ALIGNING ARCHITECTURAL VISION AND FIRE SAFETY STRATEGIES IN SUPER TALL BUILDINGS

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Special Thanks to:
Adrian Smith + Gordon Gill Architecture

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"

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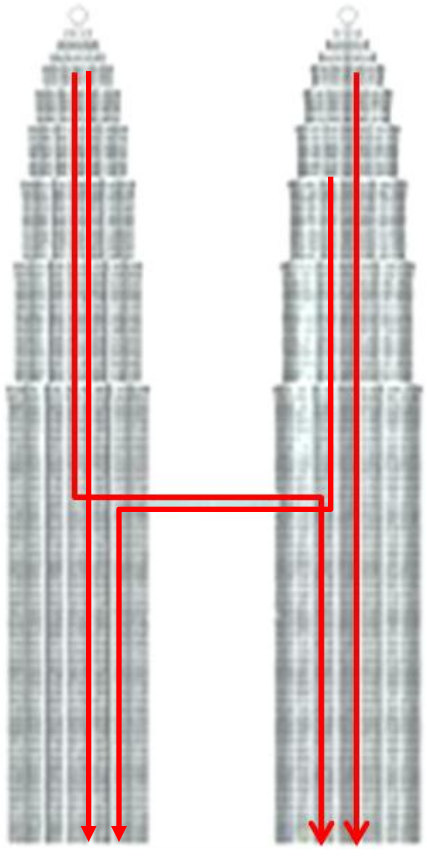
Refuge Floors

Petronas Towers – 1998

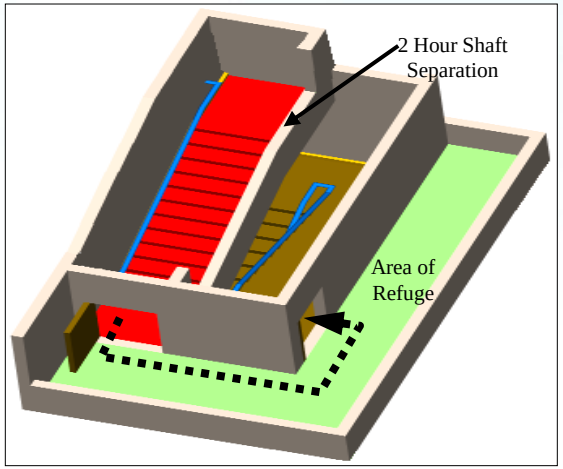
- Active Suppression and Smoke Management Systems
- Use of Sky Lobby and Sky Bridge as Refuge Areas
- Evacuation Sequence – Occupants could exit from either tower by means of sky bridge



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



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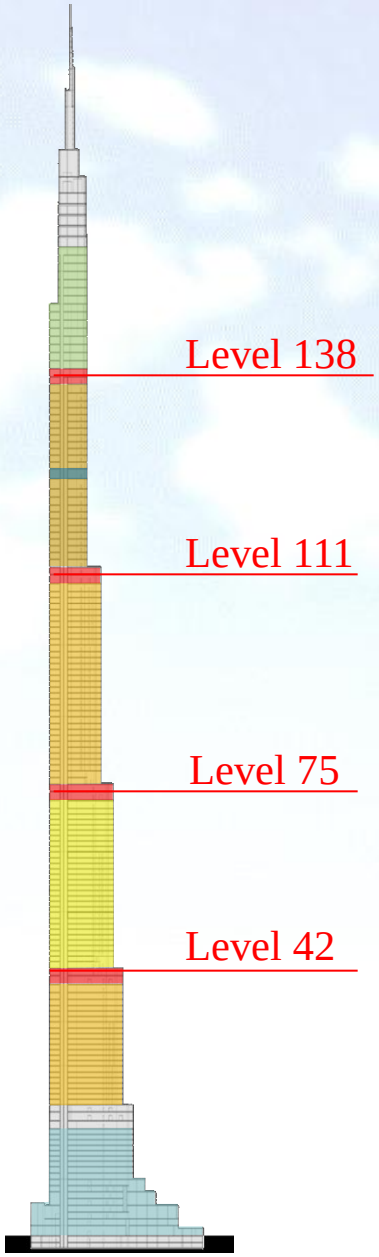
Refuge Floors

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



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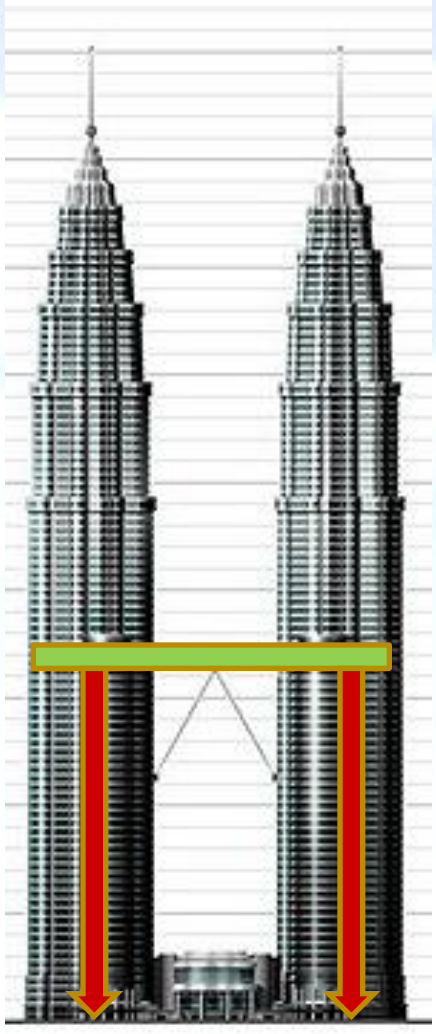
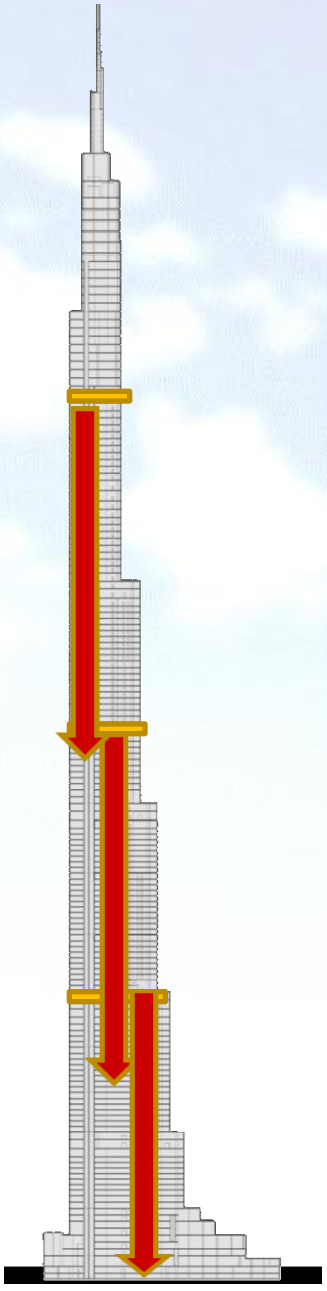
Evacuation Elevators

- 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



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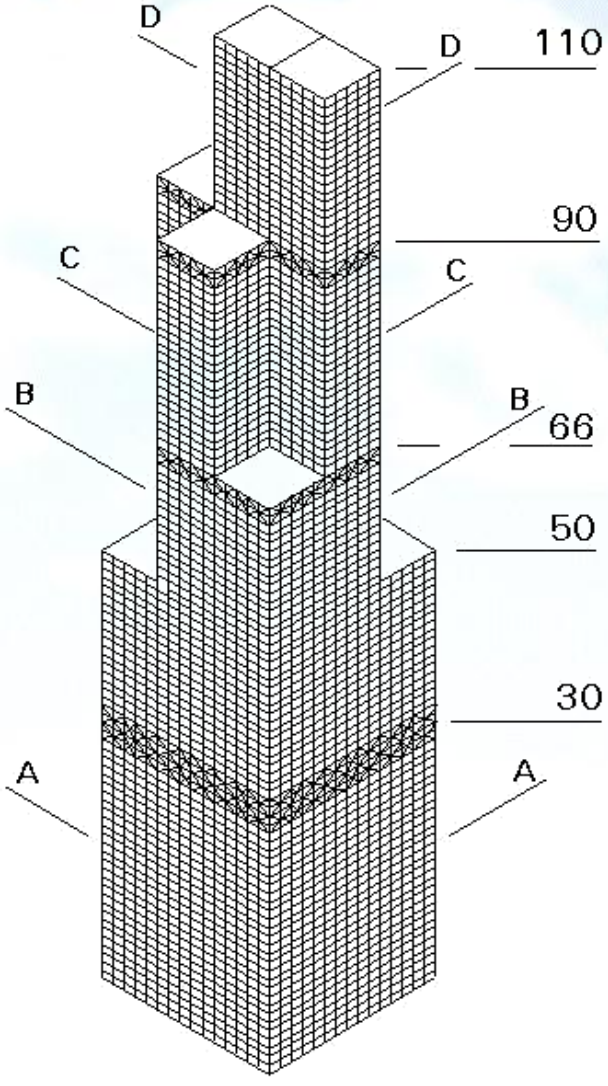
Evacuation Elevators

