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The Tallest Concrete Building in Shanghai, China – Plaza 66

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1.0 INTRODUCTION

Plaza 66 is the latest addition to the skyline of Shanghai, China; with a height of 281.5 meters, it's the tallest concrete building in the city (see Figure 1). A 62-story tower, adjacent five-story retail podium and three level below-grade parking area form a three million square foot mixed-use commercial development (see Figure 2). This project embodies the challenges of building in a seismic and typhoon area with poor foundation conditions and materials of relatively limited strength, and illustrates solutions developed to meet those challenges.

Figure 1 City with Plaza 66.

2.0 DESCRIPTION OF THE PROJECT

The most visible feature of the project is the 62-story concrete tower, topped by a 36.5 m (120 ft.) tall steel-framed lantern that will glow on the skyline. Total building height is 281.5 m (923 feet). Adjacent to the tower is a 60,000 m^2 (600,000 ft^2) retail podium (see Figures 3 and 4). The retail podium includes three feature spaces: an atrium with a boat shaped skylight, an arc-shaped sky lit galleria, and a column-free rotunda six stories tall (see Figure 5).

Under the retail podium, a three-story underground parking structure for 9,000 cars and 1,500 bicycles encompasses the entire project footprint. The underground structure is enclosed by a slurry wall built with special construction bracing techniques.

Figure 2 Aerial Overall Plaza 66.

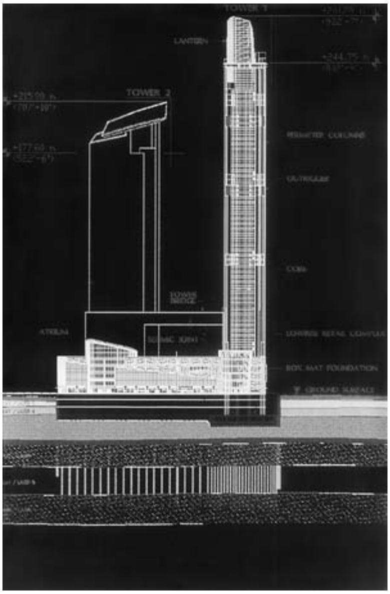

Figure 3 Cross Section.

3.0 TOWER STRUCTURAL SYSTEMS

3.1 Lateral Load Resisting System

The key to designing the tallest concrete building in Shanghai was its lateral system. The challenge of resisting lateral loads from typhoon winds was compounded by the limited strength of available materials to resist the forces generated. Modern concrete high-rise towers often use concrete strengths exceeding 80 MPa cube strength (10 ksi cylinder strength), but locally only strengths up to 50 MPa (6 ksi) were available. Steel reinforcing with fy = 410 MPa (60 ksi) is typically used today for main reinforcing, but locally available reinforcing was limited to about 335 MPa (48 ksi).

A further challenge was a local building code that limited the allowable drift of the building due to wind loads to height/800, whereas height/500 is commonly used for high-rise towers in other areas. Based on wind studies and analyses of building accelerations, Thornton-Tomasetti Engineers was able to convince a panel of local building authority experts over several meetings that an allowable drift of height/650 was acceptable for this project.

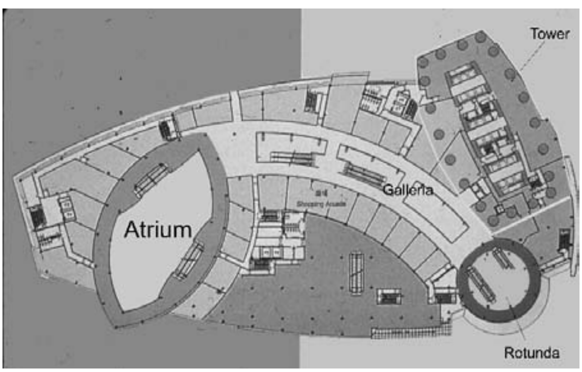

Figure 4 Overall Plan.

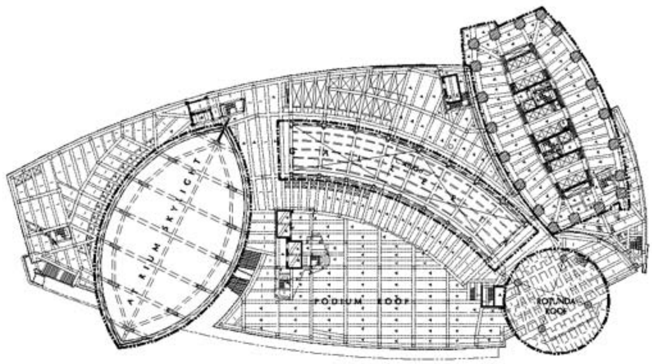

Figure 5 Roof Structural Plan.

