Title: **Case Study: Trump International Hotel & Tower**

Authors:
William Baker, Partner, Skidmore, Owings & Merrill
Paul James, Senior Vice President, Bovis Lend Lease
Richard Tomlinson, Partner, Skidmore, Owings & Merrill
Andrew Weiss, Executive Vice President, The Trump Organization

Subjects:
Architectural/Design
Building Case Study
Structural Engineering

Keywords:
Concrete
Design Process
Foundation
Structure
Sustainability
Urban Planning

Publication Date: 2009

Original Publication: CTBUH Journal, 2009 Issue III

Paper Type:
1. Book chapter/Part chapter
2. **Journal paper**
3. Conference proceeding
4. Unpublished conference paper
5. Magazine article
6. Unpublished

Case Study: Trump International Hotel & Tower


William F. Baker


Paul James


Richard F. Tomlinson


Andrew Weiss

Authors

[1]**William F. Baker**, *Partner, Skidmore, Owings & Merrill LLP*
William F. Baker is the Structural and Civil Engineering Partner for Skidmore, Owings & Merrill. Throughout his distinguished career, Bill has dedicated himself to structural innovation- most notably in the design of tall buildings within the urban landscape. In addition to working at SOM, Bill's expertise is frequently solicited by institutions of higher learning, as well as numerous professional organizations. Bill is the 2008 recipient of the Fazlur Rahman Khan medal from CTBUH and the 2009 recipient and first American to receive the Fritz Leonhardt Prize.

[2]**Paul James**, *Senior Vice President, Bovis Lend Lease*
Paul James, with over 37 years of construction expertise, has been an integral member of the Bovis Lend Lease Chicago office since 1989. Prior to coming to Bovis Lend Lease, Paul spent 17 years with James McHugh Construction Co. As Senior Vice President and Director of Technical Services, Paul manages a team of estimators, value engineers, and schedulers who provide design phase services including estimating and budget control, development of procurement criteria, schedules, and constructability and logistics planning.

[1]**Richard F. Tomlinson II**, *Partner, Skidmore, Owings & Merrill LLP*
Richard F. Tomlinson is a managing partner of the SOM Chicago office. Under his leadership, SOM continues to design some of the world's largest, most complex and high-profile projects. Mr. Tomlinson manages professionals from various disciplines within the firm and oversees the progress of key projects. As the key liaison between SOM and clients, general contractors, construction teams and specialty consultants, he ensures that SOM meets client expectations.

[3]**Andrew Weiss**, *Executive Vice President, The Trump Organization*
In charge of all major development projects, Andrew Weiss has been managing the design and construction of real estate developments for The Trump Organization, for over 25 years, including all major Trump-affiliated developments since 1981. As Owner Representative/ Project Director, Mr. Weiss leads through the development of the program, selection of the project team members, including architects, engineers, consultants and contractors to the preparation of construction documents and award of contracts.

[1-3]For author contact information, company profile and project team please see page 22.

> "Born of a place with a history of great tall buildings, the tower contributes to an exciting and ever-evolving architectural dialogue."

Chicago, a city known worldwide for its tall buildings, welcomed a new supertall tower to its skyline this year. Bookended by the 442-meter (1,450-foot) Sears Tower to the south and the 344-meter (1,128-foot) John Hancock Center to the north, the 415-meter (1,362-foot) Trump International Hotel and Tower is the tallest residential, and the largest concrete, building in the United States. It is also the tallest building project in North America since the completion of the Sears Tower in 1974, and one of the largest buildings to be partially open to the public while under construction. This last distinction, although not as glamorous as the rest, is one of the most innovative stories behind Trump Tower. It represents a feat of planning, mixed-use programming, and construction that required a remarkable degree of collaboration between the Trump Organization, architect Skidmore, Owings & Merrill LLP (SOM), construction manager Bovis Lend Lease, and the City of Chicago.

Collaboration Between Client, Architect, and City

Trump Tower rises from the heart of the city, at a point where the Chicago River curves gently to the southwest. Its 401 N. Wabash address is the former site of the low-rise Chicago Sun-Times building. When the Trump Organization purchased the land in 2001, they saw the waterfront as a natural location for a tall building that would offer 360-degree city and lake views and direct connections to the river (see Figure 1).

