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Author(s): Kenneth Lewis¹
Nicholas Holt²

Affiliation(s): ¹Skidmore Owings & Merrill, USA
²Skidmore Owings & Merrill, USA

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Case Study: One World Trade Center, New York



Kenneth Lewis



Nicholas Holt

Authors

Kenneth Lewis, Managing Director
Nicholas Holt, Technical Director

Skidmore, Owings & Merrill LLP
14 Wall Street
New York, NY 10005

t: +1 212 298 9300
f: +1 212 298 9500
e: somnewyork@som.com
www.som.com

Kenneth Lewis

Kenneth Lewis is a Director in SOM's New York office. He joined the firm in 1986 and has served on a diverse range of projects including mixed-use developments, commercial towers, corporate headquarters, and healthcare facilities.

Kenneth began his career at SOM as Senior Designer. He has managed and brought to successful completion several projects of enormous scale, complexity, and visibility, including the award-winning mixed-use Time Warner Center at Columbus Circle in New York and the 7 World Trade Center in Lower Manhattan, and Brookfield Properties' Hudson Yards Competition Entry. He is currently managing One World Trade Center. All of the projects Ken is managing are slated to achieve a Gold rating under the USGBC LEED® CS rating system. He was also closely involved in the development of sustainability design guidelines for the World Trade Center. He is active in the public realm, and his projects have been honored with numerous design awards.

Nicholas Holt

Directing the technical architecture team in SOM's New York office, Nicholas Holt oversees the detailed development and documentation for all of the New York office's projects. Since joining SOM in 1995, he has developed extensive experience working on high-rise and supertall commercial/mixed-use towers, financial trading facilities, health science projects and multi-family residential/hotel towers.

Nicholas is an industry leader in the practical application of Building Information Modeling (BIM) and the associated implementation of new project delivery models aimed at developing projects more efficiently and effectively. Recent examples are 250 West 55th Street, and the Mt. Sinai Center for Science and Medicine, which were among the first major projects in NYC to be designed and documented in a 100% BIM environment.

He also leads the Center for Architecture Science and Ecology (CASE), a research collaboration between SOM and Rensselaer Polytechnic Institute. With a focus on developing new sustainable materials and technologies, CASE blends private sector practicality, academic exploration and scientific rigor to seek emergent technologies and develop them for practical application in buildings.

“While, in an era of supertall buildings, big numbers are the norm, the numbers at One World Trade are truly staggering. But the real story of One World Trade Center is the innovative solutions sought for the unprecedented challenges faced in building a project of this size on such a difficult site.”

The world knows what happened in Lower Manhattan on September 11, 2001. The twin towers of the World Trade Center and several other buildings were damaged or destroyed, and more than 3,000 people were killed. The ground smoldered for months. Rescue was replaced by recovery, which was followed by eight brutal months of removing thousands of tons of debris from what became known as Ground Zero. What most people do not realize is that reconstruction of the 6.5-hectare (16-acre) site began soon after the cleanup, due to the fact that the initial work began underground and was therefore out of sight.

Now that buildings are emerging into the light of day, the ambitious redevelopment is clearly visible. One World Trade Center (1WTC), designed by Skidmore, Owings & Merrill, is rising on the northwest corner of the site. The National September 11 Memorial is also under construction and will be completed by the

10th anniversary of the attacks in September 2011. The Port Authority is developing a major transportation hub. Silverstein Properties, the previous developer of 1WTC, is building three additional office towers for the site.

Even with all of these high-profile projects, 1WTC will dominate the site, not merely as New York City's (and North America's) tallest building, but as an icon representing perseverance, innovation, and urban modernism (see Figure 1). The US\$3.2 billion tower, based on a revised 2005 design, now rises from a footprint measuring 61 by 61 meters (200 by 200 feet), set back from the site's northwest corner. Constructed of concrete and steel, the 104-story tower will include a multi-level observation deck and reach 417 meters (1,368 feet) above ground. A two-story ring supporting broadcasting services will support a spire, which will culminate at a symbolic 1,776 feet (541 meters) – 1776 being the year of American independence.