- 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



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Structural Fire Resistance- Sears Tower

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Structural Fire Resistance- Sears Tower

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Structural Fire Resistance- Jin Mao

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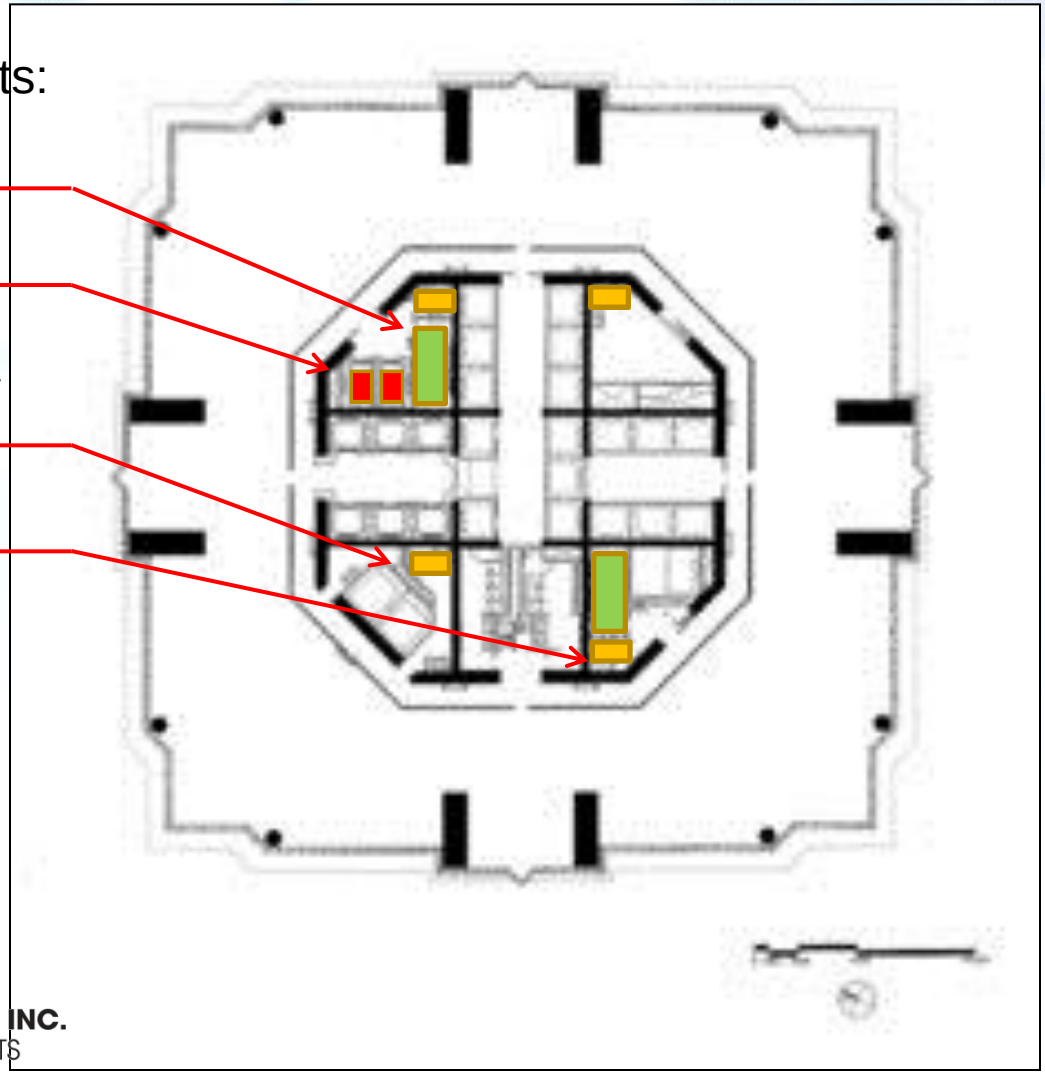
Structural Fire Resistance- Jin Mao

Critical Life Safety Elements:

- Stairs
- Firemen's Elevators
- Fire Alarm and Emergency Power Risers
- Smoke Control Risers



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Structural Fire Resistance- Jin Mao

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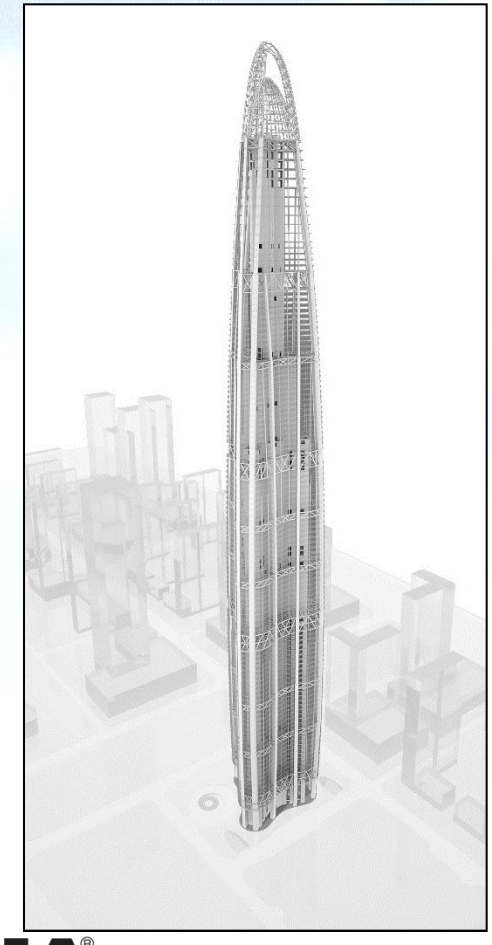
Structural Fire Resistance- Wuhan



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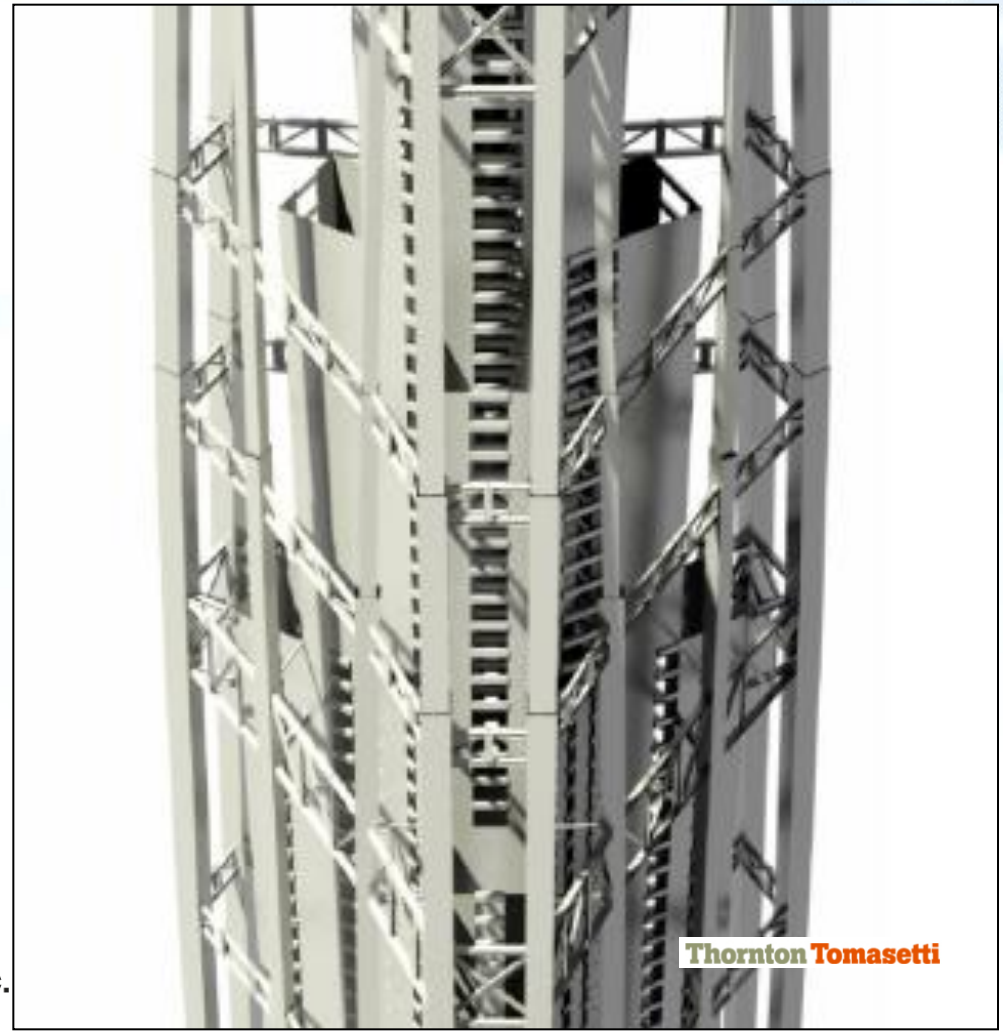
Structural Fire Resistance- Wuhan



