Fire Protection Engineering
FPE 596 Culminating Project
Nolan McCarthy

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Final Presentation
Outline

- Applicable Codes
- Building Description
- Occupancy Classification (building use)
- Construction Type
- Building Area Limitations
- Fire-Resistive Rated Construction Requirements
- High-Pile Combustible Storage Requirements
- Egress Systems
- Performance-Based Design (“PBD”)
Applicable Codes

- 2012 ed. International Fire Code (“IFC”)
- NFPA 10, NFPA 13, NFPA 20, NFPA 24, NFPA 70, NFPA 72, NFPA 204 as referenced by applicable building and fire codes

*http://publicecodes.cyberregs.com/icod/
Building Description (1)

- Single story distribution warehouse
- 1,246,864 square feet (ft²) on ground level
  - Multiple mezzanine levels adding 1,228,259 ft², for total usable space of 2,475,123 ft²
- Roof deck peak at 40 ft above finished floor ("AFF")
Building Description (2)

- Building, as designed, cannot meet the all prescriptions of the building/ fire codes.
- Therefore, the design approach is inherently a hybrid between prescriptive and performance-based [IBC/ IFC §104.10; §104.11].
Occupancy Classification (1)

- Main use of the building is receiving, storage, packaging, sorting, labeling and shipping of ordinary combustible commodities (i.e., Class I-IV with some Group A Plastics)
- IBC: Group S-1 main use, with Group A & B accessory spaces ancillary to the main use
Occupancy Classification (2)
Occupancy Classification (3)
## Construction Type (1)

- Type IIIB Construction [Excerpt of IBC Table 503]

<table>
<thead>
<tr>
<th>GROUP</th>
<th>TYPE OF CONSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TYPE I</td>
</tr>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>UL</td>
</tr>
<tr>
<td>S-1</td>
<td>S</td>
</tr>
</tbody>
</table>
Building Area Limitations (1)

- IBC §507 Unlimited Area Buildings
- §507.3 Sprinklered, one story: includes Group S buildings of other than Type V construction; states that the building area shall not be limited when:
  - Sprinklered per §903.3.1.1; &
  - Surrounded and adjoined by public ways or yards not less than 60 ft in width
Building Area Limitations (2)

- Mezzanines are limited to not more than 1/3 of the ground floor area; allowed to get up to 1/2 with sprinkler protection and emergency voice/ alarm communication system [IBC §505.2.1; Exception 2]
- Building will not comply with prescription of code – aggregate mezzanine about 100% of ground floor area; increased mezzanine area will be included in PBD
# Building Area Limitations (3)

<table>
<thead>
<tr>
<th>AREA DESCRIPTION</th>
<th>FLOOR AREA PER LEVEL (ft²)</th>
<th>NUMBER OF ELEVATED AREAS</th>
<th>TOTAL AREA (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A CENTRAL MEZZANINE</td>
<td>256,039</td>
<td>1</td>
<td>256,039</td>
</tr>
<tr>
<td>B EAST MEZZANINE</td>
<td>243,055</td>
<td>2</td>
<td>486,110</td>
</tr>
<tr>
<td>C WEST MEZZANINE</td>
<td>243,055</td>
<td>2</td>
<td>486,110</td>
</tr>
<tr>
<td>D AGGREGATE MEZZANINE AREA</td>
<td>= A + B + C</td>
<td></td>
<td>1,228,259</td>
</tr>
<tr>
<td>E GROUND LEVEL</td>
<td>1,246,864</td>
<td>N/A</td>
<td>1,246,864</td>
</tr>
<tr>
<td>F MEZZANINE COVERAGE [ = D / E]</td>
<td></td>
<td></td>
<td>99%</td>
</tr>
</tbody>
</table>
Building Area Limitations (4)
Fire-Resistive Rated Construction (1)

- Fire-Resistance Rating Requirements for Building Elements (hours) [Excerpt from IBC Table 601]