The Trump Organization initially envisioned a 150-story structure that would eclipse the height of the Sears Tower, but revised those plans after the terrorist attacks of September 11, 2001, when developers began to re-evaluate the perceived benefits, public perception, and marketability of supertall buildings. To maintain economic viability in the post-9/11 real estate market, the plans for Trump Tower would require continual adjustment – and readjustment – to trends that were difficult to anticipate.

Over the next two years, the tower was scaled back to a shorter office and residential building and then, when it became apparent that the Chicago market had a greater need for centrally located residential and high-end hotel space, the plans were again revised and the project re-emerged as a slender, 92-story tower that would combine luxury condominiums with a world-class hotel, riverfront retail, and amenities. With the City of Chicago's input and support, the Trump Organization and SOM approached the project with the flexibility necessary to create a building that would thrive in the city, in both the near and long term.

Urban Planning

The project's centrally located site presented an opportunity to create active open space for the city, as well as a connective link between the Chicago Loop, North Michigan Avenue, and the riverfront. With the understanding that the tower could change the way in which people experienced the Chicago River, designers shaped the building to reflect its orientation along the water. The south side of the tower parallels the riverbank and, at its base, engages with a dynamic, three-level walkway that anchors the waterfront and enlivens it with restaurants and shopping. The tower's massing, lifted by 12 meters (39 feet) at ground level, further opens up an expansive promenade that steps down, like terraces on a hillside, until it meets the water. This lively gathering place includes retail, pedestrian paths, and an extended riverwalk park system (see Figure 2 on page 18).

...livable city

> "I told them it should be like a downtown American city, with three skyscrapers, yes, but with open islands, keeping historic buildings, with pocket parks."
>
> *Christian de Portzamparc, Founder and Principal of Atelier Christian de Porzamparc comments on his urban design proposal for Brussels, to turn it into a more livable city. From 'A Bubble of Diplomats and Officials Is Set to Pop' New York Times, June 22, 2009*

In addition to creating a one-acre landscaped riverwalk, this promenade establishes a pedestrian link between North Michigan Avenue (the city's "Gold Coast" shopping district) and State Street (a key corridor that leads to the Chicago Loop). On the northern edge of the tower, at a site formerly used as a loading dock, the plan creates a lushly landscaped, walkable link between Wabash Avenue to the west and the Wrigley Building arcade to the east (see Figure 3 on page 18). A bus lane and drop-off were also planned for Lower East North Water Street to make the tower accessible by public transit and create a connection to the City's future bus corridor along Lower Carroll Street.

Figure 1. Aerial Trump International Hotel and Tower, Chicago

Architectural Concept

One of the real luxuries of living in Trump Tower is the view. As the tallest residential building in North America, the tower offers an experience of the city that exists nowhere else, with close-up views of some of Chicago's most well-known buildings. The tower relates to its neighbors through a series of setbacks, the first of which occurs at level 16, at a height that is essentially the same as the cornice line of the 130-meter (427-foot) Wrigley Building, designed by Graham, Anderson,

Figure 2. Siteplan

Figure 3. Riverwalk

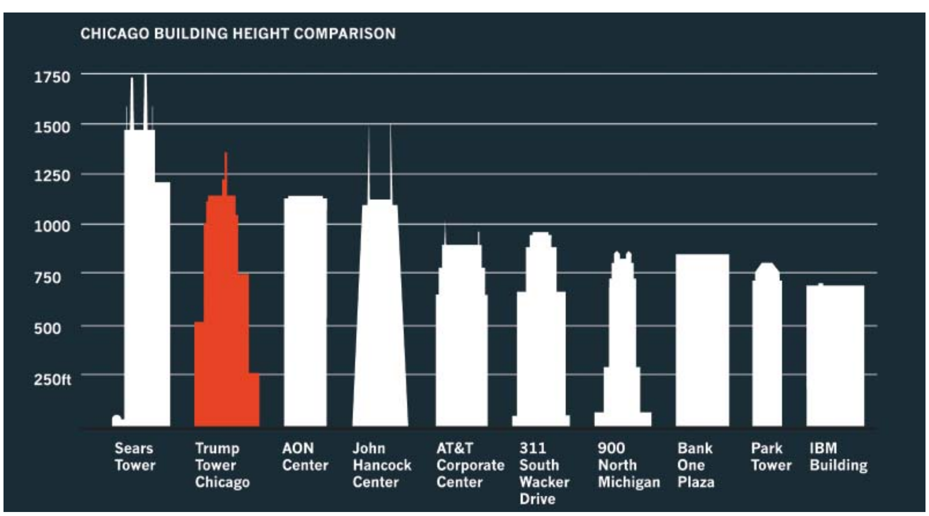

Figure 4. Chicago Building Height Comparison

Probst & White. The next setback, at level 29, relates to the height of Bertrand Goldberg's 179-meter (587-foot) Marina City towers. The third and final setback, at level 51, relates to the height of Mies van der Rohe's 212-meter (696-foot) IBM Building across Wabash Avenue (see Figure 4).

