Performance Based Seismic Evaluation of Icon Hotel in Dubai

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BSc MSc PhD
Senior Structural Engineer

WS Atkins Middle East
Dubai, UAE
Atkins Tall Buildings
Icon Hotel, Dubai
Icon Hotel Location
Icon Hotel The Site
Icon Hotel Building Geometry

Key Facts:
- 203 Guest Hotel Room
- 172 Branded Service Apartments
- 42 storey wheel
- Total built up area 110,000 sqm

Plan

160 m
34th level-Mechanical Floor
Sky Lift
8th level-Mechanical Floor

Lift cores
Atrium

10.8 m
15.2 m
4.3 m
Elevation
The areas with high shear stresses:

1. Thicken the wall - more weight and more concrete
2. Reduce the number of openings - Not favourable Architecturally
3. Use steel plates to reinforce the highly stressed concrete walls - Not standard practice
Icon Hotel Pre-Concept

Peer Review – LERA’s Proposed Alternative

Sketches Courtesy LERA
Icon Hotel Concept Design - Functional Framing & Form Finding
Icon Hotel Pre-Construction Advisor - SAMSUNG

Alternative Structural System Sketch: Option 1

Alternative Structural System Sketch: Option 2

Alternative Structural System Sketch: Option 3

Images Courtesy Samsung
Icon Hotel Preliminary Design
Icon Hotel Axial Forces Under Gravity Loads

Axial Force Diagram
Icon Hotel Construction Sequence

Images Courtesy Tekla
Icon Hotel Construction Sequence

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Icon Hotel Construction Sequence

Images Courtesy Tekla
Deformation has bending configuration and story drift increase with height.

Deformation has shear configuration with maximum inclination near the base.
Icon Hotel
Steel Weight

Trusses, Arches and vertical elements: 10250 ton
Floor Beams: 7000 ton
Icon Hotel Modes of Vibration

T1 = 4.3 Sec  T2 = 3.3 Sec  T3 = 3.0 Sec
Icon Hotel Specialist Studies

- Geotechnical Study
- Liquefaction Analysis
- Soil Improvement
- Seismic Hazard Study
- Wind Tunnel Study
- Pile Raft Settlement Analysis
- Floor vibration analysis
- Connections Detail Design
- Long Term Effect (Column Shortening)
- Performance Based Seismic Evaluation
Icon Hotel Wind Tunnel Studies

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total - [X, Y and torsional components] (milli-g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.1 - [1.2, 4.1, 0.7]</td>
<td>0.2</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>7.2 - [1.8, 7.2, 1.2]</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>8.8 - [2.1, 8.8, 1.4]</td>
<td>0.4</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Inter story drift less than H/1000
For more information please visit CTBUH website and search for CTBUH 2010 Mumbai Conference
Foundation Type

Other areas are on pile groups or individual piles

"Piled Raft"
Pile Raft Settlement Analysis—Predicted Settlement (DL+LL) by PIGLET

Maximum Settlement: 90mm

Maximum Settlement: 93mm
Pile Raft Settlement Analysis-Predicted Settlement (DL+LL) by FEAR

Contour Legend

Maximum Settlement: 107mm

Maximum Settlement: 112mm
Floor System

• Strength
• Deflection
• Vibration
• Acoustic
• 2hrs Fire
Design of Floor for Vibration  
Traditional approach

\[
f_1 = \frac{17.8}{\sqrt{\delta}} \approx \frac{18}{\sqrt{\delta}}
\]

F1 > 4 Hz
<table>
<thead>
<tr>
<th></th>
<th>PDR</th>
<th>Current Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB 1</td>
<td>217 kg/m</td>
<td>114 kg/m</td>
</tr>
<tr>
<td>SB 2</td>
<td>117 kg/m</td>
<td>100 kg/m</td>
</tr>
</tbody>
</table>
Figure 3.1 Dynamic load function for continuous excitation due to walking.
Icon Hotel Floor Vibration Analysis

Figure 10 Floor 29 (ABQ): Mode 1 (5.81Hz)

Figure 16 Floor 29: Mode 1 (5.48Hz)

Figure 11 Floor 29 (ABQ): Mode 2 (6.97Hz)

Figure 17 Floor 29: Mode 3 (6.37Hz)
Floor Vibration Analysis-In-house Program
Further R-factors for the different walking paths are given in Table 5 below.