<table>
<thead>
<tr>
<th>BUILDING ELEMENT</th>
<th>TYPE III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Primary structural frame</td>
<td>1</td>
</tr>
<tr>
<td>Bearing walls</td>
<td></td>
</tr>
<tr>
<td>Exterior</td>
<td>2</td>
</tr>
<tr>
<td>Interior</td>
<td>1</td>
</tr>
<tr>
<td>Nonbearing walls and partitions</td>
<td>0</td>
</tr>
<tr>
<td>Interior</td>
<td></td>
</tr>
<tr>
<td>Floor construction and associated secondary member</td>
<td>1</td>
</tr>
<tr>
<td>Roof construction and associated secondary member</td>
<td>1</td>
</tr>
</tbody>
</table>
Fire-Resistive Rated Construction (2)

- Accessory spaces are not required to be separated from the main occupancy [Exception to IBC §507.1, & §508.2.4]
- Corridors not required to be of fire-resistance rated construction in sprinklered Group S occupancies [IBC Table 1018.1]
- Interior Exit Stairways are required to be of fire-resistive rated construction that is no less than 1-hour [IBC §1009.2.2; §1022.2]
High-Piled Combustible Storage

- Chapter 32 of the IFC governs high-piled combustible storage
- Automatic fire-extinguishing and fire detection systems; building access (i.e., fire department access); smoke & heat removal; and draft curtains [IFC Table 3206.2]
- Fire department hose connections [§3206.8]
- Aisles [§3206.9]
- Portable fire extinguishers [§3206.10]
Fire Protection Systems (1)
Fire Protection Systems (2)

- Electric motor-driven fire pump rated for 2,000 gpm and 95 psi
Fire Protection Systems (3)
Fire Protection Systems (4)

- High-piled combustible storage is required to be provided with automatic fire-extinguishing system in accordance with §903.3.1.1 (i.e., NFPA 13) [IFC Table 3206.2; §3206.4]
- Roof peak at 40 AFF; worst-case storage commodity/arrangement combination is rack storage of cartoned, unexpanded Group A plastics stored up to 35 ft maximum
- NPFA 13 Table 17.3.3.1: pendent K16.8 ESFR, twelve (12) each operating at no less than 52 psi, with 250 gpm hose stream allowance for 1 hour
Fire Protection Systems (5)
Fire Protection Systems (6)

- Under all the various mezzanines: Mostly Class I-IV with some cartoned, unexpanded Group A plastics
- Extra Hazard (Group 2): 0.40 gpm/ ft² over hydraulically most remote 2,500 ft², with 500 gpm hose stream allowance for 2 hours
- Accessory areas classified and protected per NFPA 13: Ordinary Hazard (Group 2), Light Hazard
- Facility is fully sprinklered
- Aisles all comply with sprinkler protection scheme (e.g., racks) and IFC Section 3206.9
Fire Protection Systems (7)
Fire Protection Systems (8)

- Automatic fire detection system not required [IBC/IFC §907.2.15; IFC Table 3206.2]
- However, sprinkler monitoring system is required [IFC §903.4]
  - All sprinkler valves to be electronically supervised, system risers provided with water flow switches, fire pump fully monitored, etc.
  - Only one exterior audible device required [§903.4.2], but full-area occupant notification being provided as part of PBD
  - One manual pull station provided [IBC/IFC §907.2]
Fire Department Access (1)

- Building access (for fire fighters) is covered in IFC §3206.6
- Fire apparatus roads required within 150 ft of all portions of exterior walls of the building which is used for high-piled combustible storage – i.e., the entire building
- Access doors (typically man-doors no less than 3 ft wide by 6 ft 8 in tall) to be located no more than every 100 lineal ft of exterior walls facing fire apparatus access roads – i.e., the entire building – and locked with approved devices [§3206.6.1.1 thru §3206.6.1.3]
Fire Department Access (2)
Smoke & Heat Removal; Draft Curtains; and Portable Fire Extinguishers