Engineered with a stiff internal concrete core and outriggers, Trump Tower's design allows the façade to be opened up and sheathed in a diaphanous glass curtain wall. The façade is adorned with clear anodized aluminum and mirror-finished stainless steel that reflects and refracts light from the sun. Outset from the glass surface, this mullion system provides density and thickness – as well as a metallic quality – to the otherwise flush glass wall.

The tower's design is also strongly influenced by the presence of water. In the lobby, for instance, a 10.6-meter-high (35-foot) structural glass wall, hung from the second floor, resembles a cascading wave. Free of steel supports, the wall is composed of a series of angled glass fins that provide open, unobstructed views of the waterfront.

Program and Use

From the outset, it was the Trump Organization's vision to develop a world-class multifunctional building with the flexibility to address market needs. In its final form, it now combines 486 super luxury condominium units with the 339-room Trump International Hotel, 9,300 m^2 (100,000 sf) of retail space, 960 parking spaces, and a number of amenities including a restaurant, banquet space, health club, lounges, and spa.

Stacking these different programs on top of one another creates a building that is not only adaptable, but also has a sense of presence on the city skyline. As in any large-scale, very tall mixed-use project, the tower required a lengthy and complex construction process. The team addressed this problem by rethinking the traditional model for mixed-use construction and commissioning, designing a plan to finish and open the parking garage and hotel in stages, in advance of the completion of the entire building. This enabled the Trump Organization to occupy the lower floors almost two years before the completion of construction and, thus, start generating income for the property.

Early Phased Occupancy

The occupancy of the garage and hotel was incredibly unique – while the bottom 30 floors of the building were occupied by the public, construction continued on the remaining 62 floors, including 32 floors of the structure yet to be built. Known as "early phased occupancy," this arrangement offers the advantage of a greater financial bottom line, since the project generates income with the completion of each phase (see Figure 5).

This type of phasing had never before been orchestrated on such a large scale, and would not have been possible without the team's expertise in advanced planning, project management and construction scheduling. Bringing in prior experience with phased occupancy from previous smaller projects, the Trump Organization made the phasing an integral and non-negotiable part of the project program. In response, from the beginning of the design process, SOM engaged in a collaborative effort with WMA, Bovis, the Trump Organization, and the City to create a comprehensive plan that met all applicable codes and standards for MEP, life safety and building systems. Drawing on insights and input from the entire team, as well as SOM's architectural ingenuity, a design was developed that could be opened and operated in five separate stages, each phase operating like a complete, self-sustaining, fully code-compliant occupied building within the greater framework of the construction activities. Occupancy began with the opening of the hotel and parking garage in January, 2008 and continued in multiple stages with the completion and occupancy of the tower, including the high-rise condos in spring of 2009. The final completion of the plaza will take place in the fall of 2009.

Coordination with City Agencies

In addition to the achievement of early phased occupancy, there were other key successes that directly resulted from well-coordinated teamwork and a shared set of goals. The Trump Organization, SOM, and Bovis worked with city agencies to tailor the project to its downtown location, improving access and connectivity between the site and the surrounding city. In collaboration with the Chicago Department of Transportation (CDOT), the team rebuilt the Wabash Avenue viaduct and realigned Wabash Avenue with Lower Kinzie Street and Wacker Drive. The project replaced the nearly 75-year-old viaduct with a bridge that meets modern CDOT standards, improving the pedestrian experience crossing the river and enhancing the riverwalk.

