Overview

I. Building Description

II. Prescriptive Analysis
   ◦ Code Analysis
   ◦ Egress
   ◦ Detection and Alarm
   ◦ Suppression

III. Performance Based Analysis
Building Description

- Location: UC Davis Campus
- Cost: $60,000,000
  - Construction began – 2000
  - First performance – Oct. 2002
- Floor area: 104,000 sqft
- Height: 97.5 ft
- Theaters:
  - Jackson Hall – 1801 max seating
  - Vanderhoef Studio Theater – Up to 250 capacity
- Automatic sprinkler system
- Automatic detection and alarm system with emergency voice alarm/communication system
- Atrium lobby with smoke management system
Relevant Codes

Original Codes
- California Building Code – 1995
- California Fire Code – 1995
- NFPA 13 – 1994
- NFPA 72 – 1993

Project Codes
- California Building Code – 2010
- California Fire Code - 2010
- NFPA 13 – 2010
- NFPA 72 – 2012
Building Occupancy

• Mixed Occupancy

• Main Occupancy Classifications
  • Assembly Group A-1
  • Assembly Group A-3 (Vanderhoef Studio Theater)

• Accessory Occupancies
  • Business
  • Storage

<table>
<thead>
<tr>
<th>Separation Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1 &lt;-&gt; A-3</td>
</tr>
</tbody>
</table>
Building Height and Area

Mixed occupancy classification, most stringent requirements must be used -> A-1.

Original Construction Type: II FR

Current Construction type: IB

<table>
<thead>
<tr>
<th></th>
<th>Allowable</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building height</td>
<td>160+20* ft</td>
<td>97.5 ft</td>
</tr>
<tr>
<td>Stories</td>
<td>5+1*</td>
<td>5</td>
</tr>
<tr>
<td>Area per story</td>
<td>Unlimited</td>
<td>48,000 ft² max.</td>
</tr>
</tbody>
</table>

* Automatic Sprinklers
# Structural Protection

<table>
<thead>
<tr>
<th>Building Element</th>
<th>Required Fire-Resistance Rating (hour)</th>
<th>Applied Fire-Resistance Rating (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary structural frame</td>
<td>2, 1*</td>
<td>2, 1*</td>
</tr>
<tr>
<td>Bearing walls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exterior</td>
<td>2, 1*</td>
<td>2, 1*</td>
</tr>
<tr>
<td>Interior</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Nonbearing walls/partitions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exterior</td>
<td>0, 1</td>
<td>0</td>
</tr>
<tr>
<td>Interior</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Floor construction</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Roof construction</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**CODE ANALYSIS**
# Separation Requirements

## Incidental Accessory Occupancies

<table>
<thead>
<tr>
<th>Room/Area</th>
<th>Req. Separation</th>
<th>Applied Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire Pump Room</td>
<td>2-hr; or 1 hr w/ fully sprinklered</td>
<td>2-hr fire barrier and sprinklers</td>
</tr>
<tr>
<td>Storage rooms &gt;100 sqft</td>
<td>1-hr or auto fire-extinguishing system</td>
<td>Sprinklers</td>
</tr>
<tr>
<td>Furnace Room</td>
<td>1-hr or auto fire-extinguishing system</td>
<td>Sprinklers</td>
</tr>
</tbody>
</table>

## Egress

<table>
<thead>
<tr>
<th>Space</th>
<th>Req. Separation</th>
<th>Applied Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridors</td>
<td>1-hr or 0-hr w/ Fully Sprinklered</td>
<td>1-hr fire partition</td>
</tr>
<tr>
<td>Horiz./Vert. Exit Enclosures</td>
<td>2-hr fire barrier</td>
<td>2-hr fire barrier</td>
</tr>
</tbody>
</table>

## Special Situations

<table>
<thead>
<tr>
<th>Space</th>
<th>Req. Separation</th>
<th>Applied Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrium &lt;-&gt; Rest of building</td>
<td>1-hr fire barrier or horiz. assembly</td>
<td>1-hr constr. 20-min. doors</td>
</tr>
<tr>
<td>Proscenium wall</td>
<td>2-hr construction</td>
<td>2-hr fire barrier</td>
</tr>
<tr>
<td>Stage to adjacent spaces</td>
<td>2-hr fire barrier</td>
<td>2-hr fire barrier*</td>
</tr>
<tr>
<td>Adjacent &lt;-&gt; adjacent spaces</td>
<td>1-hr fire barrier</td>
<td>1-hr fire barrier</td>
</tr>
</tbody>
</table>
Special Requirements