- Smoke and heat vents are not required where ESFR sprinkler systems are utilized [IFC Table 3206.2, note j]
- However, mechanical smoke exhaust will play a role in the PBD
- Draft curtains are not required [IFC Table 3206.2]
- Portable fire extinguishers are provided throughout [IFC §3206.10, §906; NFPA 10]
Egress Systems (1)

- Occupant Load: 6,999 persons
- Occupancy Groups: S-1, A-2, A-3, & B
- Occupant Load Factors ("OLF") per IBC Table 1004.1.2
- LSC OLF for General Industrial Occupancy (100 ft²/ person) is unreasonably high and not indicative of actual use of the space; therefore, 500 ft²/ person, as tabulated in IBC and LSC for storage occupancies is used [LSC 40.1.7; Table 7.3.1.2]
# Egress Systems (2)

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>Area (ft²)</th>
<th>Occupancy Type</th>
<th>Occupant Load Factor (ft²/ person)</th>
<th>Occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse - Ground Level</td>
<td>1,173,709</td>
<td>S-1</td>
<td>500</td>
<td>2,347</td>
</tr>
<tr>
<td>Main Office Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office, Toilet Rooms</td>
<td>23,621</td>
<td>B</td>
<td>100</td>
<td>236</td>
</tr>
<tr>
<td>Breakroom (Large)</td>
<td>7,128</td>
<td>A-2</td>
<td>15</td>
<td>475</td>
</tr>
<tr>
<td>Breakroom (small)</td>
<td>5,561</td>
<td>A-2</td>
<td>15</td>
<td>371</td>
</tr>
<tr>
<td>Training Room (1st Day)</td>
<td>2,031</td>
<td>A-3</td>
<td>20</td>
<td>102</td>
</tr>
<tr>
<td>Training Room (Large)</td>
<td>2,889</td>
<td>A-3</td>
<td>20</td>
<td>144</td>
</tr>
<tr>
<td>Training Room (Small)</td>
<td>830</td>
<td>A-3</td>
<td>20</td>
<td>42</td>
</tr>
<tr>
<td>Lockers</td>
<td>4,496</td>
<td>A-3</td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>Recruiting Office</td>
<td>4,894</td>
<td>B</td>
<td>100</td>
<td>49</td>
</tr>
<tr>
<td>Southwest Entry - Lockers</td>
<td>3,331</td>
<td>A-3</td>
<td>50</td>
<td>67</td>
</tr>
<tr>
<td>Maintenance Area</td>
<td>7,366</td>
<td>B</td>
<td>300</td>
<td>25</td>
</tr>
<tr>
<td>Central Office West</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakroom</td>
<td>1,485</td>
<td>A-2</td>
<td>15</td>
<td>99</td>
</tr>
<tr>
<td>Office, Toilet Rooms</td>
<td>2,775</td>
<td>B</td>
<td>100</td>
<td>28</td>
</tr>
<tr>
<td>Central Office East</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakroom</td>
<td>1,485</td>
<td>A-2</td>
<td>15</td>
<td>99</td>
</tr>
<tr>
<td>Office, Toilet Rooms</td>
<td>2,775</td>
<td>B</td>
<td>100</td>
<td>28</td>
</tr>
<tr>
<td>Truckers' Lounge</td>
<td>1,627</td>
<td>A-2</td>
<td>15</td>
<td>108</td>
</tr>
<tr>
<td>Remote Toilet, Misc.</td>
<td>861</td>
<td>B</td>
<td>100</td>
<td>9</td>
</tr>
<tr>
<td>Total Ground Level</td>
<td>1,246,864</td>
<td></td>
<td></td>
<td>4,318</td>
</tr>
<tr>
<td>Process Mezzanine Level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office, Toilet Rooms</td>
<td>240,300</td>
<td>S-1</td>
<td>500</td>
<td>481</td>
</tr>
<tr>
<td>Equipment Platform</td>
<td>4,123</td>
<td>B</td>
<td>100</td>
<td>41</td>
</tr>
<tr>
<td>Breakroom</td>
<td>8,646</td>
<td>S-1</td>
<td>500</td>
<td>17</td>
</tr>
<tr>
<td>Total Process Mezz. Level</td>
<td>256,039</td>
<td></td>
<td></td>
<td>737</td>
</tr>
<tr>
<td>Mezzanine Level 1</td>
<td>486,110</td>
<td>S-1</td>
<td>500</td>
<td>972</td>
</tr>
<tr>
<td>Mezzanine Level 2</td>
<td>486,110</td>
<td>S-1</td>
<td>500</td>
<td>972</td>
</tr>
<tr>
<td>Total Mezz/ Platform</td>
<td>972,220</td>
<td></td>
<td></td>
<td>1,944</td>
</tr>
<tr>
<td>Total Area</td>
<td>2,475,123</td>
<td></td>
<td></td>
<td>6,999</td>
</tr>
</tbody>
</table>
Egress Systems (3)

