Trump International Hotel and Tower

CHICAGO, ILLINOIS

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Figure 1: Computer rendering, Trump International Hotel and Tower, Chicago. Courtesy of Skidmore, Owings & Merrill LLP and Crystal CG.

The recently completed structure of the Trump International Hotel & Tower, designed by Skidmore, Owings & Merrill LLP (SOM), rises to a height of 1,134 feet (345.6 m), or 1,362 feet (415.1 m) including the spire. The 92-story building is located in downtown Chicago, on the north side of the Chicago River (*Figure 1*). It is the tallest concrete building in the United States, and the tallest building constructed in North America since the completion of Sears Tower in 1974. The project is highlighted by a series of high-performance concrete mixes specified by SOM and designed by the concrete supplier, Prairie Material Sales, Inc. It is believed to be the first application of 16,000 psi (110 MPa) self-consolidating concrete pumped and placed to an elevation up to 650 feet (200 m) above grade.

The tower's 2.6 million square feet (240,000 square meters) of floor space incorporates 100,000 square feet (9300 square meters) of retail space, parking for 1,000 cars, 486 condominium units, 339 hotel units, a health club, and restaurant and banquet spaces. The stainless steel and glass tower will rise from a newly landscaped plaza that will include a new river walk that will link the pedestrian level with retail shops. The building features setbacks at levels 16, 29, and 51 that correspond to the top elevations of prominent neighboring buildings, providing visual continuity with the structure's surroundings.

Structural System Summary

A core and outrigger system provides lateral stability for the Trump Tower. Large outrigger elements at the mechanical levels tie the concrete core to perimeter columns, significantly increasing the building's lateral stiffness as well as its resistance to overturning due to wind.

The core is located at the center of the building and consists of four I-shaped and two C-shaped walls at the base, and gradually reduces to two I-shaped walls above the final setback at level 51. The webs of these I- and C-sections are oriented in the north-south direction, are 18 inches (460 mm) thick, and are 41 feet (12.5 m) long. The flanges of the sections are oriented in the east-west direction, are 48 inches (1.2 m) thick, and range from 9 feet to 22 feet (2.7 to 6.7 m) in length (*Figure 2*). Above the entries to the elevator cores at each level, 48-inch (1.2-m) wide by 30-inch (0.8-m) deep reinforced concrete link beams connect the flanges of adjacent walls.

The outrigger effect is most pronounced in the shorter direction of the building (north-south), as the width of the lateral system increases from 49 to 140 feet (15 to 43 m) when the perimeter building columns are engaged. The outriggers are large reinforced concrete wall-beams, 66 inches (1.7 m) wide and 17 feet 6 inches (5.3 m) deep, that extend from the flanges of the core walls to the exterior columns at three of the double-height mechanical floors in the tower (levels 28-29, 50-51, and 90-91). These outrigger levels occur just below the building setbacks, and the outriggers also serve as transfer girders as the columns are relocated at the façade. At the lowest setback (level 16), transfer girders allow for a column-free space at the ten parking levels. Perimeter belt walls at the roof and the three mechanical levels provide additional torsional stiffness and redundancy, and also serve to equalize column loads along the perimeter.

Typical residential floors are 9-inch (230-mm) thick flat plates spanning up to a maximum of 30 feet (9.1 m) without perimeter spandrel elements. This construction minimizes the structural depth of the floor, allowing higher ceilings. Tower columns are typically 2 by 4 feet (600 by 1200 mm) rectangular sections at the top of the building and 6-foot (1800-mm) diameter circular sections at the base.

The superstructure is supported by a total of 57 rock caissons. The tower columns are supported by 33 of these caissons, which are up to 8 feet (2.4 m) in diameter and stabilized by a series of caisson caps and grade beams. A 10-foot (3-m) thick concrete mat under the core walls transfers their enormous loads into a grid of 24 caissons that are 10 feet (3 m) in diameter and extend about 80 feet (25 m) down into solid Chicago limestone bedrock, where they are socketed at 6 feet (1.8 m).