A crucial innovation for the Plaza 66 tower was the use of a concrete core with perforated concrete outriggers. The concrete outriggers are located at three mechanical zones at floors 24–26, 39–41 and 54–56. Although steel truss outriggers have been used in steel framed and composite towers, the use of concrete outriggers has been limited because typically they are solid wall elements that cannot readily be penetrated. In the case of Plaza 66, an innovative two-story outrigger system addressed this problem. Each outrigger wall has four large openings, two on each floor (see Figure 6).

In this arrangement, the top and bottom members of the outrigger provide the tension and compression force couple required of the outrigger while the central member at the middle floor transfers the shear. The result is four large planned openings that allow mechanical ducts, piping and pedestrians to circulate around the core (see Figure 7).

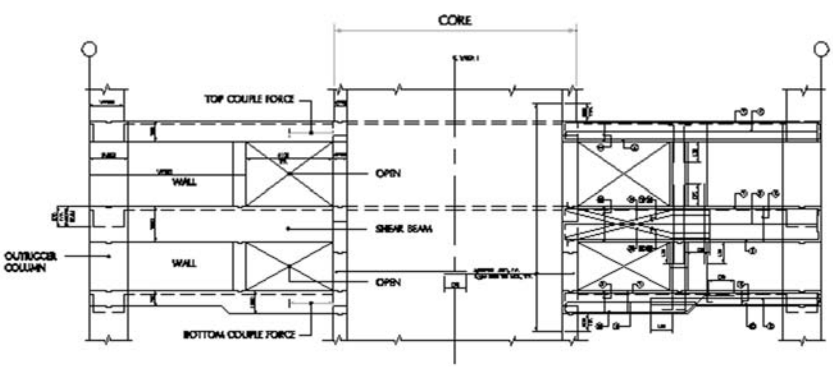

Figure 6 Outrigger Elevation.

Figure 7 Outrigger Photo.

Six paired sets of outriggers extend from the long faces of the core, enabling all longitudinal perimeter columns to efficiently contribute to the lateral load resisting system (see Figure 8). Augmenting the outrigger system is a perimeter frame to resist torsional modes of building motion. Perimeter beams are 1250 mm (49") deep by 975 mm (38") wide, between perimeter columns spaced about 9 meters (30 feet) on center. The perimeter frame meets the requirements of a special seismic moment frame.

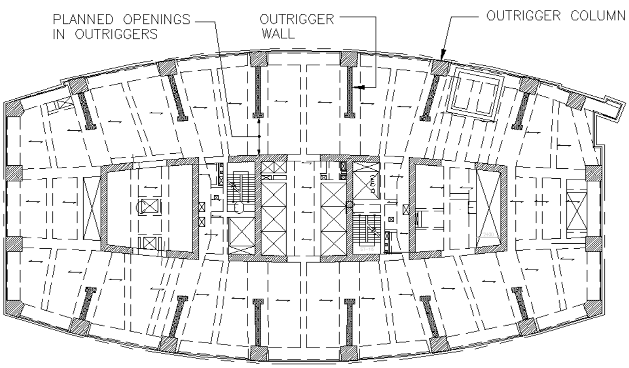

Figure 8 Typical Plan.

3.2 Foundation System

Soil conditions in Shanghai are not conducive to supporting the heavy loads generated by tall buildings. Layers of sand and clay alternate to a great depth. Bedrock is beyond reach. Therefore, this tower is supported on a dense sand-bearing stratum about 90 meters (300 feet) below grade. End bearing concrete bored piles 800mm (2' 7") in diameter, 80 meters (263 feet) long were used. The piles extend 9 meters (30 feet) into the sand bearing strata (see Figure 3) to create effective embedment.

Complicating the challenge of resisting overturning moments, the tower was located near the perimeter of the site. A special cellular mat, bearing on the concrete bored piles, was designed to resist tower gravity and overturning forces (see Figure 9). Although the tower is 58.5 meters (193 feet) long and 34 meters (111 feet) wide at its widest point, the mat is considerably larger, 80 meters (253 feet) long and 55 meters (180 feet) wide to resist the overturning and minimize differential settlement.

Differential settlement is a major concern in Shanghai due to highly compressible clay layers, long piles and varied loading between towers and podiums. Initial geotechnical studies predicted tower settlement to exceed 1000 mm (40 inches). But after studying the actual behavior of other towers nearby, predicted settlement of the tower was revised to 280 mm (11") with anticipated differential settlement between the tower and the podium of up to 230 mm (9"). Through the use of the load-spreading cellular mat, actual performance to date has been consistent with these revised settlements, and differential settlement is only about 80% of predictions. The structure was designed to accept this differential settlement through use of delayed concreting at pour strips.

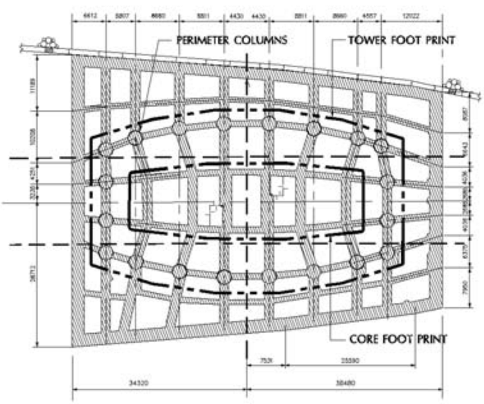

Figure 9 Mat Plan.