- Egress capacity provided for no less than 6,999 persons
- Exits mainly consist of a typical 36-inch wide man-door with 66-inch wide stairs to finished grade level
- Exit capacity factors of 0.2 in/ person for level components, 0.3 in/ person for stairs [IBC 1005.3; LSC 7.3.3.1]
- Limiting component is door (180 persons/ exit)
Egress Systems (4)

- Total of 39 man-doors required to egress occupant load – 1,400 inches of egress capacity = 38.9 exits, rounded up
- Fire fighter access requires many more man-doors along exterior, which will double as exits
- Location requirements will inherently be complied with [IBC §1015.2; LSC §7.5.1.3.2]
- Total egress capacity being provided: 2,376 inches (66 different exits, 12 of which are double-doors)
Egress Systems (5)

- Exit access travel distance (for Group S-1) limited to 250 ft [IBC Table 1016.2; LSC Table A.7.6]
- This Facility, and the operations within it, require more than 250 ft travel distance; therefore, it will not comply 2012 code and extending the travel distance to 400 ft will be included in the PBD
Egress Systems (6)

- Exit Access Stairways are not required to be enclosed since serving 2 stories or less [IBC §1009.3, Exception 1]
- Total of eight (8) interior exit stairways included in means of egress, all 1-hour rated
- Six (6) of these stairways serve the eastern and western multi-level mezzanines and discharge to exterior
- Other two (2) serve central process mezzanine as well as eastern and western mezzanines, discharge to exterior through 1-hour rated exit passageway
- A number of exit access stairways from all mezzanines
Egress Systems (7)
Performance-Based Design (1)

- As previously noted, the building will not meet the prescriptive requirements with respect to allowable mezzanine area; travel distance; and smoke & heat vent provisions.
- Goal of PBD is to show by way of fire & smoke modeling and egress analysis that the intent of the code is met; i.e., the level of safety afforded to occupants is not diminished by not complying with the prescriptive requirements of the code.
A number of fire scenarios are considered but one in particular drives the analysis and will be discussed.
Performance-Based Design (3)

- PBD tenability criteria
  - Toxicity (CO): ≤1,000 ppm
  - Temperature: ≤140°F (60°C)
  - Visibility: ≥33 ft (10 m)
    - With respect to highest occupiable space, which is topmost level of both the eastern and western multi-level mezzanines
      - Critical Height set at 27 ft AFF, which is 6 ft above the highest mezzanine levels [IBC/IFC §909.8.1]
  - Maintain criteria for 20 minutes or 1.5 times calculated egress time, whichever is greater [2015 IBC/IFC §909.4.6]

- First need to define the design fire [IBC/IFC §909.9]
Performance-Based Design (4)