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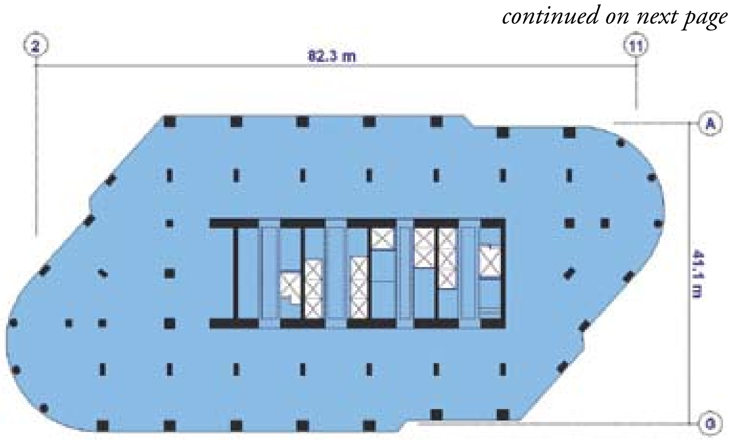

Figure 2: Typical residential floor plan.

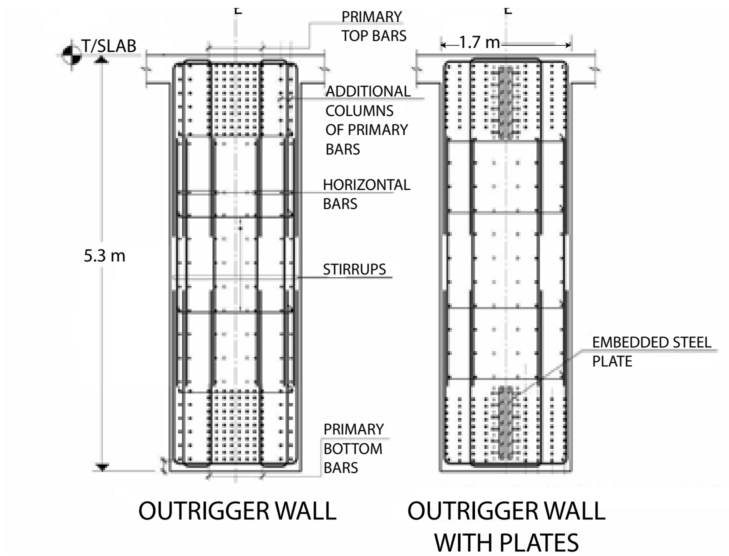

Figure 3: Outrigger wall reinforcing.

Design and Utilization of High-Performance Concrete

Because of the magnitude of the applied loads and the scale of the outrigger elements, their structural design was unique and extremely challenging. Large tie forces are resisted by top and bottom longitudinal reinforcing and vertical ties. The heavy longitudinal reinforcing steel must pass from the thicker outrigger through the thinner core wall web to transfer forces between the columns and core. To reduce congestion, all primary reinforcing bars in the outrigger levels are U.S. Grade 75 (520 MPa yield strength). Further, in three especially tight locations, high-strength structural steel plates with welded shear studs are used in lieu of reinforcing bars to transfer the necessary forces through the core wall web (*Figure 3*).

The outriggers are also significantly affected by differential shortening of the concrete columns and core walls resulting from creep and shrinkage. The columns typically have higher axial stresses, and therefore shorten more than the core walls, transferring load through the outriggers into the core walls. A special analysis was used to account for time-dependent effects, including creep, shrinkage, construction sequencing, and the variation of material properties. This analysis included eight different finite element models of the building, each representing a different period in time during and after construction. The calculated forces in the outriggers and walls were taken into account in the forces applied to the strut-and-tie model for the design of the outriggers, and were also incorporated into the design of all elements of the lateral system.

A series of high-performance concrete mixtures, specified by SOM and designed by Prairie Material Sales, Inc., are advancing the state-of-the-art. Concrete strengths of 12,000 psi (83 MPa) (cylinder strength) at 90 days have been specified for all vertical column and wall elements up to level 51. Local areas in the outrigger zones, however, require 16,000 psi (110 MPa) (cylinder strength) concrete at 90 days. Because the 16,000 psi concrete is located in areas with high reinforcement congestion, self-consolidating concrete (SCC) with a minimum flow spread of 24 inches (600 mm) has been specified. Further, to reduce the heat gain in the massive elements, the high-performance SCC incorporates slag cement, fly ash, and silica fume, as well as portland cement.