Atrium

- Approved Sprinkler system throughout building
- Fire alarm system with detection throughout atrium and emergency voice alarm/communication system
- Smoke control system

Stage

- Standpipe system
  - Class III with 1-1/2” and 2-1/2” hose connections on each side of stage
- Emergency ventilation
  - Roof vents >5% stage area or smoke control system
## Egress Analysis

<table>
<thead>
<tr>
<th>Use</th>
<th>Load Factor (ft²/occupant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly – Fixed</td>
<td>See note</td>
</tr>
<tr>
<td>Assembly – Standing</td>
<td>5 net</td>
</tr>
<tr>
<td>Assembly – Concentrated</td>
<td>7 net</td>
</tr>
<tr>
<td>Assembly – Unconcentrated</td>
<td>15 net</td>
</tr>
<tr>
<td>Stage</td>
<td>15 net</td>
</tr>
<tr>
<td>Business</td>
<td>100 gross</td>
</tr>
<tr>
<td>Storage</td>
<td>300 gross</td>
</tr>
</tbody>
</table>

Assembly – Fixed seating: Number of seats + wheel chairs and non-fixed seating in accordance with Table 1004.1.1
## Egress Analysis

<table>
<thead>
<tr>
<th>Location</th>
<th>Floor Area (ft²)</th>
<th>Load Factor (ft² per person)</th>
<th>Load</th>
<th>Limiting Door/Stair Exit Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lobby</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Floor</td>
<td>8,615</td>
<td>5</td>
<td>1,725</td>
<td>3,105</td>
</tr>
<tr>
<td>2nd Floor</td>
<td>4,500</td>
<td></td>
<td>900</td>
<td>560</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>5,949</td>
<td></td>
<td>1,190</td>
<td>761</td>
</tr>
<tr>
<td>Jackson Hall Seating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orchestra/Parterre</td>
<td>580</td>
<td># seats, 7, 100</td>
<td>1,179</td>
<td>1309</td>
</tr>
<tr>
<td>First Balcony</td>
<td>580</td>
<td></td>
<td>393</td>
<td>400</td>
</tr>
<tr>
<td>Second Balcony</td>
<td>300</td>
<td></td>
<td>364</td>
<td>400</td>
</tr>
<tr>
<td>Studio Theater</td>
<td>3,334</td>
<td># seats, 7, 15</td>
<td>335</td>
<td>390</td>
</tr>
<tr>
<td>Stage</td>
<td>9,500</td>
<td>15, 300, 100</td>
<td>498</td>
<td>675</td>
</tr>
<tr>
<td>Back of House</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Floor</td>
<td>6,000</td>
<td>7, 15, 100, 300</td>
<td>718</td>
<td>756</td>
</tr>
<tr>
<td>2nd Floor</td>
<td>1,500</td>
<td></td>
<td>96</td>
<td>329</td>
</tr>
<tr>
<td>Basement</td>
<td>2,700</td>
<td>7, 15, 100, 300</td>
<td>107</td>
<td>467</td>
</tr>
</tbody>
</table>
Fire Detection and Alarm

- Addressable Emergency Voice Alarm/Communication System
  - Manual and automatic detection
  - Visual/voice notification
- Proprietary Supervising Station
  - UCD Police Department Communications Center
- Control Panels
  - Main Fire Alarm Control Panel
  - Voice Evacuation Panel
  - Fire Fighter’s Control Panel
  - 2 – Remote Fire Alarm Power Supply
  - Smoke Control Panel
  - 4 – Fire Alarm Annunciator Panel
## Detection

<table>
<thead>
<tr>
<th>Initiating Device</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual pull stations</td>
<td>&lt;5 ft from exits, &lt;200 ft from any location</td>
</tr>
<tr>
<td>Photoelectric smoke detectors</td>
<td>Throughout occupiable space, Except studio theater/stage zone/audience chamber zone</td>
</tr>
<tr>
<td>Additional smoke detectors</td>
<td>• Elevator lobbies&lt;br&gt;• Above automatic closing/holding doors</td>
</tr>
<tr>
<td>Heat and smoke detectors</td>
<td>Elevator equipment rooms/boiler room</td>
</tr>
<tr>
<td>Ionization smoke detectors</td>
<td>Supply/return air ducts</td>
</tr>
<tr>
<td>Sprinkler water flow switches/tamper switches</td>
<td>Pump room/each zone riser/exterior O.S.&amp;Y. Valves</td>
</tr>
<tr>
<td>Beam detector</td>
<td>Lobby atrium</td>
</tr>
</tbody>
</table>
Beam detection (30%): 37 seconds
Spot type detection: 26 seconds
## Notification