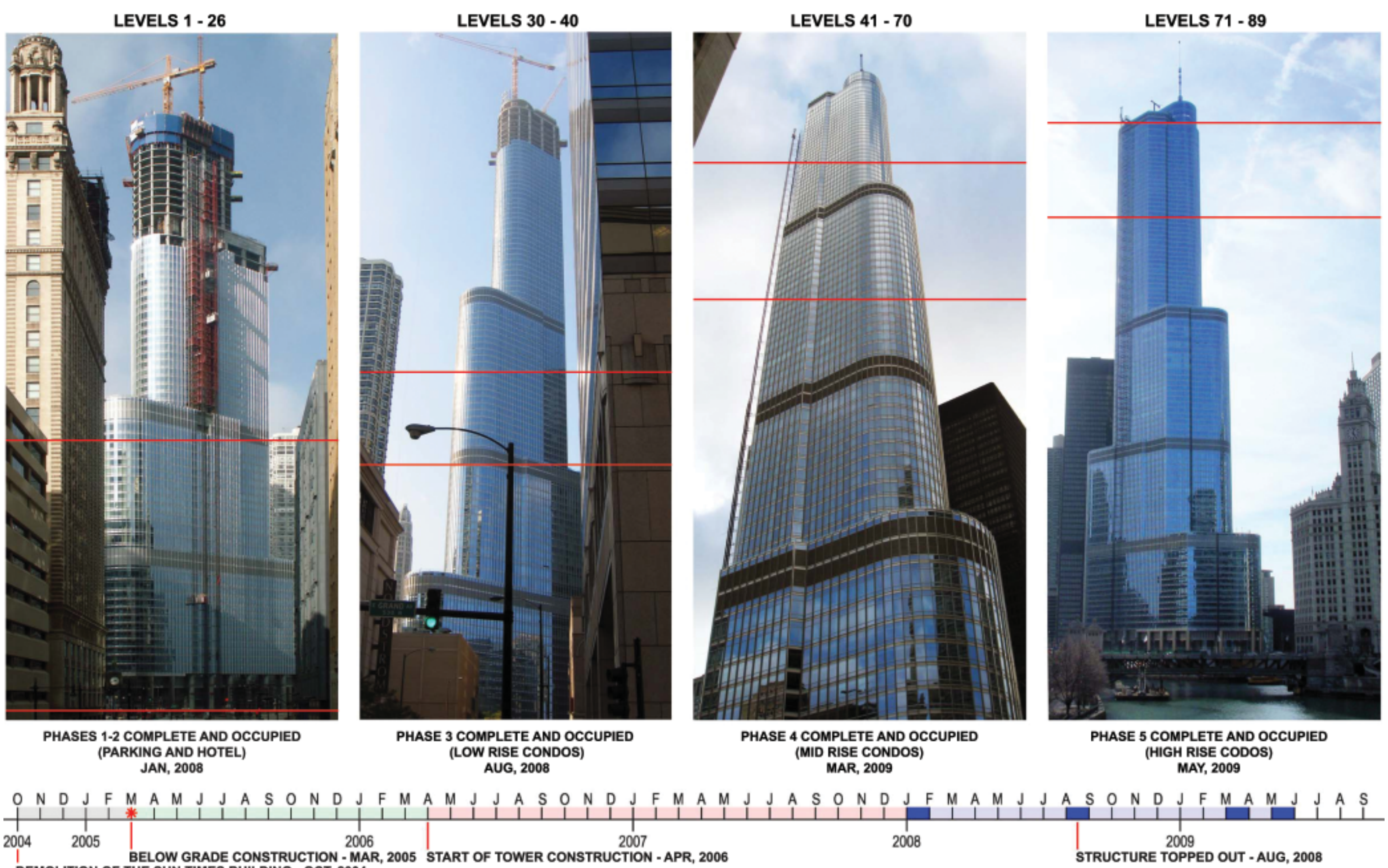

Figure 5. Phasing of the Trump International Hotel and Tower

The team also provided peer reviews and structural tests to the City to reaffirm the integrity of Trump Tower's design. When the building's program was revised from an office/residential mix to a hotel/residential building (see Figure 6), the shorter unit spans allowed the floor framing system to be revised from structural steel with a four-meter floor-to-floor height to concrete with a three-meter floor-to-floor height. This enabled three additional floors of hotel to be added within the same building height. To accommodate the increased live and dead load for these floors, SOM and geotechnical specialists, STS Consultants Ltd., utilized an Osterberg load cell test that allowed the team to increase the foundation capacity from the previous 200-tons-per-square-foot allowed by City Code to 270-tons-per-square-foot, the highest allowed bearing pressure at the time.

Sustainable Strategies

The tower employs three main sustainable strategies that translate into considerable cost savings. Chicago River water is used to cool the building. This cooling system allows water to recirculate back into the river, avoiding the costly and more energy-intensive and wasteful requirements of conventional cooling, which would require a pump and cooling tower system to eject water vapor via the roof. A computerized-control system regulates the temperature and ventilation of the tower, determining how much the air must be conditioned.