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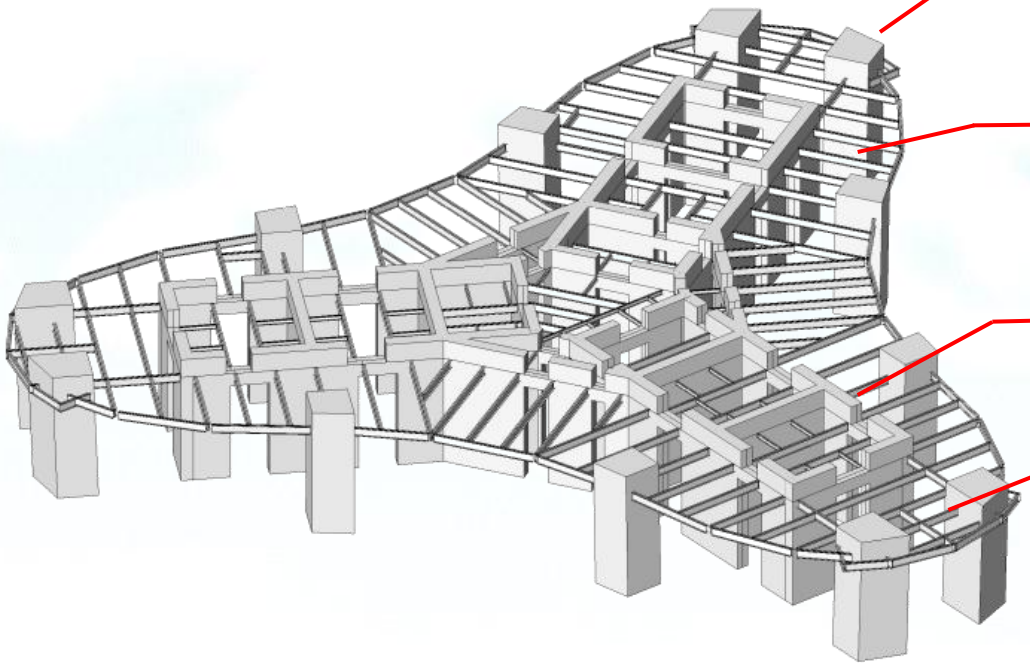
Structural Fire Resistance- Wuhan



Thornton Tomasetti

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Structural Fire Resistance - Codes

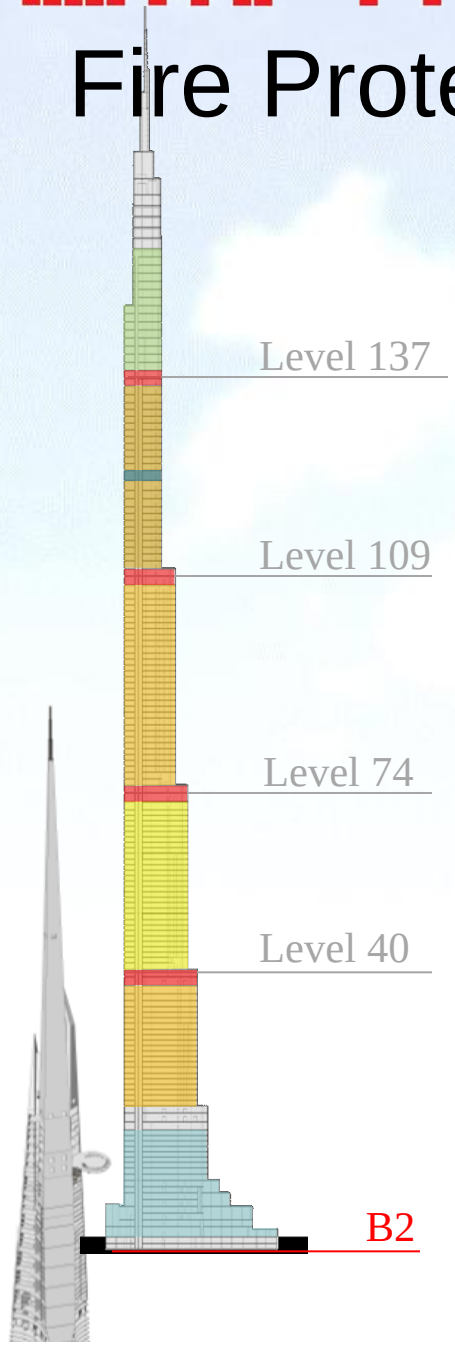
Recent Changes to International Building Code:

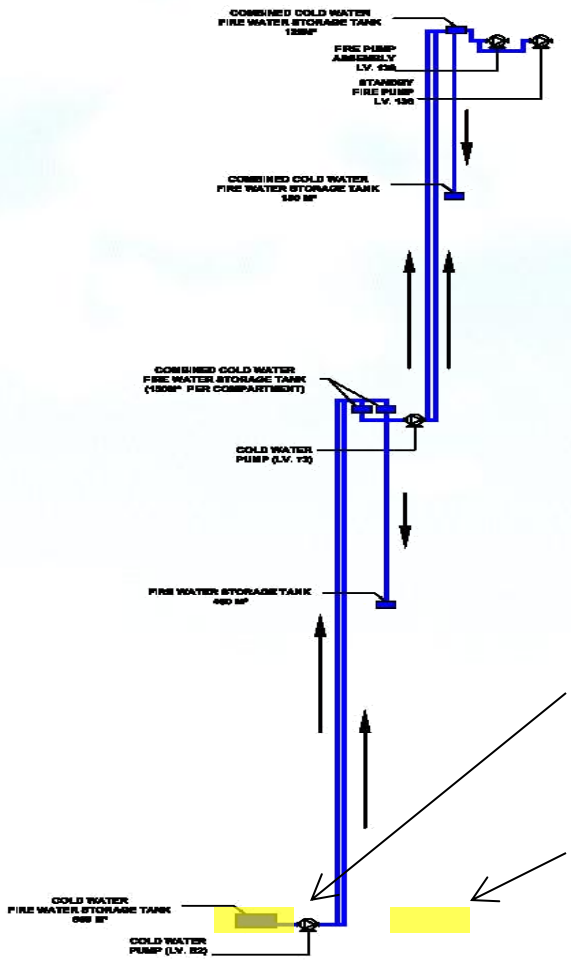
- Impact Resistant Materials for Core Elements
- Increased Bond Strength for Fire Protection Materials for Structural Steel