- Ultra-fast $t^2$ fire growth curve is represented by a parabolic curve reaching 1,055 kW in 75 seconds
Performance-Based Design (5)

- Most severe commodity present in Facility will be Group A plastics [IBC/ IFC §909.9.2]
- Conservatively, data in NFPA 204 [Table F.1(a)] for cartoned polystyrene (“PS”) jars was used to develop growth curve for Fire Scenario #1, which reaches 1,055 kW in 55 seconds [IBC/ IFC §909.9.3]
- With ESFR sprinkler protection, it would be expected that HRR would reduce at sprinkler activation (i.e., curve would enter a decay phase), but a steady-state curve is, again, conservative [IBC/ IFC §909.9.4]
Performance-Based Design (6)

- DETACT model approximates sprinkler activation at 139 seconds; HRR ≈ 6,750 kW
Performance-Based Design (7)

- DETACT model approximates sprinkler activation at 139 seconds; HRR $\approx 6,750$ kW
Performance-Based Design (8)

- Adding 30 seconds of growth for conservatism before reaching steady-state without decay

![Fire Scenario #1 HRR vs Time](chart.png)
Next need to consider/ calculate egress time (aka RSET)

Based on calculating occupant load of top-most level of mezzanine, 486 people are considered
Hand calculations used in lieu of any electronic egress models
Performance-Based Design (10)

- DETACT sprinkler activation (i.e., detection): 139 sec, plus 30 sec for conservatism = 169 sec
- Hesitation time of occupants: 60 sec
  - Reasonable for able-bodied employees aware of their surroundings and properly trained [SFPE HB Table 3-12.3]
- Total ‘delay time to start’: 229 sec (≈3.8 min)
- Movement time considers “moderate” parameters [SFPE HB 3-13]
  - 200 ft/ min on level surfaces
  - 14 persons/ min/ ft of effective exit width
Topmost level of mezzanine has four (4) interior exit stairways and several unenclosed stairways. Analysis assumes only three (3) enclosed interior exit stairways are available for occupants.

\[
\frac{400 \text{ ft}}{200 \text{ ft/min}} = 2 \text{ min}
\]

\[
\frac{486 \text{ persons}}{(14 \text{ persons/min- ft}) \times 2 \text{ ft/exit} \times 3 \text{ exits}} \approx 5.8 \text{ min}
\]
Performance-Based Design (12)

- Total egress time is 11.6 min
  
  \[3.8 \text{ min} + 2 \text{ min} + 5.8 \text{ min} = 11.6 \text{ min}\]

- Safety factor of 1.5

- Total egress time (RSET): 17.4 min (1,042 sec)
Performance-Based Design (13)

- FDS model for rack storage scenario (Fire Scenario #1)
Performance-Based Design (14)

- Placed relatively close to corner to simulate smoke banking back towards the space from the exterior walls.
- Fire placed on multiple faces to simulate rack storage fire with HRR described previously – i.e., total HRR/ ft$^2$ spread across enough area to represent PS HRR.
- 52 smoke exhaust fans included, modeled via 4 ft by 4 ft vents [IBC/ IFC §910.3.3], spaced evenly over both eastern and western multi-level mezzanines.
  - 35,000 cfm each.
Performance-Based Design (15)

- CO at 28 ft and 1,200 seconds (20 min)
Performance-Based Design (15)

- Temp. at 28 ft and 1,200 seconds (20 min)
Performance-Based Design (15)

- Visibility at 28 ft at 1,040 seconds (RSET)
Performance-Based Design (15)

- Visibility at 28 ft at 1,200 seconds
Performance-Based Design (16)

- Visibility criteria set at 10 m (33 ft); research shows that occupants familiar with their surroundings can safely egress 4 m (13 ft) of visibility, and those unfamiliar would need 13 m (42.7 ft) of visibility [SFPE HB Table 2-4.2]
References