Partial green roofs can be found on the tower's terrace levels. The roofs will have a longer life span than standard asphalt, since they are protected from the ultraviolent radiation and extreme fluctuations in Chicago weather that can cause roof membranes to deteriorate. The insulation provided by the green roofs also helps to moderate the heat island effect, improve stormwater management, purify air and water, and reduce energy consumption.

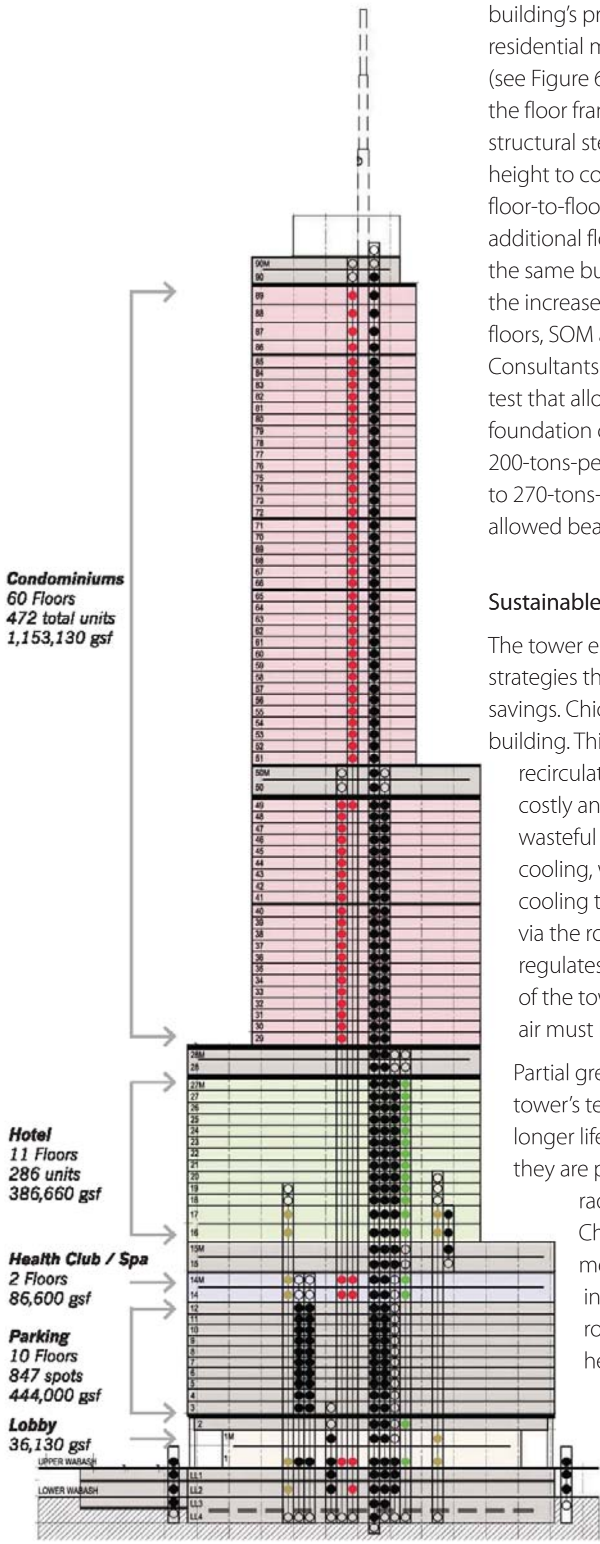

Figure 6. Section indicating Program and Use

Each of the tower's 3-meter-tall by 1.5-meter-wide (11 by 5 feet) curtain wall panels are made of thermal-pane glass encased in aluminum, with dual low-emissivity coatings that help to retain interior heat in the winter and cool air in the summer. The double-thick glass also decreases the amount of air seeping through, while tinting reduces summer sunlight, keeping inside temperatures cooler.

Structural Engineering

By integrating architectural design with engineering expertise, the team was able to minimize the number of large structural supports, both at the tower's base and throughout the upper levels, therefore maximizing views. A single round column at the bottom of the building (1.8 meters, or 6 feet, in diameter) supports 14,000 kips or 14,000,000 pounds. This translates into less perimeter columns which facilitate panoramic views of the riverbank at the lower stories, and wraparound vistas of the surrounding city at the upper levels.

