Designing a Supertall for the Venice of China

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Project Description

- Tallest building when built
- West of Jinji Lake in Suzhou CBD
- 137-story, 729m tall
- Total site area: ~ 16,573 m²
- Total GA: 498,795 m²
  - Above Ground: 375,453 m²
  - Basement: 123,342 m²
- Functions:
  - Tower: Office, Apartment, Hotel
  - Podium: Retail, Ballroom
  - Basement: Parking, MEP space

3D View- Courtesy of Gensler
Title: Tower Vertical Stacking: 9 Zones

- L1 (0.0 m) - Z1: Retail/Conference
- L11 (74 m) - Z2~Z3: Office
- L43 (+210.5 m) - Z4~Z7: Apartment
- L104 (+457.1 m) - Z8~Z9: Hotel
- L138 (+598 m) - Tower Crown
- (+729 m)
Tower Lateral system

Core-Outriggers-Mega Frame

- Concrete Composite Core
- Exterior Mega Frame:
  - (12) sloping Super columns
  - 5 Sets of Outrigger Trusses
  - 9 sets of Belt Trusses
Tower Lateral system

- Composite Core Wall
- Super Column
- Outrigger Truss
- Belt Truss
- Horizontal Bracing
Tower Lateral system

- Composite Core Wall
- Super Column
- Outrigger Truss
- Belt Truss

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Tower Lateral system

Composite Concrete Core

- Zone 1 & 2:
  - 35m square, 4X4 cells

- Zone 3 to 5:
  - Cut corners

- Zone 6 to 8:
  - 20.2m square, 2X2 cells

- Zone 9: 20 X 14m Rectangle, 2X2 cells
Tower Lateral system

Composite Core Wall: Embedded Steel in Core
- Steel plate at bottom zones
- Steel column at corner and intersection
- Outrigger truss member in wall
Tower Lateral system

Super Column:

- 8 Middle Columns + 4 Corner Columns
- Max Size: 3.7m X 5.2 m
- Steel Reinforced Column (SRC)
  - Reduce Column Size
  - Enhance strength and stiffness
- Work with Outrigger Trusses to provide bending stiffness
Tower Lateral system

Outrigger Truss (ORT)

- 5 sets along building height
- 2-story tall
- Link Core Wall and Super Columns to provide bending stiffness
- Effective to control story drift to meet stringent code limit of 1/500
Tower Lateral system

Tower Perimeter Mega Frame

.Symbol: Super Columns
.Symbol: Belt Trusses
  - 9 sets along building height
  - Located at MEP/Refuge levels
  - 2-story tall
  - Serve as transfer truss to support gravity column with one zone
.Symbol: Provide Secondary Lateral Resisting system
.Symbol: Enhance structural redundancy
**Tower floor system**

- Composite Slab System
- Lighter Weight and no formwork
- Typical Floor: 125 mm thick composite slab
- Typical MEP/Refuge floor: 200 mm thick steel trussed formwork system

- Closed form deck

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Tower Crown

- **Spire structure**: 729m
- **Quadra-pod structure**: 688.6m
- **TMD supporting structure**: 643.5m
- **Height from base**: 523.0m
Supplemental Damping System (SDS)

China Academy of Building Research (CABR) performed 3 types of wind tunnel test
- High-frequency Force-Balance (HFFB)
- High-frequency Pressure Integration (HFPI)
- Aeroelastic model

Max accelerations for 10-year wind exceed code limits (unit m/s^2)

<table>
<thead>
<tr>
<th>Test Model</th>
<th>EL.598m (Hotel)</th>
<th>EL.462.6m (Residential)</th>
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</thead>
<tbody>
<tr>
<td>HFFB</td>
<td>0.274</td>
<td>0.180</td>
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<tr>
<td>HFPI</td>
<td>0.267</td>
<td>0.177</td>
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<tr>
<td>Aero-elastic model</td>
<td>0.258</td>
<td>0.185</td>
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<tr>
<td>Code limit</td>
<td>0.25</td>
<td>0.15</td>
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</tbody>
</table>

Supplemental Damping System (SDS) is required
Supplemental Damping System (SDS)

- Combined System to reduce space
  - ~600-ton Tuned Mass Damper (TMD)
  - ~600-ton Tuned Sloshing Damper (TSD)
Tower Analysis

- State of art Analysis Approaches
  - Linear spectrum analysis
  - Linear time-history analysis
  - Nonlinear dynamic time-history analysis

- Two different analysis software to cross check

- Performance-Based Design
  - Evaluate tower performance under 2475-year earthquake