The tower structure is designed to limit the perception of motion by the building occupants during wind events to acceptable levels, and for this the stiffness of the concrete is critical. The modulus of elasticity of the high-strength concrete was therefore specified to at least achieve the modulus of elasticity values indicated in the ACI 318 equations. In contrast to the stringent minimum strength requirements in ACI 318, concrete modulus of elasticity may be specified on an average basis. Somewhat lower modulus values in local areas are therefore acceptable, as long as the average value remains as specified. Further, such modulus values may be obtained at a much later date – for example, 180 or 365 days after placement – as the motion perception criteria are long-term serviceability issues and will not be critical until the building is complete and occupied.

Construction progress – Spring 2008. Courtesy of Skidmore, Owings & Merrill LLP.

Self-Consolidating Concrete Caisson Mat Foundation

The mat pour in late September 2005 consisted of approximately 5,000 cubic yards (3,800 cubic meters) of 10,000 psi (69 MPa) self-consolidating concrete over plan dimensions of 200 x 60 feet (60 x 18 m) in a single continuous pour. The pour was accomplished in a period of 22 hours and required more than 30 ready-mix trucks making a total of 600 trips to the job site. The choice of SCC for the mat was based on the ease of placing concrete and finishing in a confined, below-grade area. It is believed that the mat foundation pour for the Trump Tower represented the largest single SCC placement in North America to date.

Mat foundation construction.

Superstructure High Strength Concrete

Trump Tower is not only a very tall building, it is also quite slender; the aspect ratio of the tower, measured as the overall height divided by the smaller base dimension, exceeds 8 to 1. Such slender buildings are known to be significantly influenced by the dynamic nature of the wind and its interaction with the structure. Concrete was chosen as the primary structural material for the Trump Tower, to take advantage of its ability to provide a highly massive frame with high damping. The high lateral stiffness of the tower was accomplished by using high modulus of elasticity concrete in the massive column, wall, and outrigger elements. All of these factors resulted in predicted peak accelerations at the topmost occupied floors that are comfortably within the ISO criteria for residential buildings.

Conclusion

The completion of the Trump International Hotel and Tower is scheduled for fall 2009. However, the owner desired to open the hotel and some of the residential levels before the topping out of the structure. Collaboration between the designers, construction manager, contractors, and the City of Chicago produced a six-stage phased occupancy plan, which allowed the hotel to be in operation as of January 2008, well before the structure topped out in mid-2008. The 228-foot tall spire was erected on top of the tower in January 2009, bringing the building to its final full height. The spire is a structural steel space truss clad in fiberglass. Erection of the upper eight segments of the spire was accomplished using a Sikorsky S-61 helicopter. It was the exclamation point to cap off a world-class building combining rigorous engineering, state-of-the-art materials, and graceful architecture.▪

William F. Baker, P.E., S.E. is the Structural and Civil Engineering Partner for Skidmore, Owings & Merrill (SOM). According to the CTBUH, three of the four tallest buildings to top out in 2009 are credited to Baker: Burj Dubai, Trump International Hotel and Tower, and Nanjing Greenland Financial Center.

Stan Korista, P.E., S.E. serves as a Senior Structural Consultant for Skidmore, Owings & Merrill LLP (SOM). Stan's work on high-rise buildings includes Jin Mao, Three First National Plaza, AT&T Corporate Center, Nanjing Greenland Financial Center and Burj Dubai.

Dane Rankin, P.E., S.E. is an Associate Director for Skidmore, Owings & Merrill LLP (SOM). In addition to his work on Trump International Hotel and Tower, Dane's project work includes 601 Congress Street, 7 Tower Bridge, GM Renaissance Center, Korea World Trade Center and Canary Wharf.

Jeremy Kirk, P.E., S.E is a project engineer with Skidmore, Owings & Merrill LLP (SOM). Jeremy's project work includes 7 Tower Bridge and University of North Carolina Genome Science Laboratory Building.

Acknowledgements

Developer:	401 North Wabash Venture LLC (The Trump Organization)
Structural Engineer:	Skidmore, Owings & Merrill LLP
Architect:	Skidmore, Owings & Merrill LLP
Construction Manager:	Bovis Lend Lease LMB, Inc.
Concrete Contractor:	James McHugh Construction Co.
Concrete Supplier:	Prairie Material Sales, Inc.
SCC Admix. Supplier:	Degussa Admixtures, Inc.

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