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

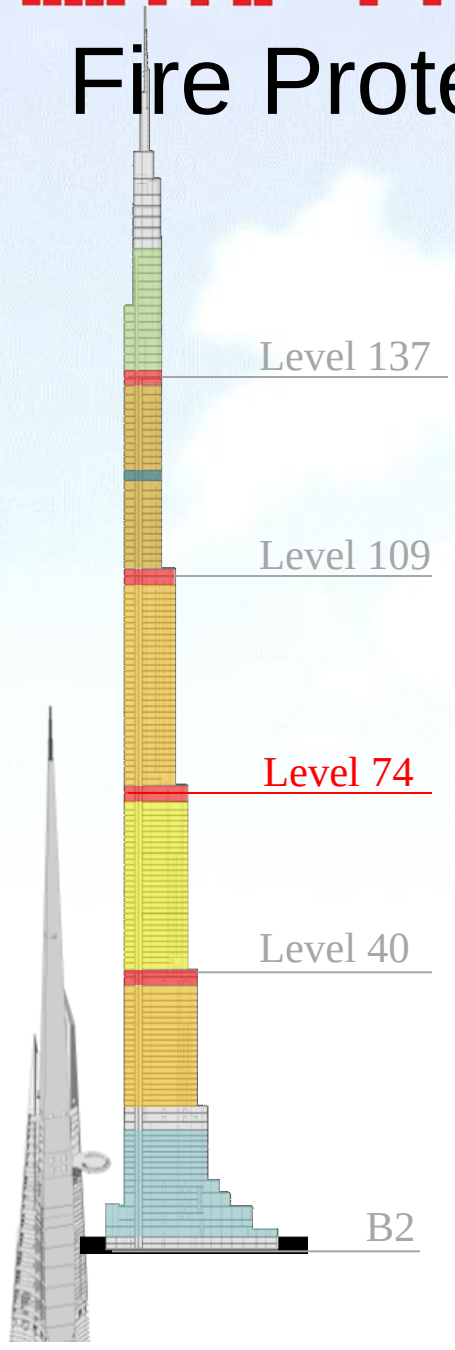


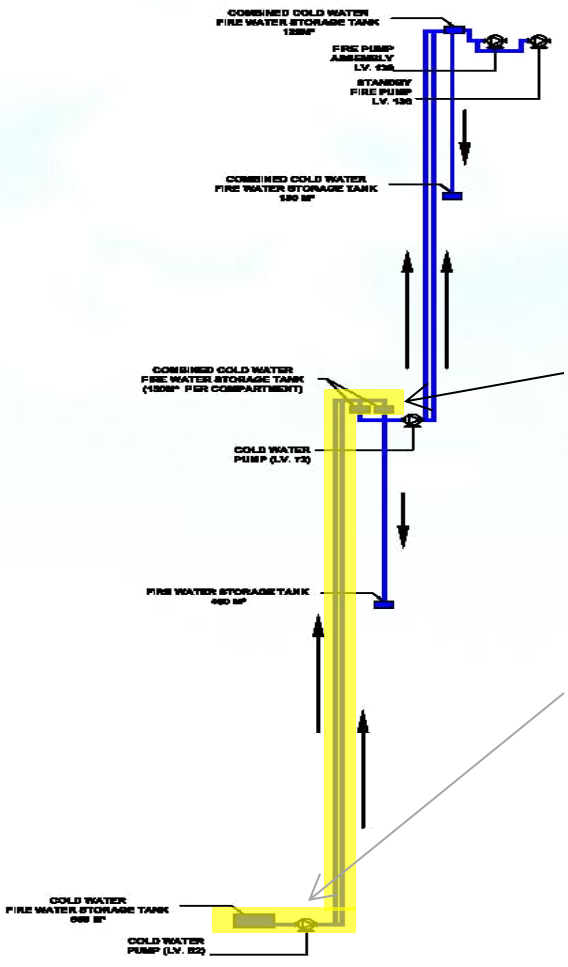


Primary Storage Tank Level B2
2 Hour Capacity – 425,000 Liters

Separate Storage Tank for Outside Hydrants – 2,311,000 Liters

Fire Protection Water Supply- Burj Khalifa

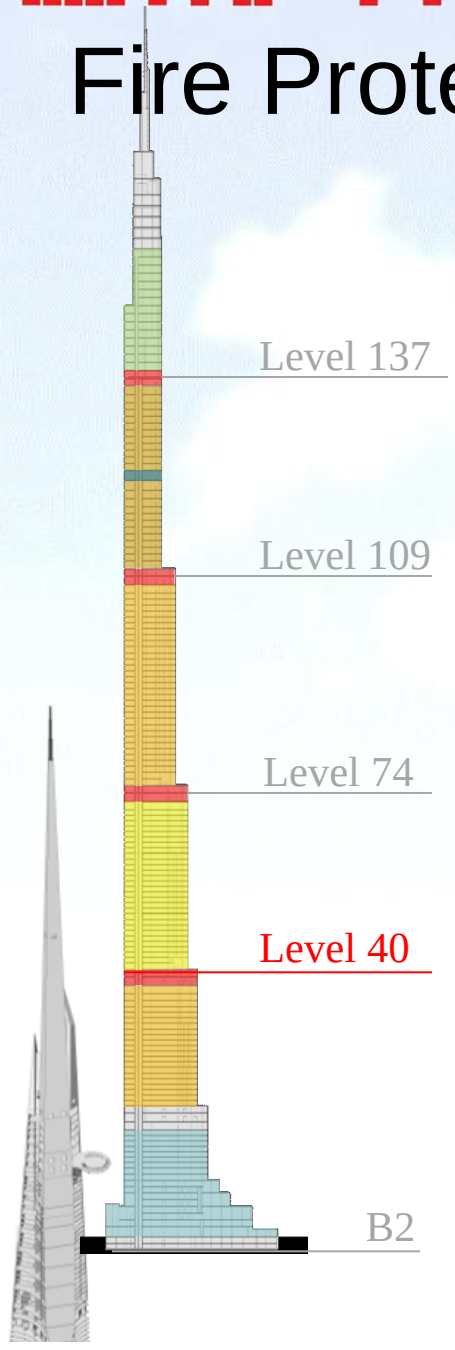


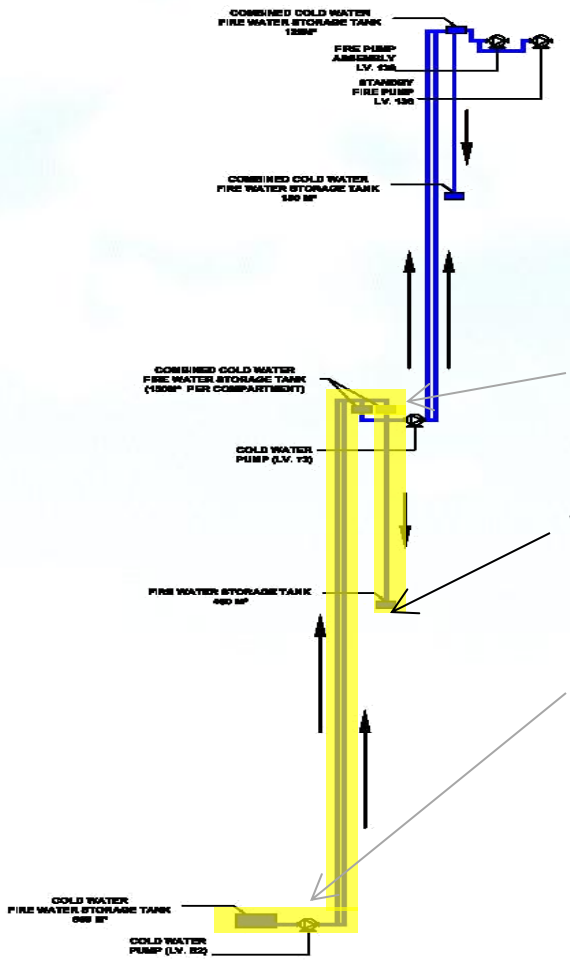


Water is Pumped to Tank on Level 74
1 Hour Capacity

Primary Storage Tank Level B2
2 Hour Capacity

Fire Protection Water Supply- Burj Khalifa



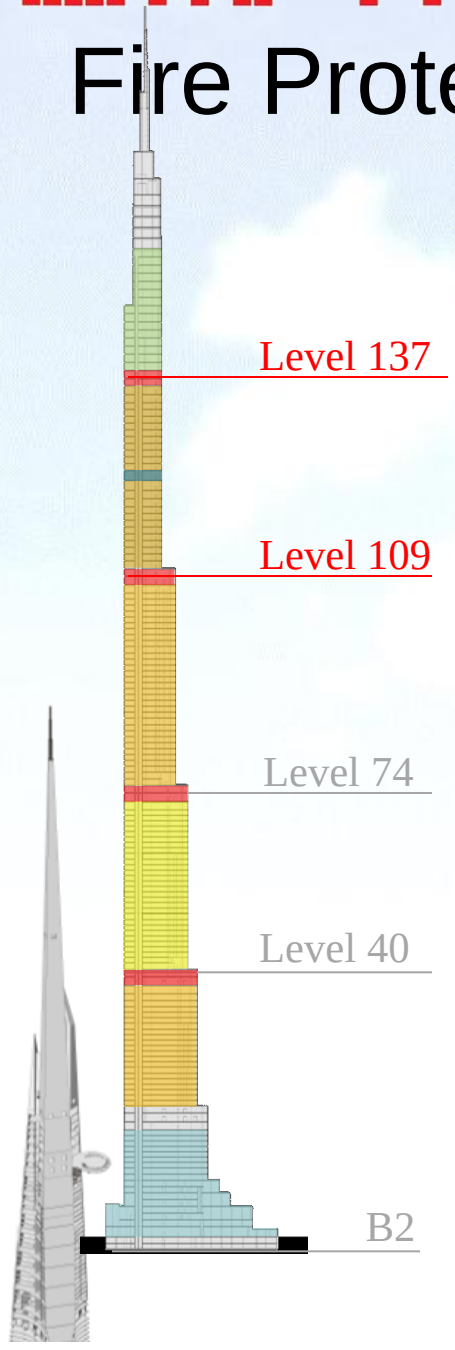


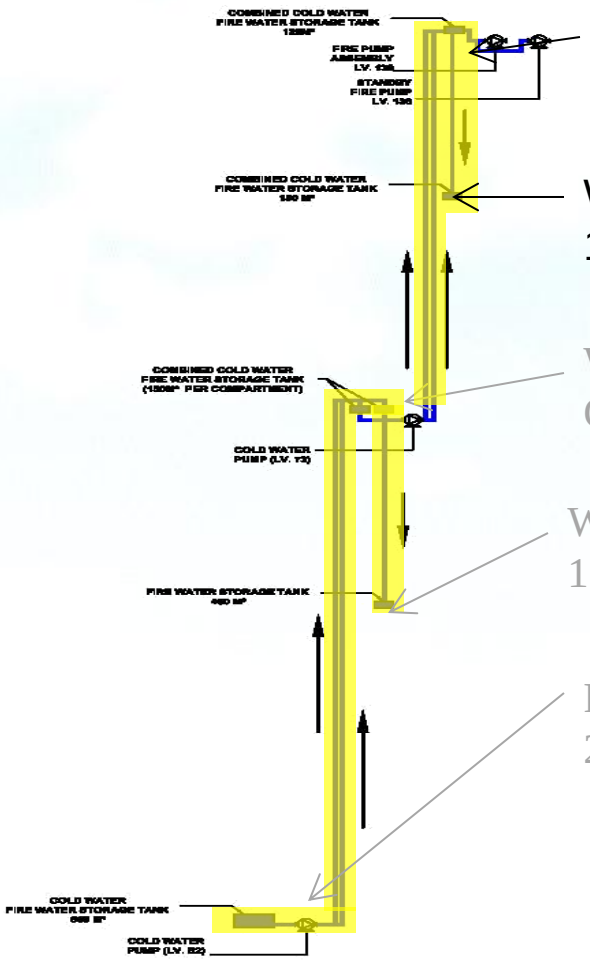
Water is Pumped to Tank on Level 74
1 Hour Capacity

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