<table>
<thead>
<tr>
<th>Walking Path</th>
<th>R-factor (continuous vibration)</th>
<th>R-factor (impulsive response)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.1*</td>
<td>3.8*</td>
</tr>
<tr>
<td>2</td>
<td>2.5*/2.1**</td>
<td>3.3*/2.4*</td>
</tr>
<tr>
<td>3</td>
<td>1.8*</td>
<td>3.1*</td>
</tr>
<tr>
<td>4</td>
<td>1.8*</td>
<td>3.7*</td>
</tr>
<tr>
<td>5</td>
<td>1.9*</td>
<td>3.0</td>
</tr>
<tr>
<td>6</td>
<td>0.3*</td>
<td>3.7</td>
</tr>
<tr>
<td>7</td>
<td>7.9</td>
<td>n/a</td>
</tr>
<tr>
<td>8</td>
<td>5.4</td>
<td>5.5</td>
</tr>
<tr>
<td>9</td>
<td>0.4***</td>
<td>2.1**</td>
</tr>
<tr>
<td>10</td>
<td>0.6***</td>
<td>3.3**</td>
</tr>
<tr>
<td>11</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>12</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>13</td>
<td>3.3</td>
<td>2.7</td>
</tr>
<tr>
<td>14</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>15</td>
<td>2.7</td>
<td>3.0</td>
</tr>
</tbody>
</table>
Floor Vibration Analysis-MIDAS model
Walking Load

![Graph showing time history data for walking load](image-url)
Vibration Mode Shapes - MIDAS model
More than 21 million AED SAVED

37th Floor - Floor beam weight comparison

<table>
<thead>
<tr>
<th>Design stage</th>
<th>Beam label</th>
<th>Section size</th>
<th>weight kg/m</th>
<th>Total area sq.m</th>
<th>Total weight kN</th>
<th>Wt per sq.m kg/sq.m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part floor 2 (Grid 9 - 25)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDR</td>
<td>SB1</td>
<td>Built-up section</td>
<td>217.1</td>
<td>2644.022</td>
<td>2096.45</td>
<td>80.63</td>
</tr>
<tr>
<td></td>
<td>SB2</td>
<td>Built-up section</td>
<td>116.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DD Final</td>
<td>SB1</td>
<td>W16x77</td>
<td>114.9</td>
<td>2644.022</td>
<td>1562.07</td>
<td>60.22</td>
</tr>
<tr>
<td></td>
<td>SB2</td>
<td>W16x67</td>
<td>100.0</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Samsung</td>
<td>SB1</td>
<td>W16x67</td>
<td>100.0</td>
<td>2644.022</td>
<td>1448.63</td>
<td>55.65</td>
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<tr>
<td></td>
<td>SB2</td>
<td>W14x61</td>
<td>91.0</td>
<td></td>
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<tr>
<td>LERA</td>
<td>SB1</td>
<td>W16x67</td>
<td>100.0</td>
<td>2644.022</td>
<td>1288.48</td>
<td>49.68</td>
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<tr>
<td></td>
<td>SB2</td>
<td>W16x40</td>
<td>60.0</td>
<td></td>
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</tbody>
</table>
Icon Hotel Column Shortening

MIDAS Model
Icon Hotel Differential Shortening Between Inner and Outer Walls
Seismic Hazard Study
courtesy Fugro West Inc.
## Magnitude Probability Density Function

<table>
<thead>
<tr>
<th>Zones</th>
<th>Source Type</th>
<th>Magnitude PDF</th>
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</thead>
<tbody>
<tr>
<td>Zones 1 through 12</td>
<td>Shallow Crustal Areal Sources</td>
<td>Truncated Exponential</td>
</tr>
<tr>
<td>Zone 13</td>
<td>Subduction Interplate Sources</td>
<td>Youngs and Coppersmith</td>
</tr>
<tr>
<td>Zones 14 and 15</td>
<td>Subduction Intraplate Sources</td>
<td>Truncated Exponential</td>
</tr>
<tr>
<td>Line Sources 1-12</td>
<td>Planar Sources</td>
<td>Pure Characteristic</td>
</tr>
</tbody>
</table>

### Seismic Hazard Study

Courtesy Fugro West Inc.
The estimated equal hazard horizontal response spectrum at rock boundary.

