>0.1875</td>
<td>96.3%</td>
</tr>
<tr>
<td>d</td>
<td>20</td>
<td>6</td>
<td>0.1875</td>
<td>79.4%</td>
</tr>
</tbody>
</table>
Effect on Volume Flux at Floor

Original Spray Pattern

Spray distribution 15’ below sprinkler

8’ to grate (6” Deep, 1” Spacing)

72% of water volume
FDS Simulation

Simulation Details

- Domain: 2 m x 2 m x 5 m
- Mesh Size: 0.025 m x 0.025 m x 0.025 m
- Heatmap Quantity: Accumulated mass of water per unit area
- Sprinkler Elevation: 4.8 m (centered)
- Walkway Dimensions: 1 m wide / 0.05 m x 0.05 m cross section / 0.05 m gaps
- Walkway Elevation: 2.5 m
- Modeled Sprinkler: K16.8/ 45 psi
Simulation Details

Domain
2 m x 2 m x 5 m

Mesh Size
0.025 m x 0.025 m x 0.025 m

Heatmap
Quantity
Accumulated mass of water per unit area

Sprinkler
Elevation
4.8 m (centered)

Walkway
Dimensions
1 m wide, 0.025 m x 0.05 m bar cross section

Spacing (gaps):
Main: 0.05 m
Cross-member: 0.1 m

Walkway
Elevation
2.5 m
Initial Takeaways

• What % of spray altered is acceptable needs to be determined
• Sprinklers with strong downward central cores (170-190°) less impact to spray
• Smaller droplets (less momentum) transition to primarily vertical velocity component earlier, larger drops later
• Percent open is not only driver of blockage, horizontal component of droplet velocity also what drives obstruction with grating
Ongoing Work

• Additional modeling efforts
  • Trajectory model
  • CFD modeling of additional configurations and fire scenarios

• Spray testing

• Comparison of relative momentums (drop size, observed velocities, and plume velocities) to aid in acceptable reduction determination

• Large-scale test matrix development & ID of additional work
Questions?

Noah L. Ryder
nryder@fireriskalliance.com
301.775.2967