ALIGNING ARCHITECTURAL VISION AND FIRE SAFETY STRATEGIES IN SUPER TALL BUILDINGS

Aaron F. Vanney, P.E., LEED® AP
Associate Manager - International
Rolf Jensen & Associates, Inc.

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Adrian Smith + Gordon Gill Architecture

Rolf Jensen & Associates, Inc.
FIRE PROTECTION CONSULTANTS

ASGG
Introduction

- Evolution of Current Practices
- Contemporary Design: Kingdom Tower
- Future Directions in High Rise Fire Safety
- Regulatory Issues
- Operational Issues
- Conclusions
Evolution of Current Practices

- Codes and Regulations
- Refuge Floors
- Evacuation Elevators
- Structural Fire Safety
- Fire Protection Water Supply
Codes and Regulations

Post-1945 Expansion of High Rise Construction in US

“Model Codes” Add Specific Provisions for High Rises

1975 Chicago Building Code - High Rise Chapter 13:

- Automatic Sprinklers
- Standpipes
- Occupant and Fire Dept. Voice Communications
- Stairway Unlocking
Refuge Floors

U.S. High Rise Design 1970’s and 80’s

• Active Suppression to Control Fire Growth
• Fire Rated Building Structure
• Each Floor is an Area of Refuge
• Evacuation Sequence – Fire Floor, 2 Above, 1 Below – Evacuate “4 Floors Down”
Refuge Floors

Petronas Towers – 1998

- Active Suppression and Smoke Management Systems
- Use of Sky Lobby and Sky Bridge as Refuge Areas
- Evacuation Sequence – Occupants could exit from either tower by means of sky bridge
Refuge Floors

Jin Mao Tower – 1999

- Active Suppression and Smoke Management
- Refuge Floors required by China Code every 15 floors
  - Office – Refuge Areas on Office Floors
  - Hotel – Refuge Areas Every Floor
- Stairs are Interrupted at Refuge Floors – Office Floors
Refuge Floors

Burj Khalifa – 2010

- Active Suppression and Smoke Management Systems
- Fire Rated Building Structure
- Refuge Areas coordinated with MEP floors
- Refuge Areas sized for Partial Occupant Load
- Stairs are Interrupted at Refuge Floors
Evacuation Elevators

• Petronas Towers- 1998
  • How can Elevators Be Used for Evacuation
  • Refuge Areas Combined with Sky Lobbies
  • Elevators could be Used Safely from Sky Lobbies
  • Time Evacuation Calculation Including Elevators
Evacuation Elevators

- Burj Khalifa - 1999
- Shanghai Tower - 2004
- Wuhan Tower - 2012
  - Shuttle Elevators with Protection Features
    - Resistant to Water Infiltration
    - Emergency Power
  - Limited stops – Lobby to Refuge Floor or Sky Lobby
  - Operated by Trained Staff
Evacuation Elevators

• First Codified into Building Regulations in IBC 2012
• Provisions for Self Evacuation Elevators as an Alternative to Additional Stairway.
  • Self Evacuation – For Occupant Use with No Attendant
  • Available Prior to Phase 1 Recall
  • Signage to Notify if Elevators are Available for Egress
  • Applies to “All” Elevators in High Rise Building
• Implemented Selectively in U.S.
Structural Fire Resistance

• Robust Structural Frame
  • Resistant to Progressive Collapse
  • Resistant to Impact Loads
  • IBC Provisions for Impact Resistant Materials for Core Elements
• Critical Life Safety Elements “Protected within Core Elements”
  • Cores are typically Reinforced Concrete
  • Life Safety Features – Stairs, Fire & Evacuation Elevators, Fire Suppression risers and Fire Alarm & Communications Riser – Are Protected within the Core Construction
Structural Fire Resistance - Sears Tower
Structural Fire Resistance - Sears Tower
Structural Fire Resistance - Sears Tower
Structural Fire Resistance - Jin Mao
Critical Life Safety Elements:

- Stairs
- Firemen’s Elevators
- Fire Alarm and Emergency Power Risers
- Smoke Control Risers
Structural Fire Resistance - Wuhan
Structural Fire Resistance - Wuhan
Structural Fire Resistance - Wuhan