<table>
<thead>
<tr>
<th>Set</th>
<th>Earthquake</th>
<th>Magnitude</th>
<th>Distance (Km)</th>
<th>Recording Station</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1994 Northridge, USA</td>
<td>6.7</td>
<td>18.2</td>
<td>90053 Canoga Parl-Topanga Can</td>
<td>CNP 106 CNP 196</td>
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<tr>
<td>2</td>
<td>1976 Gazli, USSR</td>
<td>6.8</td>
<td>22.3</td>
<td>9201 Karakyr</td>
<td>GAZ000 GAZ090</td>
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<tr>
<td>3</td>
<td>1992 Landers, USA</td>
<td>7.3</td>
<td>42.5</td>
<td>12025 Palm Springs Airport</td>
<td>PSA 000 PSA090</td>
</tr>
</tbody>
</table>

Seismic Hazard Study

Courtesy Fugro West Inc.
Icon Hotel Performance Based Design – Seismic Evaluation
Icon Hotel Performance Based Design – Seismic Evaluation

![Graph showing seismic evaluation](image)
Icon Hotel Performance Based Seismic Design – Perform 3D
Icon Hotel  Performance Based Seismic Design – Material Behaviour

Un confined C70 (70 Mpa) concrete

Steel S355 (355 Mpa yield strength) built up section

Reinforcement (460 Mpa yield strength)
Icon Hotel Performance Based Seismic Design – Damping
<table>
<thead>
<tr>
<th>Earthquake Level</th>
<th>Performance objective</th>
<th>Design Stage I-A</th>
<th>Design Stage I-B</th>
<th>Design Stage III</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>LS/CD</td>
<td>LS/CD</td>
<td>CP/ED</td>
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<tr>
<td>Analysis Type</td>
<td></td>
<td>3-D Linear Response Spectrum Analysis</td>
<td>2-D Nonlinear Time History Analysis</td>
<td>2-D Nonlinear Time History Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seismic Zone 2A UBC 97-Soil type Sc</td>
<td>Time history obtained from Seismic Hazard Study-475 years return period</td>
<td>Time history obtained from Seismic Hazard Study-2475 years return period</td>
</tr>
<tr>
<td>Earthquake load/Time History</td>
<td></td>
<td>UBC 97-R=4.5-Bearing Wall System</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td></td>
<td></td>
<td>%2 for inelastic deformation=0.7<em>R</em>elastic deformation</td>
<td>2.5% (DM 2009)</td>
<td>3.5% (DM 2009)</td>
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<tr>
<td>Ductility Factor</td>
<td></td>
<td>Member to be designed according to UBC 97</td>
<td>Design to be verified</td>
<td>Design to be verified</td>
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<tr>
<td>Story Drift Ratio Limit</td>
<td></td>
<td>Factored load combinations</td>
<td>Service load combinations</td>
<td>Service load combinations</td>
</tr>
<tr>
<td>Member Strength Design</td>
<td></td>
<td>Design Strength</td>
<td>Expected strength</td>
<td>Expected strength</td>
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<tr>
<td>Load Factors</td>
<td></td>
<td>Strength &amp; Story drift ratio</td>
<td>Strain &amp; Story drift ratio</td>
<td>Strain &amp; Story drift ratio</td>
</tr>
<tr>
<td>Material strength</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Acceptance Criteria</td>
<td></td>
<td></td>
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</tbody>
</table>
Icon Hotel Performance Based Seismic Design – Desired Behaviour
Icon Hotel Performance Based Seismic Design – Perform 3D

Concrete Coupling beams behave nonlinear

Compression strain about 0.0012

Deflected shape showing element usage ratios:
- Structure: Icon-PBD-21 (Icon Hotel elev 0-Performance Base Design)
- Analysis Series: Dynamic Earth (Gravity+Dynamic)
- Load Case: [1] = [2] + gravity=0
- Load Factor: 1
- Limit state group: all deformation and strength states
- Minimum usage ratio for each color: 0.0 0.2 0.3 0.4 3
Icon Hotel  Performance Based Seismic Design – Perform 3D

Envelope of the concrete compression strain at critical locations

All the members remained elastic except coupling beams – Building met the performance objectives.
**Icon Hotel** Performance Based Seismic Design – Perform 3D

The envelope inter-story drift ratios for MCE

The envelope of shear force and the capacity of central shear wall.
Icon Hotel Performance Based Seismic Design – Dissipated Energy
Icon Hotel Performance Based Seismic Design – Usage Ratios
Icon Hotel  Performance Based Seismic Design – Perform 3D

Scaled Lander 1992 increased 4x to see the extreme behaviour
Conclusions and observation

• Large gravity transfer structures can be used efficiently to mobilise frame action by coupling the core walls.
• Icon hotel Performance Based Design evaluation showed that this building will behave in a desired manner for future anticipated earthquake.
• Bearing wall system: Ductility ?? Overstrength √
• Minimum base shear from the code. Do we need to follow?
• Performance based design provides valuable information for the seismic design of geometrically complex structures which lie beyond the realms of established building codes.