Water is Pumped to Tank on Level 137
1 Hour Capacity

Water by gravity fills Tank on Level 109
1 Hour Capacity

Water is Pumped to Tank on Level 74 1 Hour Capacity

Water by gravity fills Tank on Level 40
1 Hour Capacity

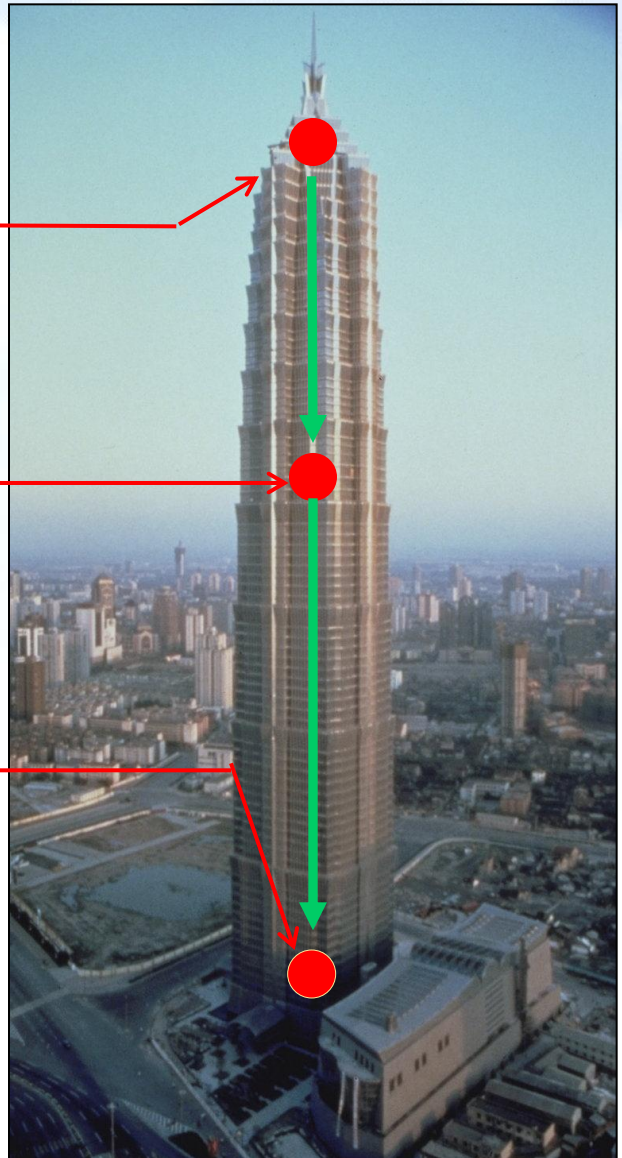
Primary Storage Tank Level B2
2 Hour Capacity

Fire Protection Water Supply- 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

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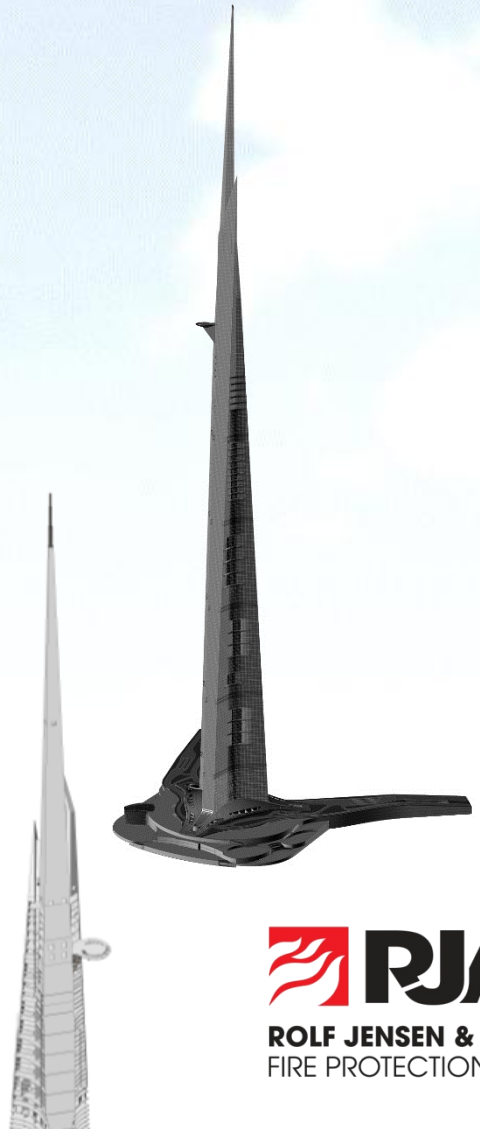
Kingdom Tower – Building Program



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

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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