<table>
<thead>
<tr>
<th>Notification Appliance</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall/ceiling mounted speakers</td>
<td>All occupied spaces except some small offices and some storage rooms</td>
</tr>
<tr>
<td>Wall mounted synchronized strobes</td>
<td>All occupied spaces except some small offices and some storage rooms</td>
</tr>
<tr>
<td>Fire sprinkler exterior bell</td>
<td>West exterior wall</td>
</tr>
</tbody>
</table>
Fire Sprinkler System

- Total building area >52,000 ft²
  - Split into zones

Water Supply

- Campus water supply
  - Static Pressure: 65 psi
  - Residual Pressure: 20 psi
  - Flow: 16,825 gpm

- Pump
  - Flow: 750 gpm
  - Net Pressure at 150% capacity: 61 psi
  - Max. net pressure developed: 97 psi
Design Basis

- Density/area method

<table>
<thead>
<tr>
<th>Zone</th>
<th>Occupancy Classification</th>
<th>Density (gpm/ft²)</th>
<th>Area (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OH (GRP 1)</td>
<td>0.15</td>
<td>1500</td>
</tr>
<tr>
<td>3</td>
<td>OH (GRP 2)</td>
<td>0.20</td>
<td>1500</td>
</tr>
<tr>
<td>2, 4, 5, 6</td>
<td>Light Hazard</td>
<td>0.10</td>
<td>1500</td>
</tr>
</tbody>
</table>

- 250 gpm required hose stream allowance
- 60 minute required water supply duration for OH with full supervision

Most hydraulically demanding
  - Zone 4: Audience Chamber
  - Extended coverage sprinklers
    - Design for 5 sprinklers or 1,500 ft², whichever is highest
  - 20 ft spacing
Required Flow: 406 gpm
Required Pressure: 132.2 psi
Total: 721 gpm at 132.2 psi
Performance Based Analysis

Available Safe Egress Time (ASET) > Required Safe Egress Time (RSET)

Time available to escape > Time needed to escape

Tenability requirements:

- Visibility > 10 meters
- Temperature < 60° C
- CO conc. < 950 ppm
- Heat Flux < 2.5 kW/m²
## Required Safe Egress Time

<table>
<thead>
<tr>
<th>Detection + Alarm Time</th>
<th>Pre-movement Time</th>
<th>Movement Time</th>
<th>Safety Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDS Est. + 20 s</td>
<td>60 s</td>
<td>Pathfinder Est.</td>
<td>1.5</td>
</tr>
<tr>
<td>British Standard</td>
<td></td>
<td></td>
<td>CBC 909.4.6</td>
</tr>
<tr>
<td>PD7974-6:2004</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Lobby Fire Scenario

- Location: 4 story lobby atrium
- Fuel package: Backpacks, coat rack
- Occupant load: Fully loaded lobby
- Fire protection systems:
  - Full smoke detection
  - Full automatic sprinklers
  - Mechanical exhaust system
    - Exhaust: Two 77,000 CFM exhaust fans
    - Make-up air: Lobby doors, mechanical air supply
Lobby Fire Scenario

- Location: Coat check area
- Fire size: $t^2$ HRR until sprinkler activation
- Smoke control activated by smoke detection or sprinkler activation
PERFORMANCE BASED ANALYSIS
\[
R = \sqrt{\frac{Q_r}{4\pi q_{r,t}''}} = \sqrt{\frac{(800 \text{ kW})(0.3)}{4\pi (2.5 \text{ kW/m}^2)}}
\]

\[R = 2.8 \text{ m} = 9 \text{ ft}\]

\[R_{SF} = 9 \text{ ft} \times 2 = 18 \text{ ft}\]
Lobby Fire – Concerns
Lobby Design Fire

- Sprinkler activation time:
  - DETACT: 120 s
  - FDS: 130 s -> HRR = 800 kW

- FDS estimated smoke detection time: 21 s
Lobby Fire – FDS Analyses
CO Concentration at 600s