The three-story below-grade foundation walls, almost totally under water, also used an innovative approach, slurry wall construction with concrete cross-lot bracing. The slurry wall in the podium area is 800 mm (32") thick and 25 meters (82 feet) deep. In the tower area it is 1 m (39 inches) thick and 33 m (108 feet) deep. During construction, three planes of temporary bracing were placed in the podium and four planes of temporary bracing were used in the tower area. Bracing was constructed from top down, with bracing struts cast against earth as excavation proceeded downward. Bracing was removed from the bottom up, with each level removed as its corresponding basement floor immediately below was completed.

3.3 Floor Construction

The typical floor footprint represents a truncated ellipse (see Figure 10) 58.5 m (192 feet) long and up to 34 m (111 feet) wide. The perimeter frame discussed for the lateral system extends through the podium. In addition, beams at 4.5 m (15 feet) on center span between the core and perimeter frame. Beams on column lines participate in the lateral resistance of the tower and are 1200 mm (48") deep. Other beams are 450 mm (18") deep, including the 125 mm (5") slab.

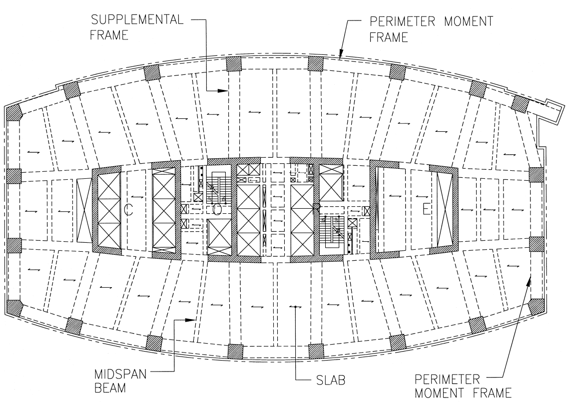

Figure 10 Typical Framing Plan.

3.4 Roof Top Lantern Structural System

The 36.5-meter (120 feet) high lantern structure is a hollow irregular square in plan. It surrounds and supports the mechanical cooling towers. The lantern consists of perimeter horizontal trussed rings (see Figure 11) and vertical trussed column pairs. Lateral resistance is provided by vertical bracing parallel to the perimeter, creating an open-topped trussed "box". Architectural lighting completes this luminescent structure that crowns Plaza 66.

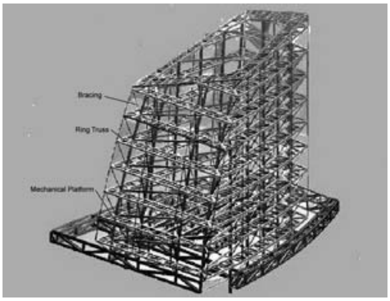

Figure 11 Isometric Lantern.

Figure 12 Atrium Skylight.

4.0 PODIUM STRUCTURAL SYSTEMS

4.1 Atrium Roof Skylight

The atrium roof skylight structure consists of tapered concrete portal frames spanning the 67-m (220') by 38 m (125') atrium plan. The architect conceived the atrium configuration as a hollow, reflecting the inverse of the solid form of the tower (see Figures 12 and 5). The tapered frame members that span the space vary in depth, shallow at their column bases and beam mid spans, and deeper at beam/column "knees". The sculptural effect at the columns is further emphasized by using elongated octagons in cross section.

4.2 Galleria Skylight

The curved gallery skylight utilizes a structural frame system similar to the atrium skylight but with smaller spans, as the galleria is 66 m (217') by 17 m (54') (see Figure 5).

4.3 Rotunda Roof

The drama of the rotunda structure is enhanced by a roof 28 m (93 feet) in diameter, bearing on only four column supports and shifted off the rotunda's center. The four columns form a square in plan, with two of the columns 3 meters (10 feet) in from the circumference and the other two 9 meters (30 feet) in.

The rotunda roof cantilevers varying distances past the four support columns to reach the circumference, creating a special sense of entry for the Plaza 66 project (see Figure 5).

5.0 CONCLUSION

Plaza 66 is a unique project that overcame challenges of poor soil conditions, limited material strengths, and a conservative building code to create a tower that soars above the city, providing a new landmark for Shanghai. Innovative design approaches included creating two-story outriggers with a system of cross openings. Plaza 66 stands out as an example of designing and building a tower under difficult conditions and achieving economical structural solutions without compromising aesthetic design integrity

6.0 CREDITS

The Authors would like to thank Len Joseph, I. Paul Lew and Yi Zhu, Project Manager, for their tireless work during design and construction.

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