- Composite Super Column
- Composite Floor Beam
- Concrete Core
- Composite Deck

Thornton Tomasetti
Structural Fire Resistance - Codes

Recent Changes to International Building Code:

- Impact Resistant Materials for Core Elements
- Increased Bond Strength for Fire Protection Materials for Structural Steel
Fire Protection Water Supply

- Gravity Fed Water Supply from Tanks
  - Reliability of Public Water Supply
  - Simplicity and Reliability
  - Redundancy
- Multiple Fire Protection Water Supply Risers
- Protection of Risers within Core Elements
Fire Protection Water Supply - Burj Khalifa

Primary Storage Tank Level B2
2 Hour Capacity – 425,000 Liters

Separate Storage Tank for Outside Hydrants – 2,311,000 Liters
Fire Protection Water Supply- Burj Khalifa

Water is Pumped to Tank on Level 74
1 Hour Capacity

Primary Storage Tank Level B2
2 Hour Capacity
Fire Protection Water Supply- Burj Khalifa

Water is Pumped to Tank on Level 74
1 Hour Capacity

Water by gravity fills Tank on Level 40
1 Hour Capacity

Primary Storage Tank Level B2
2 Hour Capacity
Fire Protection Water Supply - Burj Khalifa

- **Primary Storage Tank Level B2**
  - 2 Hour Capacity

- Water is Pumped to Tank on Level 74
  - 1 Hour Capacity

- Water by gravity fills Tank on Level 109
  - 1 Hour Capacity

- Water is Pumped to Tank on Level 137
  - 1 Hour Capacity

- Water by gravity fills Tank on Level 40
  - 1 Hour Capacity

- Level 40

- Level 109

- Level 74

- Level 137

- B2
Fire Protection Water Supply - Jin Mao

Combined Water Tanks and Pumps - level 92

Combined Water Tanks and Pumps - level 50

Fire Department Inlet and Tank Fill Riser Pumps - Basement levels
Contemporary Design: Kingdom Tower

- Located in Jeddah, KSA
- Part of Kingdom City Development
- Mixed-Use
  - Office
  - Hotel
  - Residential
  - Observation Levels
- GFA: 320,000 SM
- Height: 1,000+ Meters
Kingdom Tower – Building Program

<table>
<thead>
<tr>
<th>LEVELS</th>
<th>PROGRAM</th>
<th>AREA</th>
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</thead>
<tbody>
<tr>
<td>LEVEL 157 – 159</td>
<td>Observatory &amp; Sky Terrace</td>
<td>1,583 m²</td>
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<tr>
<td>LEVEL 126 – 153</td>
<td>Void Space – No Occupancy</td>
<td>1,618 – 1,167 m²</td>
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<tr>
<td>LEVEL 99 - 120</td>
<td>Residential – Group 4</td>
<td>1,552 – 1,143 m²</td>
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<td>LEVELS 87 – 94</td>
<td>Residential – Group 3</td>
<td>1,572 – 1608 m²</td>
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<td>LEVELS 73 – 83</td>
<td>Residential – Group 2</td>
<td>1,841 – 1,698 m²</td>
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<td>LEVELS 44 – 67</td>
<td>Residential – Group 1</td>
<td>2,094 – 1,893 m²</td>
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<tr>
<td>LEVELS 27 – 37</td>
<td>Service Apartments</td>
<td>2,057 – 2,120 m²</td>
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<tr>
<td>LEVELS 20 – 26</td>
<td>Hotel Guest Rooms</td>
<td>2,148 – 2,269 m²</td>
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<td>LEVELS 7 – 14</td>
<td>Office</td>
<td>2,756 – 2,682 m²</td>
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<td>LEVELS B2 - 6</td>
<td>Lobbies, Hotel Function Spaces, Spa</td>
<td>14,992 – 2,757 m²</td>
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<td>LEVELS B3 – B1</td>
<td>Parking</td>
<td>47,718 - 20,511 m²</td>
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Basis of Design Approach

• Local Codes – To the Extent Feasible
• International Standards
  • International Building Code
  • NFPA
• Enhancements
  • Structural Fire Resistance
  • Refuge Areas
  • Elevator Evacuation
  • Fire Protection Water Supply
**Basis of Design - Comparative Code Matrix**

### Comparative Building Code Matrix

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<td><strong>Occupancies</strong></td>
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<td>Group A - Manufacturing</td>
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<td>Group B - Business</td>
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<tr>
<td>Group C - Residential (Including Townhouses, Semi-Detached, Rowhouses, and Detached Houses)</td>
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<td><strong>Means of Egress</strong></td>
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<td>Emergency Exit</td>
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Basis of Design - Why IBC & NFPA?