Kingdom Tower - Riyadh, Kingdom of Saudi Arabia

COMPARATIVE BUILDING CODE MATRIX

In-Progress
9/9/2013

TOPIC	Saudi Building Code (Assume IBC section 101 unless otherwise specified.)	IBC 2006	IBC 2009	NFPA 101 2006	NFPA 101 2009	Enhancement Recommendations RJA FLS Strategy Report (TBD)	Other Comments / Requirements	RECOMMENDATIONS	DECISION
OCCUPANCIES	Group A: Assembly	Group A: Assembly (303)	Group A: Assembly (303)	Assembly (6.1.2)	Assembly (6.1.2)				
	Group B: Business	Group B: Business (304)	Group B: Business (304)	Residential (6.1.8)	Residential (6.1.8)				
	Group M: Mercantile	Group M: Mercantile (309)	Group M: Mercantile (309)	Mercantile (6.1.10)	Mercantile (6.1.10)				
	Group R-2: Residential	Group R-1: Residential Apartments (310) Group R-2: Residential Apartments (310)	Group R-1: Residential Apartments (310) Group R-2: Residential Apartments (310)	Business (6.1.11)	Business (6.1.11)				
	Group S: Storage S-1: Storage rooms, MEP rooms, Utility rooms S-2: Parking Garages	Group S: Storage (311) S-1: Storage rooms, MEP rooms, Utility rooms S-2: Parking Garage	Group S: Storage (311) S-1: Storage rooms, MEP rooms, Utility rooms S-2: Parking Garage	Storage (6.1.12)	Storage (6.1.12)				
MEANS OF EGRESS	Chapter 8	Chapter 10	Chapter 10	Chapter 7	Chapter 7				
Occupant Load	Table 8.4.1.2	IBC Table 1004.1.1	IBC Table 1004.1.1	Table 7.3.1.2	Table 7.3.1.2				
Residential	200 gsf/p (18.6 gsm/p)	200 gsf/p (18.58 gsm/p)	200 gsf/p (18.58 gsm/p)	200 gsf/p (18.6 gsm/p)	200 gsf/p (18.6 gsm/p)				
Business	100 gsf/p (9.3 gsm/p)	100 gsf/p (9.29 gsm/p)	100 gsf/p (9.29 gsm/p)	100 gsf/p (9.3 gsm/p)	100 gsf/p (9.3 gsm/p)				
Mercantile									
Basements and first floor	30 gsf/p (2.79 gsm/p)	30 gsf/p (2.79 gsm/p)	30 gsf/p (2.79 gsm/p)	30 gsf/p (2.8 gsm/p)	30 gsf/p (2.8 gsm/p)				
Other floors	60 gsf/p (5.57 gsm/p)	60 gsf/p (5.57 gsm/p)	60 gsf/p (5.57 gsm/p)	60 gsf/p (5.6 gsm/p)	60 gsf/p (5.6 gsm/p)				
Storage, stock, shipping areas	300 gsf/p (27.87 gsm/p)	300 gsf/p (27.87 gsm/p)	300 gsf/p (27.87 gsm/p)	300 gsf/p (27.87 gsm/p)	300 gsf/p (27.87 gsm/p)				
Assembly Areas									
Standing	5 nsf/p (0.47 nsm/p)	5 nsf/p (0.47 nsm/p)	5 nsf/p (0.47 nsm/p)	N/A	N/A				
Concentrated (chairs only, not fixed)	7 nsf/p (0.65 nsm/p)	7 nsf/p (0.65 nsm/p)	7 nsf/p (0.65 nsm/p)	7 nsf/p (0.65 nsm/p)	7 nsf/p (0.65 nsm/p)				
Unconcentrated, (tables and chairs)	15 nsf/p (1.39 nsm/p)	15 nsf/p (1.39 nsm/p)	15 nsf/p (1.39 nsm/p)	15 nsf/p (1.39 nsm/p)	15 nsf/p (1.39 nsm/p)				
Gaming Floors (keno, slots, etc.)	11 nsf/p (1.02 nsm/p)	11 nsf/p (1.02 nsm/p)	11 nsf/p (1.02 nsm/p)	11 nsf/p (1.02 nsm/p)	11 nsf/p (1.02 nsm/p)				
Exercise areas w/equipment	50 gsf/p (4.65 gsm/p)	50 gsf/p (4.65 gsm/p)	50 gsf/p (4.65 gsm/p)	50 gsf/p (4.6 gsm/p)	50 gsf/p (4.6 gsm/p)				
Locker rooms (excl. lockers)	50 gsf/p (4.65 gsm/p)	50 gsf/p (4.65 gsm/p)	50 gsf/p (4.65 gsm/p)	Bench-type seating 1p/18 linear inch, 46.7 linear mm	Bench-type seating 1p/18 linear inch, 46.7 linear mm				
Pool decks	15 gsf/p (1.39 gsm/p)	15 gsf/p (1.39 gsm/p)	15 gsf/p (1.39 gsm/p)	30 gsf/p (2.8 gsm/p)	30 gsf/p (2.8 gsm/p)				
Pools	50 gsf/p (4.65 gsm/p)	50 gsf/p (4.65 gsm/p)	50 gsf/p (4.65 gsm/p)	50 gsf/p (4.6 gsm/p)	50 gsf/p (4.6 gsm/p)				
Stages and Platforms	15 nsf/p (1.39 nsm/p)	15 nsf/p (1.39 nsm/p)	15 nsf/p (1.39 nsm/p)	15 nsf/p (1.39 nsm/p)	15 nsf/p (1.39 nsm/p)				
Kitchen areas	200 gsf/p (18.58 gsm/p)	200 gsf/p (18.58 gsm/p)	200 gsf/p (18.58 gsm/p)	100 gsf/p (9.3 gsm/p)	100 gsf/p (9.3 gsm/p)				
Parking garages	200 gsf/p (18.58 gsm/p)	200 gsf/p (18.58 gsm/p)	200 gsf/p (18.58 gsm/p)	N/A	N/A				
Minimum Number of Exits	Required minimum number of exits according to occupant load: 50 - 500 = 2 exits 501 - 1000 = 3 exits More than 1000 = 4 exits (Table 8.18.1) Single exits are allowed if they comply with Table 8.10.2 for the specific occupancy.	Required minimum number of exits according to occupant load: 50 - 500 = 2 exits 501 - 1000 = 3 exits More than 1000 = 4 exits (Table 1021.1) Allowance of buildings with one exit is listed in Table 1019.2.	Required minimum number of exits according to occupant load: 50 - 500 = 2 exits 501 - 1000 = 3 exits More than 1000 = 4 exits (Table 1021.1) **Significant Change:** General requirements for the minimum number of exits remain the same as noted above. Section 1021.1 adds Exc. 1 to address the third stairway required in buildings with a height of 420 ft (128 m) or higher. (1021.1 and 403.5.2) The third stairway required in high-rise building of 420 ft (128 m) or higher is allowed to be exempted where occupant evacuation elevators are provided. (403.5.2) The 2009 IBC clarifies the allowance for single-exit from individual stories. The focus has shifted from single-exit buildings to single-exit stories within buildings depending on occupancy classification (Table 1021.2).	Required minimum number of exits according to occupant load: 50 - 500 = 2 exits 501 - 1000 = 3 exits More than 1000 = 4 exits Single Exit permitted as long as compliance with the common path of travel distance limits are met for all occupancies other than assembly. (7.4.1.2)	Required minimum number of exits according to occupant load: 50 - 500 = 2 exits 501 - 1000 = 3 exits More than 1000 = 4 exits Single Exit permitted as long as compliance with the common path of travel distance limits are met for all occupancies other than assembly. (7.4.1.2)				

Kingdom Tower_Comparative Code Matrix_31-March-2010

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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

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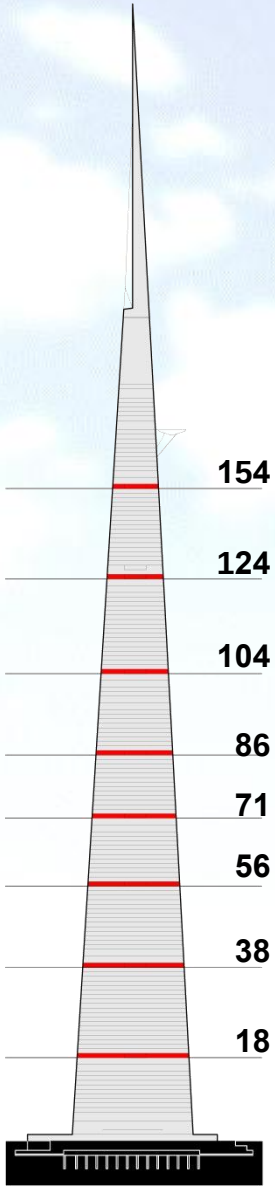
Refuge Floors

- 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



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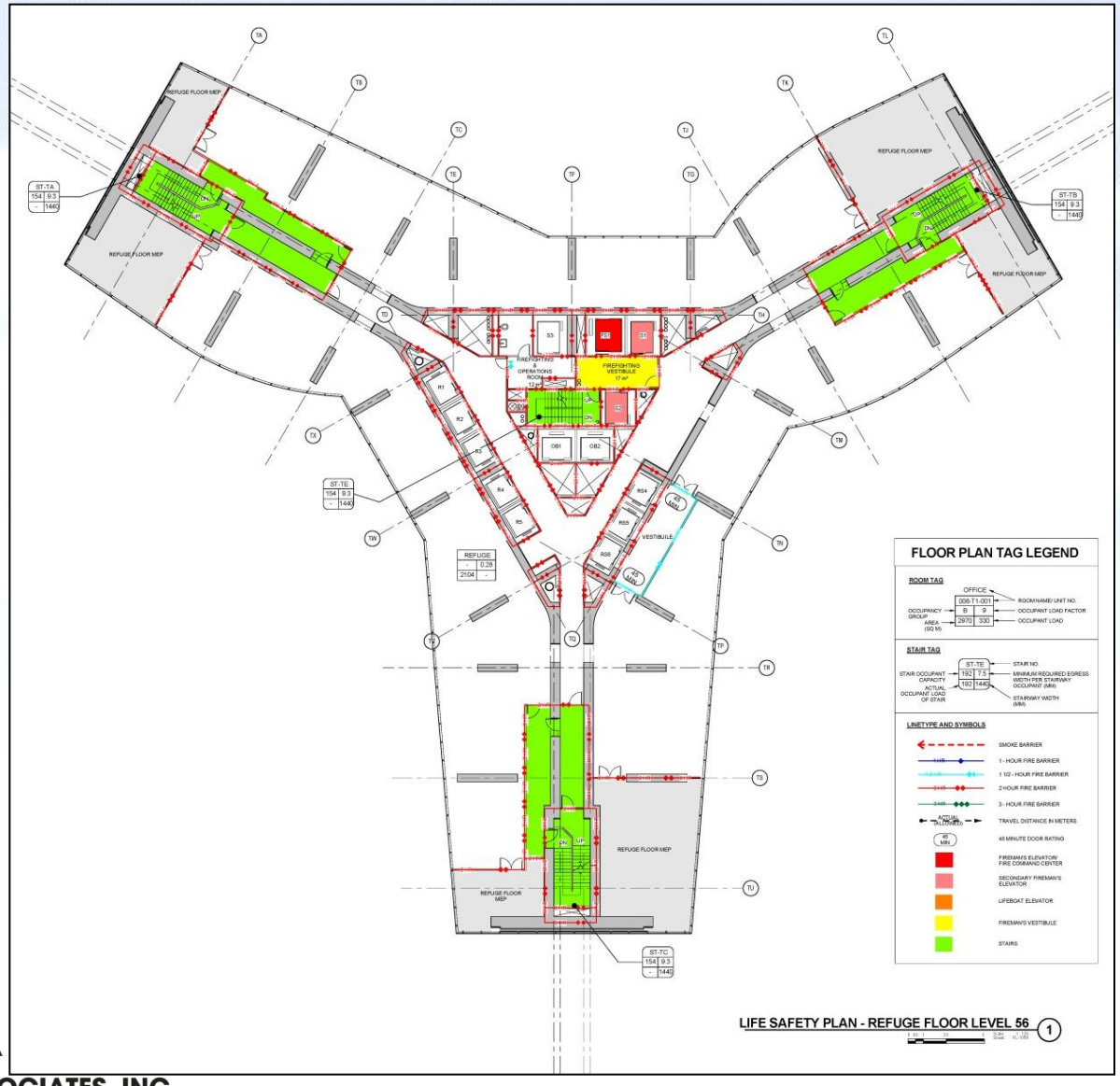
Refuge Floors