1st Floor

2nd Floor

3rd Floor

4th Floor

(PPM)
Temperature at 600s

1st Floor

2nd Floor

3rd Floor

4th Floor

(°C)
Visibility at 600s

1st Floor

2nd Floor

3rd Floor

4th Floor
Visibility at 225s
Lobby Fire—Pathfinder Analysis
Pathfinder Simulation at 39s
# Lobby Fire – ASET vs. RSET

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Detection and Alarm</th>
<th>Pre-movement</th>
<th>Movement</th>
<th>CBC Factor</th>
<th>RSET</th>
<th>ASET</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd Floor</td>
<td>21 + 20</td>
<td>60</td>
<td>39</td>
<td>1.5</td>
<td>210</td>
<td>225</td>
</tr>
<tr>
<td>3rd Floor</td>
<td>39</td>
<td>39</td>
<td></td>
<td></td>
<td>210</td>
<td>225</td>
</tr>
</tbody>
</table>

- **2nd Floor balcony**
- **3rd Floor balcony**
- **The rest of the lobby**

![Graph showing the required and available capacity for different scenarios.](image-url)
Recommendations

• Modify make-up air flow into the 2nd floor lobby.
  • Double the flow showed tenable conditions
  • Remove make-up air flow showed tenable conditions

• Move coat check

• Mondavi already has plans
Stage Fire Scenario

- Location: 45 ft tall storage area behind 87 ft tall stage
- Occupant load: Fully loaded theater seating and stage
- Fire protection systems:
  - Fully sprinklered
  - Heat activated ceiling vents
  - Manual/heat activated proscenium curtain
PERFORMANCE BASED ANALYSIS
Stage Fire - Design Fire

- Location: Storage area at the back of the stage
- Fire size: $t^2 \text{ HRR}$ until calculated maximum HRR
- Heat activated sprinklers, roof vents, proscenium curtain
- Smoke detection above storage room door
- Minimum tenable distance:

$$R = \sqrt{\frac{Q_r}{4\pi q_{r,t}}} = \sqrt{\frac{(4000 \text{ kW})(0.3)}{4\pi(2.5 \text{ kW/m}^2)}}$$

$$R = 6.2 \text{ m} = 20 \text{ ft}$$

$$R_{SF} = 20 \text{ ft} \times 2 = 40 \text{ ft}$$
Stage Fire - Fuel Package

- Stored rack full of electrical cables for stage equipment
- HRR calculated from correlations provided by Lee for cable trays.

\[ \dot{q}_{fs} = 0.45 \dot{q}_{bs} A \]

\[ \dot{q}_{fs} = 0.45 \left( \frac{589 \text{ kW}}{m^2} \right) (15 \text{ m}^2) \]

\[ HRR = 4000 \text{ kW} \]
• Sprinklers do not activate
• Roof vent fusible links do not activate
• Proscenium fusible links do not activate
• Smoke detection at 160s
CO Concentration at 1200s

2nd Floor Balcony

Stage Floor

(PPM)
Temperature at 1200s

2nd Floor
Balcony

Stage Floor
Visibility

2nd Floor Balcony

Stage Floor

415 s

445 s

750 s

800 s
Last occupant enters exit at 404 seconds.
Stage Fire – Pathfinder Analysis

Last occupant exits the space at 234 seconds.
## Stage Fire – ASET vs. RSET

<table>
<thead>
<tr>
<th>Location</th>
<th>Detection and Alarm</th>
<th>Pre-movement</th>
<th>Movement</th>
<th>CBC Factor</th>
<th>RSET</th>
<th>ASET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage</td>
<td>160 + 20</td>
<td>60</td>
<td>234</td>
<td>1.5</td>
<td>711</td>
<td>750</td>
</tr>
<tr>
<td>Seating</td>
<td>404</td>
<td></td>
<td></td>
<td></td>
<td>966</td>
<td>415</td>
</tr>
</tbody>
</table>

### Graph

- **Stage**:
  - Required: 711
  - Available: 750

- **2nd Balcony**:
  - Required: 966
  - Available: 415
Recommendations

• Improve stage smoke detection
  • Stage ceiling smoke detectors reduced activation time by about 50%
  • Detection time reduced from 160 to 77 seconds

• Optimized travel time using Pathfinder:
  • Optimized seating egress: 25% travel time reduction
  • 1st Floor Balcony egress through atrium: 30% further travel time reduction
  • Travel time reduced from 404 to 210 seconds

• Total RSET reduced from 966 to 550 seconds

• Do not use shell storage space as miscellaneous storage
Thank you

Questions or Comments?