SHANGHAI TOWER
• INTRODUCTION
• STRUCTURE FEATURES
• FOUNDATION SYSTEM
• LOADING ANALYSIS
• LATERAL LOAD BEHAVIOR
PART 1 INTRODUCTION

• General Information
• Design Concept
• Building Layout
General information

Status: Topped-out
Location: Lujiazui, Pudong, Shanghai

Architectural: 632 m (2,073 ft)
Floor count: 121
Floor area: 380,000 m² (4,090,300 sf) above
170 m² (1,800 sf) below

Architect: Gensler
Engineer: Thornton Tomasetti
Sculpted for Efficiency
The wind tunnel test is used to find the most beneficial scaling factor of about 55% and rotation at 120°, which is account for the 24% savings of the wind load working on the structure.

Technical Innovation
The concrete core acts with outriggers and supercolumns are the advances science of super-high rises.

Vertical Community
Shanghai tower embodies a new concept of super-tall building by emphasizing public spaces at the atrium levels.

Sustainable Achievements
There are two layers of skin wrapping the entire building. The atriums created by the skins features as an insulation which keep the temperature stable.
Building Layout

Shanghai tower’s program is organized into 9 vertical zones.
PART 2 STRUCTURE FEATURES

- Structure System
- Connection Description
Structure Component

- Curtain Wall System
- Main Structure System
Tower Top

Vertical fin-like truss
Two-way truss
Octagonal steel frame bracing system
Curtain Wall System

Diagram of positive and negative wind cladding loads (RWDI)
Main Structure

Inner Cylindrical Tower
• Core
• Outrigger
• Mega Frame: Super column system and belt trusses

The lateral and vertical resistance of the tower will be provided by the inner cylindrical tower.

The primary lateral resistance is provided by the core, outrigger, and supercolumn system.
Inner Cylindrical Tower
Core of the zone 1 and basement

shear wall: steel plate and concrete combination
Outrigger

Double stories
In the steel section of the super columns, there are perpendicular cross ribs that align with belt trusses.

Radical Outrigger

One story
Mega Frame

Supercolumn System: two at each end of each orthonormal axis
four diagonal supercolumns along each 45-degree axis
Connection Description

- Complexity of stress state.
- Connections should be broken after the destructiveness of members.
- Different connections have different design criteria, according to the variation of structure members.
Type A: The Joint of Outrigger to Super-column
Technical Features

- The chords of outrigger truss
- Gusset plates, 120mm thickness, Q390GJC steel
- The steel reinforced dual web of the super-column
- The belts trusses
Design Principle

- Gusset plate design should ensure that every rod of outrigger truss would be anchored strongly in the gusset plate.
- Gusset plate design should ensure that the joint action of webs and chords of outrigger have enough strength.

Stress State

- The members of outrigger bear compress and tension bending.

Safety Estimation

- The final undermine performance are the local instability and over-large plastic deformation in each plates of diagonal web members of outrigger truss, while there is no damage in node area.
Type B: The Long Bolt Joint of the Belt Truss
Technical Features

- Since there exist large member force of the chords in the belt trusses, there are large quantity of the bolts, and super length of the bolts set.
Stress State

- Internal Force Analysis under axial force
- Internal Force Analysis under bending moment
- Internal Force Analysis under real loading
Type C: The Detail of Interior Curtain Wall
Type D: The Detail of Exterior Curtain Wall
PART 3 FOUNDATION

- Soil Condition
- Foundation System
Soil condition and test pile

- Soft soil area
- Groundwater buoyancy 90% (practical design considerations 80% of water buoyancy)
- Select ⑨ 2 layer containing gravelly coarse sand layer, as pile bearing stratum
Foundation System

- Piled raft foundation
- Diameter 121 m, 6 m thick reinforced concrete circular platform
- Bored pile, pile length 56m in the core area, 52m in the extension area
Excavation

- Tower foundation pits area of 11,500 square meters and a depth of about 31 meters
- Non-beamed single building pit
Piles

- Staggered pile arrangement in load concentrated area
- Orthogonal shaped pile arrangement in other area

<table>
<thead>
<tr>
<th>Method</th>
<th>Ratio of load</th>
<th>Ratio of buoyancy considered</th>
<th>Ratio of load</th>
<th>Ratio of buoyancy considered</th>
<th>Ratio of load</th>
<th>Ratio of buoyancy considered</th>
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<td>1</td>
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<td>68.0</td>
<td>100</td>
<td>62.1</td>
<td>100</td>
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<tr>
<td>2</td>
<td>90.0~95.0</td>
<td>0</td>
<td>77.6</td>
<td>60</td>
<td>68.1</td>
<td>80</td>
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<tr>
<td>2</td>
<td>70.7</td>
<td>68.0</td>
<td></td>
<td></td>
<td>62.4</td>
<td></td>
</tr>
</tbody>
</table>