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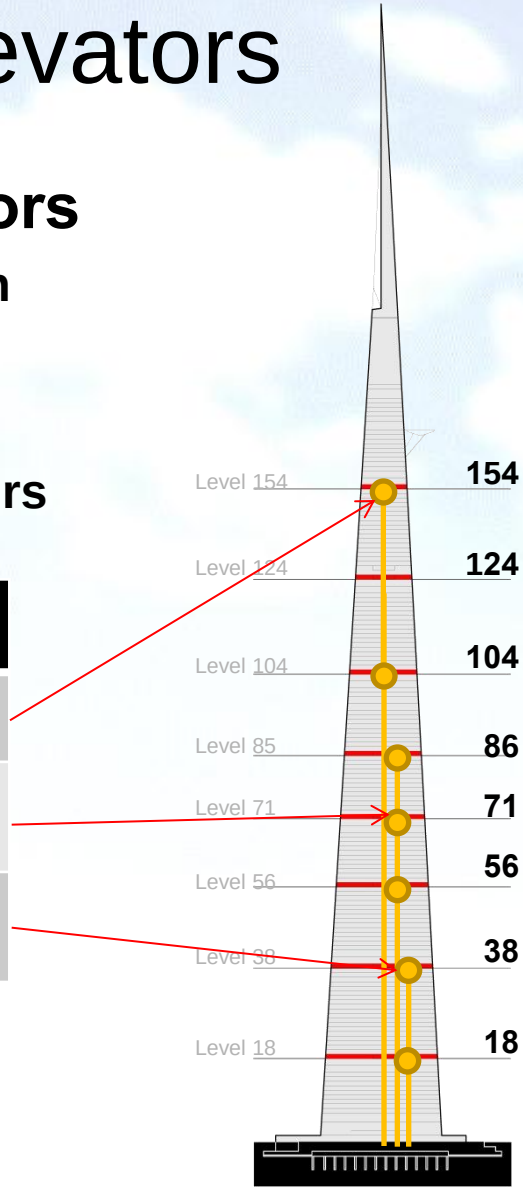
Evacuation Elevators

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**

Lifeboat Shuttle	Service
Observation Shuttles OB1, OB2	Floors 154, 104
Residential Shuttles R4, R5, R6	Floors 86, 71, 56
Residential Shuttles R1, R2, R3	Floor 38, 18



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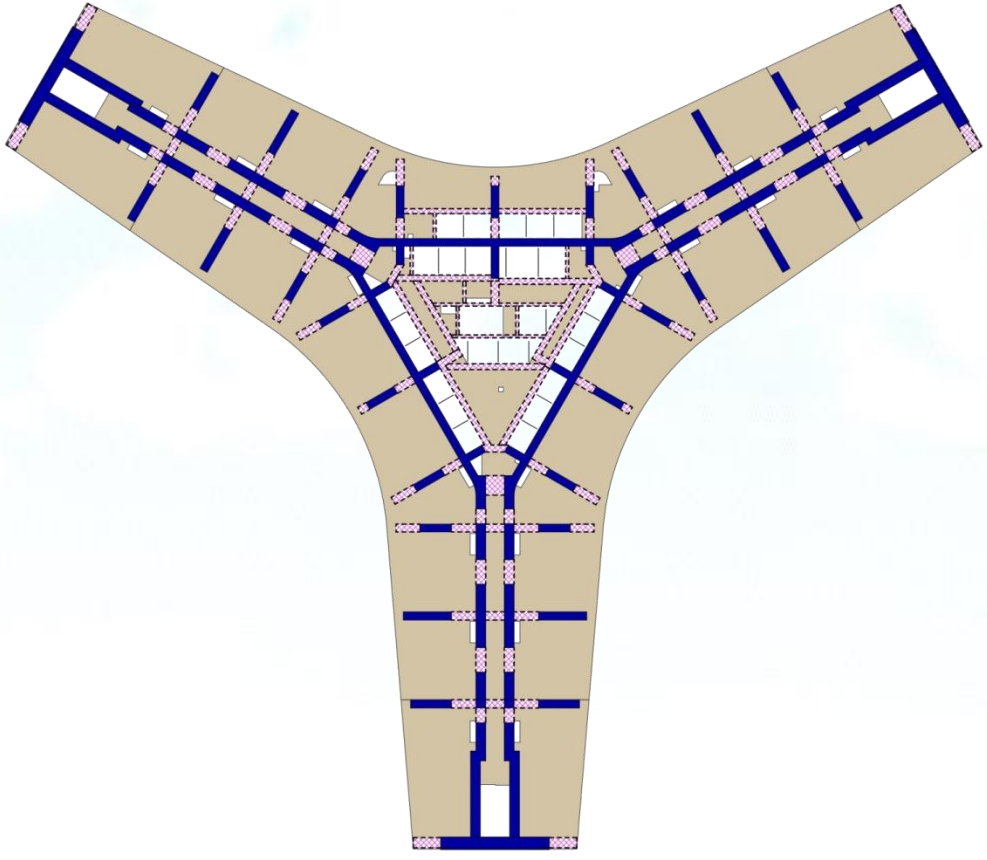
Structural Fire Safety



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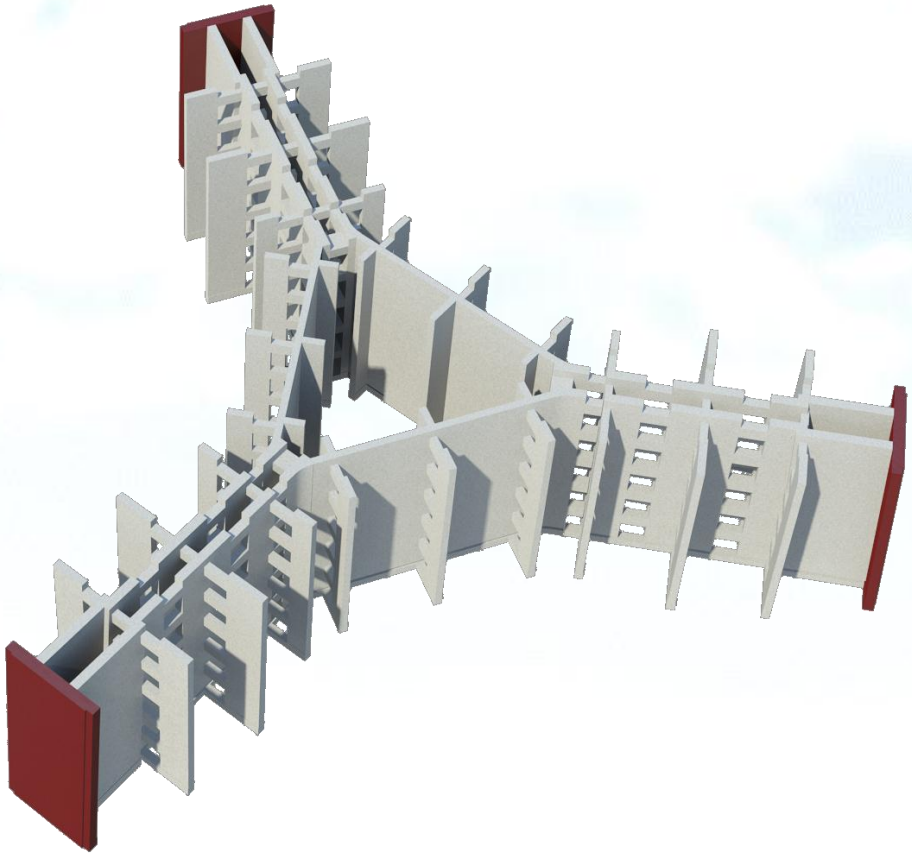
Structural Fire Safety



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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