- Progressive Collapse Analysis

- Abide by China Building codes

- Adopt specifications from international codes
Tower Analysis Result

**Height/width Ratio:**

**Building Periods:**
- T1 = 9.04 second

**Story Drift Ratio:**
- meet 1/500 code limit under 50-year wind and 63-year seismic load

<table>
<thead>
<tr>
<th>Component</th>
<th>Period</th>
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<tbody>
<tr>
<td>X Translation</td>
<td>T1 = 9.04s</td>
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<tr>
<td>Y Translation</td>
<td>T2 = 8.73s</td>
</tr>
<tr>
<td>Z Torsion</td>
<td>T3 = 3.98s</td>
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</tbody>
</table>
Podium

- 8-Story Tall
- Separated from Tower by seismic joint
- Column free at ground floor
- Large column spacing at retail and ballroom levels
Podium

Structural System

- Three cores
- Composite columns next to expansion joint
- Mega trusses at top floors connecting between cores and composite columns
Podium

Gravity system

- Composite slab: 125 mm thick (60mm concrete + 65 mm deep closed form metal deck);
- Hanger supported by mega truss to cut the floor framing span
- Floor truss for long span area - Ballroom
Podium

FLOOR VIBRATION

- Potential floor vibration due to dancing activity
- Mitigation scheme
  - Increase structure stiffness
  - Add mass damper

Figure 12 - Mitigated floor response on Level 7 due to 100 dancers (higher density)
Figure 13 - Mitigated floor response due to 100 dancers in small ballroom
Concrete Frame System

- B3 & B4: flat slab with drop panel for packing function
- B1 & B2: one-way beam slab system @ MEP space
- Ground Floor: Two-way beam slab system for fire truck and landscaping
## Geotechnical Conditions

<table>
<thead>
<tr>
<th>Soil Stratum Succession</th>
<th>Soil Stratum Name</th>
<th>Bottom of stratum Elevation (m)</th>
<th>Recommended foundation bearing capacity (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(4)</td>
<td>Silty clay</td>
<td>-2.09~ -5.52</td>
<td>150</td>
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<td>(5)</td>
<td>Sandy silt</td>
<td>-6.49~ -16.86</td>
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<td>(6)</td>
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<td>(8) 1</td>
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<td>(8) 2</td>
<td>Silty clay with sandy silt</td>
<td>-28.82~ -33.69</td>
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<td>(9)</td>
<td>Silty sand</td>
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<td>(10) 1</td>
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<td>(10) t</td>
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<td>(10) 2</td>
<td>Silty clay</td>
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<td>180</td>
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<td>(11)</td>
<td>Sandy silt with silty clay</td>
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<td>(12) 1</td>
<td>Clay</td>
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<tr>
<td>(12) 2</td>
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<tr>
<td>(13) 1</td>
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<td>-94.53~ -101.44</td>
<td>500</td>
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<td>(13)m1</td>
<td>Silty clay</td>
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<td>(13)m2</td>
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<tr>
<td>(13) 2</td>
<td>Fine sand</td>
<td>-141.82~ -146.98</td>
<td>650</td>
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</tbody>
</table>

### Site Conditions

- ** Poor soft soil condition
- ** Layers of sands and clays alternate to at least 120m below grade
- ** Long bored pile required
- ** High Water Table
- 0.5m below grade
- ** Deep basement :~27m
- ** Tension piles are required
Foundation

**Tower Area**
- 1.1m diameter pile, 110m long, 75m effective, bearing layer 13-2
  - Capacity: 16000kN
- A staggered pattern pile layout instead of a simple grid pattern under core and super column area

**Podium Core Area**
- 1.1m diameter pile, 100m long, ~65m effective,
  - Capacity: 13000kN

**Other Area**
- Top-down Column: 1.1m diameter pile, 100m long, ~65m effective, capacity 13000kN
- Tension pile: 0.8m Dia.
  - Tension capacity: 2500kN
Green Building Consideration

- For two certification
  - LEED
  - China Green Star

- Structural engineer credits:
  - All concrete are pre-mixed concrete.
  - >60% of building materials are supplied within 500km of project site.
  - >80% of concrete: C50 and above
  - >80% of structural steel: Q345 & above
  - >80% of reinforcement: HRB400 & above
Conclusion

Goal: Achieve an efficient structure that integrates with Architecture

Tower: An “Core-Outriggers-Mega Frame” system that utilize MEP / Refuge levels to improve the structural efficiency

Podium: Unique long span structures supported on three cores with floors hanging from below

Foundation: Classic Pile-Supported Mat system to sustain the massive tower

3D View- Courtesy of Gensler
Project Design Team Credits

Client: Zhong Nan Construction
Architect: Gensler
Structural Engineer: Thornton Tomasetti Inc.
MEP Engineer: Parsons Brinckerhoff
Local Design Institute: Eastern China Architectural Design & Research Institute CO., LTD
Wind Engineering Consultant: China Academy of Building Research
Fire Safety Consultant: Rolf Jensen & Associate (RJA)
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Questions?