Engineering the Structure for Jeddah Tower

John Peronto, Principal, Thornton Tomasetti
PROJECT OVERVIEW

- Structural Engineer: Thornton Tomasetti (TT)
- Architect: Adrian Smith + Gordon Gill Architecture (AS+GG)
- Developer: Jeddah Economic Company (JEC)
- Competition Start: June 2009
- Complete Design Docs: August 2013
- Reinforced Concrete: Design to ACI 318
- General Contractor: Saudi BinLaden Group (SBG)
REPRESENTATIVE SUPERTALLS WORLDWIDE
KINGDOM CITY MASTER PLAN

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MIXED USE RESIDENTIAL TOWER
CONCRETE BEARING WALL SYSTEM

- All walls connected with link beams
- No columns
- No outriggers
- No column transfers
- Flat plate floors
- No spandrel beams
HISTORICAL PRECEDENTS

<table>
<thead>
<tr>
<th>Building</th>
<th>Height</th>
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<tbody>
<tr>
<td>CN Tower</td>
<td>553 m</td>
</tr>
<tr>
<td>Burj Khalifa</td>
<td>828 m</td>
</tr>
<tr>
<td>Jeddah Tower</td>
<td>+1,000 m</td>
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</table>

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HISTORICAL PRECEDENTS
ARCHITECTURAL PLANNING
RESIDENTIAL ROOM LAYOUTS
WALL HIERARCHY – TRIANGULAR CORE

- Torsional Stiffness
- Nearly solid
- 800mm thick at base
WALL HIERARCHY – CORRIDOR WALLS

- Highly stressed
- 1.6m deep coupling beams
- Opening pattern critical
- 1000mm thick at base
WALL HIERARCHY – FIN WALLS

- Stabilizers
- 1.5m deep coupling beams
  Extend across corridor
- Drop off as tower tapers
- 850mm thick at base

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WALL HIERARCHY – END WALLS

- Most Highly Stressed
- No Openings
- Inclined
- 1200mm thick at base
ONE SYSTEM: TOWER + SPIRE

Height-to-Width Aspect Ratio = 12:1

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TAPERING GEOMETRY DEFINITION

- Same width at base for all wings
- Tapered at different rate for each wing
- Width flares from level 159 to sky raft
STRUCTURAL MATERIALS

Vertical Rebar

Concrete (f’c) Cylinder

- 65 MPa
- 9,500 psi

- 75 MPa
- 11,000 psi

- 85 MPa
- 12,500 psi

- 520 MPa
- 75 ksi

- 60 MPa / 9,000 psi

- 420 MPa
- 60 KSI

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85 MPa CONCRETE SPECIFICATION

- $f'_c = 85$ MPa (12,300 psi) at 90d
- MOE = 43.3 GPa (6300 ksi) at 90d
- Mix: Near SCC

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
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<tr>
<td>OPC</td>
<td>696 lb</td>
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<tr>
<td>SF</td>
<td>76 lb</td>
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<tr>
<td>PFA</td>
<td>170 lb</td>
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<tr>
<td>3/8&quot; CA</td>
<td>1580 lb</td>
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<tr>
<td>Fine Agg</td>
<td>1245 lb</td>
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<tr>
<td>Water/Ice</td>
<td>235 lb</td>
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<tr>
<td>HRWR</td>
<td>Polycarboxylate</td>
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<tr>
<td>VMA</td>
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<tr>
<td>Water/Cementitious Ratio</td>
<td>0.25</td>
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<tr>
<td>Density</td>
<td>156 pcf</td>
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HIGH STRENGTH CONCRETE TESTING

Jeddah Tower C85 Concrete Compressive Strength: Aggregate Comparison

- 7 Days Mekkah
- 28 Days Mekkah
- 56 Days Mekkah
- 90 Days Mekkah
- 180 Days Mekkah
- Mean Mekkah
- Standard Deviation Mekkah
- 7 Days Medina
- 28 Days Medina
- 56 Days Medina
- 90 Days Medina
- 180 Days Medina
- Mean Medina
- Standard Deviation Medina
SITE SEISMICITY

- Saudi Building Code (SBC 301)
  - Site Class B
  - Seismic Design Category B

- Site Specific Hazard Analysis Performed
  - SBC 301 is conservative
WIND CLIMATE ANALYSIS

[Bar chart showing wind speed data for various locations including Miami, Hong Kong, Shanghai, Jeddah, NYC, Chicago, and Dubai. The chart includes actual wind climate for Dubai and Jeddah.]
WIND TUNNEL TESTING

HFFB
- 6/11/2010
- 1:800 Model

HFPI
- 6/25/2010
- 1:600 Model

HFPI - SPIRE Only
- 10/19/2010
- 1:400 Model

Aeroelastic
- 1/18/2012
- 1:600 Model
WIND TUNNEL PEER REVIEW TESTING

HFPI (1:600) Tests

RWDI (JUNE 2010)  
BLWTL/UWO (DEC 2010)
WIND SPEED PROFILE

Mean Wind Speed (m/s)

0m 200m 400m 600m 800m 1000m

Atmospheric Boundary Layer

Planetary Boundary Layer

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Thornton Tomasetti

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UPPER LEVEL WIND CLIMATE ASSESSMENT

- Historical Surface Wind
- Air Balloon Sounding
- Weather Research Forecast Model
MOTION PREDICTIONS – OCCUPANT COMFORT

Highest Occupied Floor (Level 163: 654m)

- 1.5% Damping
- 2.0% Damping
- 5.0% Damping

Total Peak Acceleration (milli-g)

Typical Time Between Occurrences

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ANALYTICAL SOFTWARE
FUNDAMENTAL PERIODS / MODE SHAPES

Mode 1 - 11.9s
Single Curvature
Translation

Mode 2 - 11.2s
Single Curvature
Translation

Mode 3 - 5.8s
Single Curvature
Torsion
SUBGRADE CONDITIONS

- Competent Coraline Limestone
- Siltstone
- Gravel Layer
- Moderate/Weak Sandstone
- Hard Sandstone
PILED RAFT FOUNDATION
SETTLEMENT PREDICTIONS

Time = 47 Months

Estimated Settlement Contour 47 Months after Start of Tower Walls
Installed Wt of Tower = 7830 MN 100% Complete
PODIUM CONSTRUCTION
CONSTRUCTION STAGE ANALYSIS

Representative Stages – Construction Sequence
BAYESIAN STATISTICAL ANALYSIS

Creep Calibration

*Graph showing creep calibration with various lines representing predictions, confidence intervals, and data points.*
LOAD REDISTRIBUTION OVER TIME

Effect of Creep & Shrinkage may redistribute load over time
LONG TERM MOVEMENTS

At End of Construction

- Static (ETABS)
- Staged (Midas)

At 10 Years

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CONSTRUCTION: PILING WORKS
CONSTRUCTION: RAFT FOUNDATION
CONSTRUCTION: TOWER WALLS BEGIN
CONSTRUCTION: BASE OF TOWER
CONSTRUCTION: TOWER SLABS
CONSTRUCTION: CURRENT

April 2018

Progress:

- Height ~260m
- Exterior Wall Installation Commenced
- First Column Setback Reached
- 40% of Concrete has been placed
- Jeddah Economic City Infrastructure Works Commenced