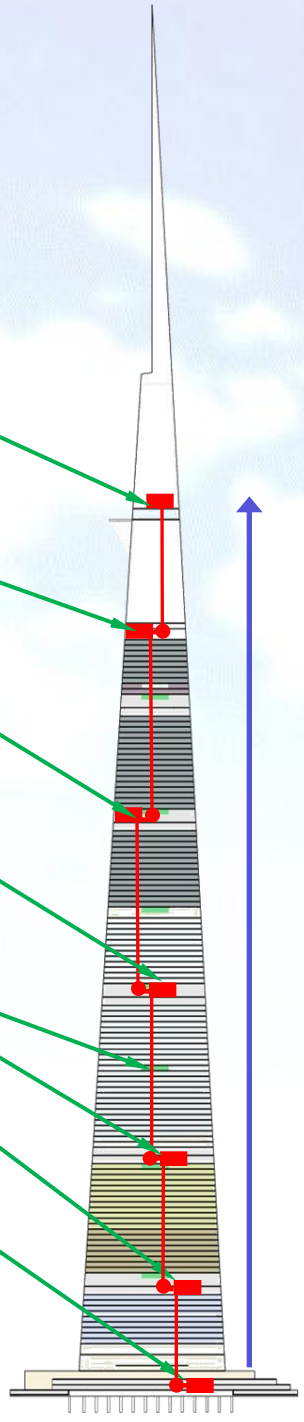
Level 69 Water Tanks – 1 Hour

Transfer Pumps & Fill Lines

Level 40 Water Tanks – 1 Hour

Level 16 Water Tanks – 1 Hour

B3 Level Water Storage Tanks – 2 Hours



RJA®
ROLF JENSEN & ASSOCIATES, INC.
FIRE PROTECTION CONSULTANTS

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

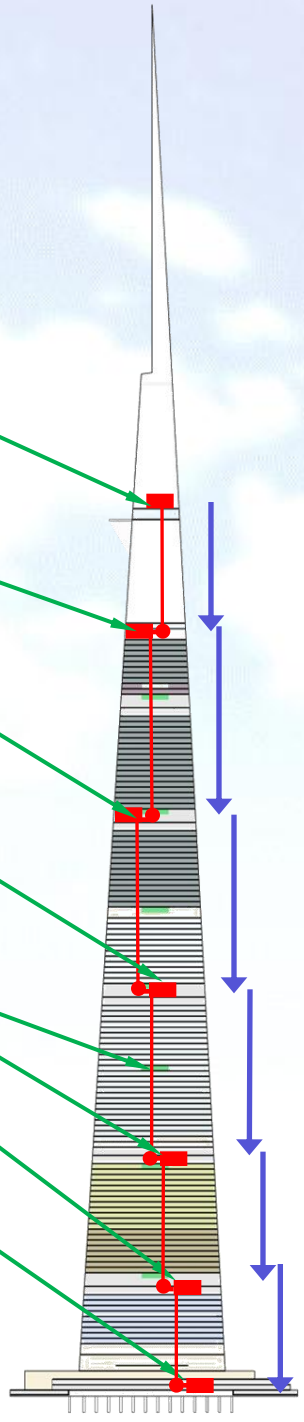
Level 69 Water Tanks – 1 Hour

Transfer Pumps & Fill Lines

Level 40 Water Tanks – 1 Hour

Level 16 Water Tanks – 1 Hour

B3 Level Water Storage Tanks – 2 Hours



RJA®
ROLF JENSEN & ASSOCIATES, INC.
FIRE PROTECTION CONSULTANTS

Fire Protection Water Supply

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

High Level Tank

Gravity Express Risers

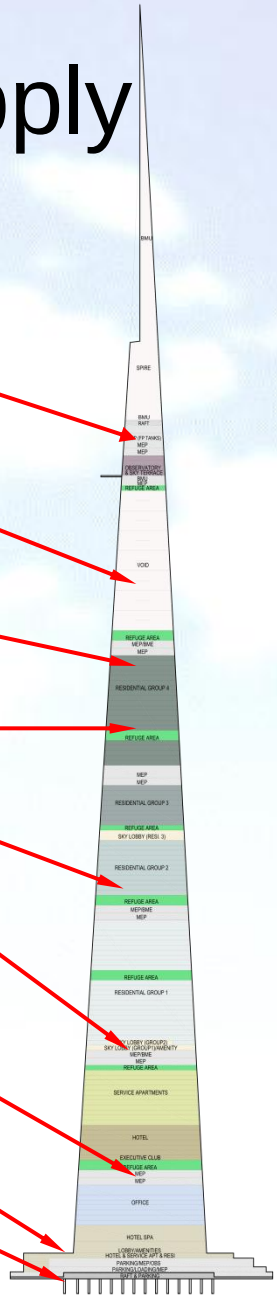
Local Zones Gravity Down –
Low Pressure through PRV's

Intermediate Tanks

Express Fill Line Up

Main Water Storage Tanks

Transfer Pumps



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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

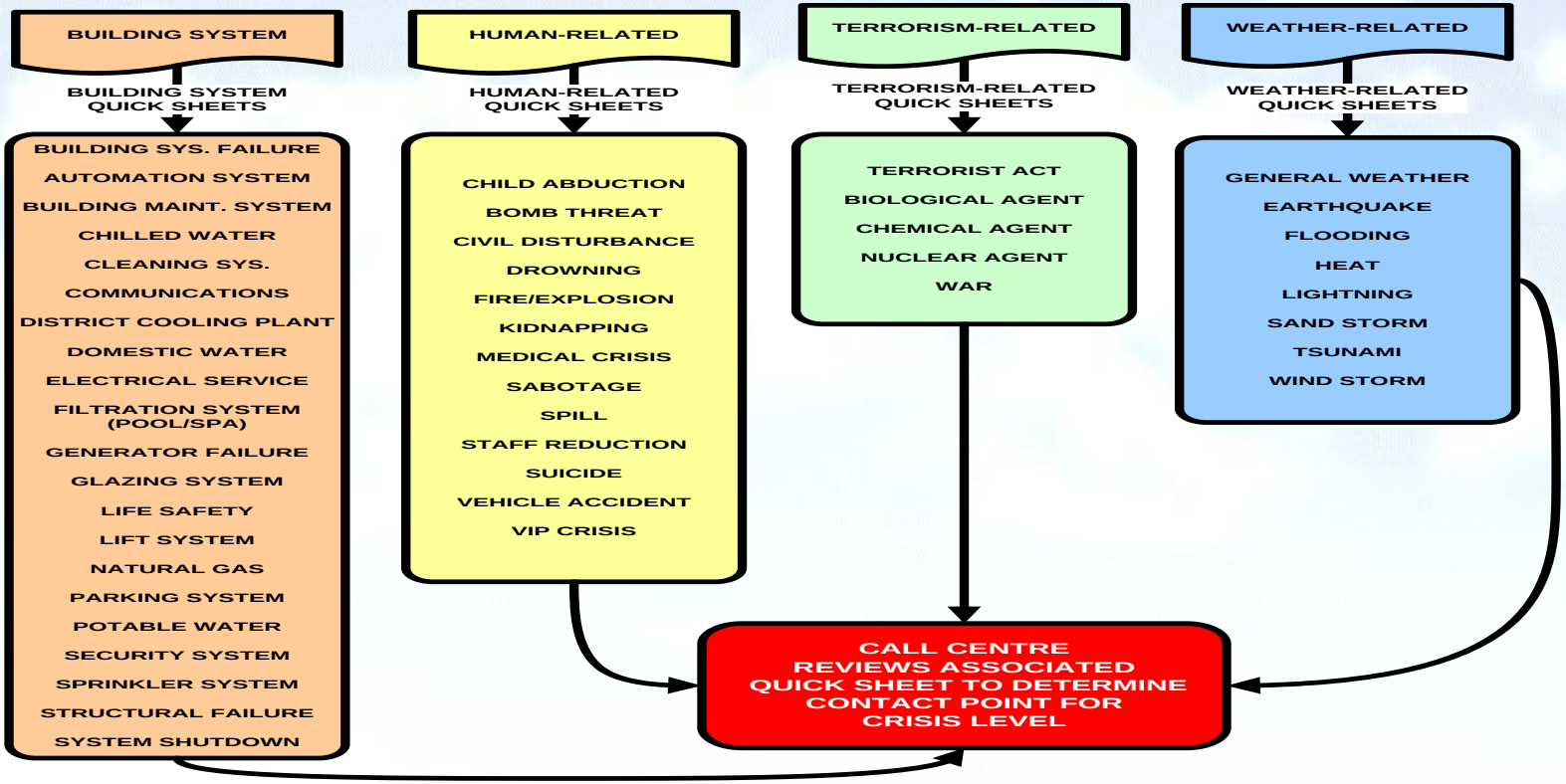
Regulatory Framework

- 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

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Conclusions

- Buildings <u>will</u> continue to grow taller
- This will push our technologies in all areas, especially fire safety
- More Active & Passive Protection
- Design, Construction, Operations

Thank You

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