Chicago's wind climate posed a significant challenge to the design of Trump Tower. In response, the tower's rounded surfaces and setbacks not only give the building its architectural character and stunning views; they also minimize wind forces. The building setbacks, along with changes in the cross-section and geometry, prevent the build-up of wind vortices, thus reducing the overall wind loads imposed on the structure (see Figure 7).

To counteract wind-induced motion perception by building occupants, many supertall buildings require dampers that reduce building accelerations. In Trump Tower, the core and outrigger system eliminates the need for dampers. The stiffness and weight of the building, combined with the asymmetric setbacks, laterally support and stabilize the tower and minimize perceptible motion.

Concrete Core and Steel Outrigger System

Concrete was chosen as the primary structural material for the tower because of its ability to provide a stiff frame with high damping. It also enables flat-slab construction, a cost-effective method with many benefits. 230-millimeter (9-inch) thick slabs span a maximum of 9.1 meters (30 feet) without perimeter spandrel elements, minimizing the structural depth of the floor and allowing higher ceilings.

The lateral system for Trump Tower consists of a reinforced concrete core and outrigger system. The central core is composed of four I-shaped and two C-shaped walls at the base of the building and decreases to two I-shaped walls above the last setback at level 51. The flanges of the core walls are up to 1.2 meters (4 feet) thick, while the 12.5-meter-long (40-foot) core wall webs are typically 460 millimeters (18 inches) thick. The massive reinforced concrete outriggers located at each of the setback levels, as well as the roof, tie the concrete core to the perimeter columns, increasing the building's lateral stiffness and resistance to overturning due to wind. The placement of outriggers within the mechanical floors also opens up occupied floors to expansive views, unobstructed by heavy outrigger elements.

Because of the magnitude of the applied loads and the scale of the building, the structural engineering design of the outriggers posed a unique challenge. To reduce congestion, all primary reinforcing bars in the outrigger levels are U.S. Grade 75-yield strength (520 N/mm^2). Further, in three especially tight locations, high-strength structural steel plates with welded shear studs were used, in addition to reinforcing bars, to transfer the necessary forces through the core wall web.

Addressing the Challenges of Concrete Construction

Recent advances in concrete – such as high-strength self-consolidating concrete, high-powered pumps, and safe and efficient formwork systems – have made construction of tall buildings like Trump Tower more efficient and more cost-effective than ever before. Concrete buildings also come with built-in challenges, including creep (the tendency of a solid to slowly shift under stress) and shrinkage (the gradual evaporation of water from concrete). Creep and shrinkage significantly influence the outrigger elements, due to higher stressed perimeter columns, which shorten more than the central core. To understand the effects of creep and shrinkage, SOM utilized finite element analysis and non-linear analysis to predict the forces in the outriggers and better understand the building's movement over time. Engineers applied this information to the creation of construction documents; then Bovis fine-tuned the concrete pouring and casting process, making millimeter adjustments at each story to "re-calibrate" and offset the short-term differential movement of the tower.

Figure 7. Wind Tunnel

Excavation and Foundations

Trump Tower's excavation and construction process began in March, 2005, immediately following the demolition of the seven-story Chicago Sun Times building. In August of the same year, workers finished drilling the foundation's 3-meter-diameter (10-foot) caisson holes through stiff clay, boulders, and fractured rock. At 34 meters (110 feet) deep, they hit a layer of Chicago limestone bedrock, and bored into it for another 1.8 meters (6 feet) before they set the foundation piles. The 36-meter-deep (118 feet) foundation holes were sheathed in steel and pumped full of 69 MPa (10,000 psi) concrete. Construction workers then placed a grid of steel rebar below the core to create a mat to tie the core caissons together. The 22-hour continuous pour, believed to be the largest single self-consolidating concrete (SCC) placement in North America to date, resulted in a three-meter-deep, 3,600 m^3 (4,700 yd^3) caisson-supported mat foundation system.