• Consensus Standards developed by Design Community and Fire Service

• Adopted Locally – Tailored to Local Norms

• Updated Every Three Years to Reflect Application Experience

• Recognized World Wide
Basis of Design Approach-
Intensive Input By Local Authorities
Refuge Floors

- Located Every 20 Floors
- Full Floor Refuge Areas
- Stairs are Discontinuous at Refuge Floors
- Refuge Floors are Mechanically Pressurized
- A Fire Officer is Resident in Each Refuge Floor
- Queuing Point for Evacuation Elevators
Refuge Floors
Evacuation Elevators

Kingdom Tower “Lifeboat” Elevators

• High Speed Shuttle Elevators For Evacuation
• Emergency Power & Protection Features
• Lifeboat Elevators Serve Refuge Floors
• Reduce Total Building Evacuation to < 2 Hours

<table>
<thead>
<tr>
<th>Lifeboat Shuttle</th>
<th>Service</th>
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<tbody>
<tr>
<td>Observation Shuttles OB1, OB2</td>
<td>Floors 154, 104</td>
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<tr>
<td>Residential Shuttles R4, R5, R6</td>
<td>Floors 86, 71, 56</td>
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<tr>
<td>Residential Shuttles R1, R2, R3</td>
<td>Floor 38, 18</td>
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Structural Fire Safety
Structural Fire Safety
Fire Protection Water Supply

Fire Protection Water Tanks are Filled by Fill Pumps

- Level 165 Water Tanks – 2 Hours
- Level 122 Water Tanks – 1 Hour
- Level 96 Water Tanks – 1 Hour
- Level 69 Water Tanks – 1 Hour
- Transfer Pumps & Fill Lines
- Level 40 Water Tanks – 1 Hour
- Level 16 Water Tanks – 1 Hour
- B3 Level Water Storage Tanks – 2 Hours
Fire Protection Water Supply

Fire Protection Water Tanks Supply Sprinkler & Standpipe Systems by Gravity

- Level 165 Water Tanks – 2 Hours
- Level 122 Water Tanks – 1 Hour
- Level 96 Water Tanks – 1 Hour
- Level 69 Water Tanks – 1 Hour
- Transfer Pumps & Fill Lines
- Level 40 Water Tanks – 1 Hour
- Level 16 Water Tanks – 1 Hour
- B3 Level Water Storage Tanks – 2 Hours
Fire Protection Water Supply

232,321 Gallons of Water Storage, Up to 90 Minutes Protection

- High Level Tank
- Gravity Express Risers
- Local Zones Gravity Down – Low Pressure through PRV’s
- Intermediate Tanks
- Express Fill Line Up
- Main Water Storage Tanks
- Transfer Pumps
Future Directions in High Rise Fire Safety

• Active Systems for Fire Control, Smoke Management and Evacuation
• Increased Structural Fire Resistance & Robustness
• Reliable and Redundant Fire Safety Systems
• Integration of Design, Construction and Operations
Regulatory Framework

• Local Codes are always the Starting Point
  • May use International Norms as Benchmark

• International Standards & Practices
  • IBC & NFPA
  • Systems, components and materials

• Building Enhancements
  • Refuge floors & Evacuation Elevators
  • Reliability & Redundancy Features
Operational Aspects

Building Operation and Maintenance
- Adequate Staffing and Training
- Maintenance of Life Safety Systems

Crisis Management Plan
- Define Threats
- Pre-Planned Response Procedures
- Training

Security Issues
Crisis Management Plan

SPECIFIC PROCEDURES DEVELOPED FOR THE VARIOUS CRISES
Conclusions

• Buildings will continue to grow taller
• This will push our technologies in all areas, especially fire safety
• More Active & Passive Protection
• Design, Construction, Operations
Thank You

Aaron F. Vanney, P.E., LEED® AP
Associate Manager - International
Rolf Jensen & Associates, Inc.
avanney@rjagroup.com