56m length in core area, staggered
52m length in others, Orthogonal
52m length in s-column area, staggered
Raft

- raft thickness is determined by the strength of anti-punching, and then check the flexural strength
- 6m thickness (3.7m of Dubai Khalifa tower)
- Variable Stiffness Design to control Settlement
- Variable Stiffness iterative method to calculate the resulting of pile stiffness after the amended merger
PART 4 LOADING ANALYSIS

- Lateral Load Resisting System Description
- Gravity Loads Transfer Path
- Lateral Loads Transfer Path
- Multi-frame Analysis
Lateral Load Resisting System

The lateral load resisting system is comprised of:

a) an interior reinforced concrete core
b) exterior composite super columns
c) steel outrigger and belt trusses

The proportion of loads carried by the mega-frame and tube of core

<table>
<thead>
<tr>
<th>Structure components</th>
<th>Gravity loads</th>
<th>Shear force</th>
<th>Overturning moment</th>
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<tbody>
<tr>
<td>The Mega-Frame</td>
<td>50%</td>
<td>47%</td>
<td>76%</td>
</tr>
<tr>
<td>The tube of Core</td>
<td>50%</td>
<td>53%</td>
<td>24%</td>
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## Gravity Loads Transfer Path

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The belt truss of each reinforcement layer transfer the gravity load to the super-columns and corner columns. In addition, in the device layer above the reinforcement layers, multi-channel radial truss are arranged to bear the vertical loads produced by electromechanical device and entertainment layers. In the cantilevered end of the radial truss, there are cables hanging the exterior curtain wall of each zone below.
Load hanging the cable of the exterior curtain wall

Load from the electromechanical device and entertainment layers
Wind loads reach to the surface of the building, and are transferred to the super-columns, thus the mega-frame could carry larger part of the lateral forces.
Lateral Loads Transfer Path

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In the reinforcement level, part of the wind load will be horizontally transferred through the outriggers to the concrete core, and then transferred to the foundation vertically.
Multi-frame Analysis

Building resist to Lateral loads through 3 layers of structure, they transfer wind and seismic load one by one, from inside to outside.

The Supper core is the first layer of Resistance.

The double belt truss and super column are the second layer of Resistance.

The outriggers and radial trusses are the third layer.
Multi-frame Analysis

- Shear
- Moment
- Tension
- Deflection
Multi-frame Analysis
PART 5 LATERAL LOAD BEHAVIOR

- Wind Load Behavior
- Seismic Load Behavior
Seismic Analysis

Building reposed to Minor Richer scale

Building reposed to Strong Richer scale

1. Core + Super Column

2. Core + Double Belt Truss

3. Core + Radial Truss
Seismic Analysis

Figure 5  Multi-layer shell element.
Figure 8  Typical load cases of mega-columns. (a) Axial compression; (b) bending in X direction without compression; (c) bending in Y direction without compression; (d) bending in X direction with varied compression; (e) bending in Y direction with varied compression; (f) bending in X and Y directions with varied compression.
Wind Load Resisted Methods

The effective building shape modification methods

a) the twisting angle
b) building orientation
c) shrink ratio of building plan along the building height

Table 2 Base reaction comparison of schemes with different twisting angle and orientation

<table>
<thead>
<tr>
<th>Building scheme</th>
<th>Base overturning moment</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular section</td>
<td>6.22E+10</td>
<td>100%</td>
</tr>
<tr>
<td>100° TA, 0° OA</td>
<td>5.18E+10</td>
<td>83%</td>
</tr>
<tr>
<td>110° TA, 0° OA</td>
<td>4.92E+10</td>
<td>79%</td>
</tr>
<tr>
<td>180° TA, 0° OA</td>
<td>4.18E+10</td>
<td>67%</td>
</tr>
<tr>
<td>120° TA, 0° OA</td>
<td>4.75E+10</td>
<td>76%</td>
</tr>
<tr>
<td>110° TA, 30° OA</td>
<td>4.48E+10</td>
<td>72%</td>
</tr>
<tr>
<td>120° TA, 40° OA</td>
<td>4.15E+10</td>
<td>67%</td>
</tr>
</tbody>
</table>

Note: 100 years return period, damping ratio 2.0%. TA: twisting angle. OA: orientation angle
Wind Load Resisted Methods

The tuned mass damper
THANKS!