Construction Process

Bovis worked closely with Chicago-based James McHugh Construction Company, the concrete sub-contractor. The construction of Trump Tower took nearly four years, from start to finish, and involved 137,620 m^3 (180,000 yd^3) of concrete and 25,000 tons of steel reinforcing bars. The size of the project, combined with deadlines for early phased occupancy, required a fast-track construction schedule. At the massive lower levels (which ranged from 3,250 to 4,180 m^2, or 35,000 to 45,000 sf) workers poured one floor per week. Above level 50 (for floor plates of 1,395 m^2, or 15,000 sf) the schedule increased to four days per floor. Two Liebherr tower cranes were used, along with one 680-horsepower Putzmeister pump, which forced the liquid concrete to the upper levels of the tower at over 2,700 kilos per minute. The project is believed to represent the first application of 110 MPa (16,000 psi) self-consolidating concrete pumped and placed to an elevation up to 200 meters (656 feet) above grade on the setback floors.

Chicago's extreme cold and high winds challenged the construction team. As the tower's height climbed skyward, temperatures dropped and wind speeds increased at the upper stories. To protect workers and materials, the team utilized a three-story-tall climbing protection panel windscreen, the first of its kind used on a construction project in the United States.

Topping Out

On August 19, 2008, construction workers used a crane to haul the last bucket of concrete to the 92nd floor of Trump Tower. Fully constructed, the overall weight of the building is approximately 360,000 tons or 720,000,000 pounds. Trump's 92 floors are served by a KONE Alta elevator system with top speeds of 8 meters per second (1,600 feet per minute). Among the fastest elevators in the United States, they serve the world's highest apartment units.

Reaching 358 meters (1,174 feet) without its spire, Trump Tower became the tallest residential project in North America. As measured by the Council on Tall Buildings and Urban Habitat, the building is the second tallest in Chicago after the Sears Tower. Bill Baker, Partner in charge of structural engineering for SOM's Chicago office, remarked at the tower's topping out, "Tall building technology has become so much more sophisticated in the last few years. It's very exciting to work on a project where we're able to integrate advanced engineering techniques into such a multi-faceted, multi-use structure."

The Spire

Trump Tower's spire rises 69 meters (226 feet) above the roofline, bringing the total building height to 415 meters (1,362 feet). Constructed from three sections of structural steel clad in fiberglass, the spire tapers from a three-meter diameter at its base to a 1.2-meter (4-foot) diameter at its top. A crane was used to erect the bottom 28 meters (90 feet) of the spire on the tower's roof, but the installation of the top of the spire required a helicopter to hoist the pinnacle into place. Fully finished, the spire consists of 1,120 pieces of steel, 7,200 bolt assemblies, and 126 fiberglass panels.

Conclusion

Trump Tower's success stems from the confluence of several key factors. From a financial perspective, the project's innovative programming and phasing have helped to offset costs and increase revenues in a volatile economic climate. Richard F. Tomlinson II, SOM Partner responsible for the management of the project, explains that adaptability was important to the client from day one: "SOM collaborated with the Trump Organization to design a building that would respond to the market. Flexibility is key in any mixed-use business and residential environment, so we agreed that the right building would be able to accommodate an evolving market. The resulting tower meets this goal."

At every level, Trump Tower is the result of close collaboration between an expert developer, an innovative architect, an experienced construction team, and a City that makes "no little plans." Born of a place with a history of great buildings, the tower contributes to an exciting and ever-evolving architectural dialogue. Among its many achievements, it is first and foremost a building that strengthens the urban environment in which it stands, and gains strength from its integration into the Chicago cityscape. ■

Figure 8. View up the spire from the roof top

Figure 9. View from North Columbus Drive - Trump International Hotel & Tower

Contact Information Authors

[1]Skidmore, Owing & Merrill LLP
224 S. Michigan Avenue, Suite 1000
Chicago, IL 60604, USA
e: William.Baker@som.com
e: Richard.Tomlinson@som.com

[2]Bovis Lend Lease
One North Wacker Drive, Suite 850
Chicago Illinois 60606, USA
e: paul.james@bovislendlease.com

[3]The Trump Organization
725 Fifth Avenue
New York, NY 10022, USA
e: AWeiss@trumporg.com

Project Team

Owner/Developer: The Trump Organization

Shell and Core Architect: Skidmore, Owings & Merrill LLP

Interior Fit-Out: PMG Architects

Structural Engineer: Skidmore, Owings & Merrill LLP

Building Systems Engineer: WMA Consulting Engineers, Ltd.

Public Space: McGinley Design

Construction Manager: Bovis Lend Lease, Inc.

Other Consultants: Cerami & Associates, Lerch, Bates & Associates, Inc., Schirmer Engineering Corp., STS Consultants Ltd., Fisher Marantz Stone