While, in an era of supertall buildings, big numbers are the norm, the numbers at One World Trade are truly staggering: 5,660 cubic meters (200,000 cubic feet) of concrete; 92,920 square meters (1 million square feet) of exterior glazing; 40,800 metric tons (45,000 US tons) of structural steel; and 241,550 square meters (2.6 million square feet) of office space.



Figure 1. One World Trade Center © SOM/dbox Studio



Figure 2. Concourse below grade © SOM

But the real story of One World Trade Center is the innovative solutions sought for the unprecedented challenges faced in building a project of this size on such a difficult site.

Site

The project team was confronted with unprecedented challenges. The site sits over a vast tangle of existing subterranean obstacles. The new tower must bridge existing PATH train tracks adjacent to existing subway tracks, as well as accommodate a planned network

of new development. The new World Trade Center Transportation Hub alone will occupy 74,300 square meters (800,000 square feet) to serve 250,000 pedestrians every day. Broad concourses (see Figure 2) will connect Tower One to the hub's PATH services, 12 subway lines, the new Fulton Street Transit Center, the World Financial Center and Winter Garden, a ferry terminal, underground parking, and retail and dining venues.

The resulting underground challenges can be likened to a four-dimensional chess game. First of all, obstructions exist three dimensionally in overlapping planes at varying depths. Secondly, per the brief, the PATH train service was to remain operational and existing structures had to be preserved throughout excavation and construction. Threading steel members, conduits, and shafts through the maze required precision timing not only to avoid service or construction disruptions, but to ensure that subsequent development would not be obstructed.

Bridging over the tracks was certainly an engineering challenge. "We used state-of-the-art methods of analysis in order to design one of the primary shear walls that extends all the way up the tower and is being transferred at its base to clear the PATH train lines that are crossing it," explains Yoram Eilon, vice president at WSP Cantor Seinuk, the structural engineers for the project. "In addition, the layout of below grade structure and columns took into account the dynamic envelope of these train lines. The design of the structure also meets the Port Authority requirements that these lines remain operable during construction. In order to comply, we designed a steel structure that bridges over the tracks, which supported the wet concrete loads during construction and was eventually integrated into the permanent structure."

Structural Design

The tower's structure is designed around a massive, redundant steel moment frame consisting of beams and columns ↗





Figure 3. Column free interior © Jan Klerks



Figure 4. Structural steel moment frame at the tower perimeter © Jan Klerks

connected by a combination of welding and bolting. Two large Manitowoc cranes – the largest ever used in New York City – positioned the steel columns and nodes, the largest weighing as much as 72.5 metric tons (80 US tons). Paired with a massive concrete-core shear wall, the moment frame lends substantial rigidity and redundancy to the overall building structure while providing column-free interior spans for maximum flexibility (see Figure 3). Within the tower, a self-jacking lift system is constructing the massive core walls. The result is brute strength veiled in prismatic elegance.

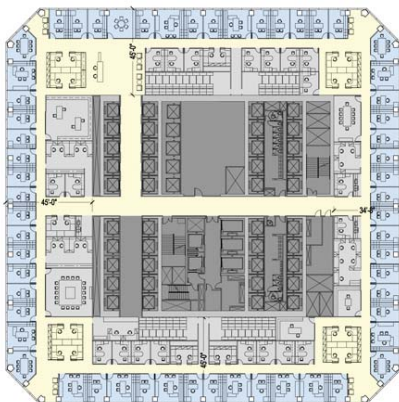
1WTC is the first project in which 14,000 psi (pounds per square inch) concrete has been used in a New York City project. 12,000 psi concrete was used at Seven World Trade Center (which sits just across Vesey Street to the north of the site of 1WTC and which was the first building reconstructed on the site

after 9/11). Before this project, the standard for high-rise buildings in New York was maxed out at 8,000 psi. Since then, 12,000 psi has been used in numerous projects in the city. The 14,000 psi concrete was used at the lower portion of 1WTC's shear walls.

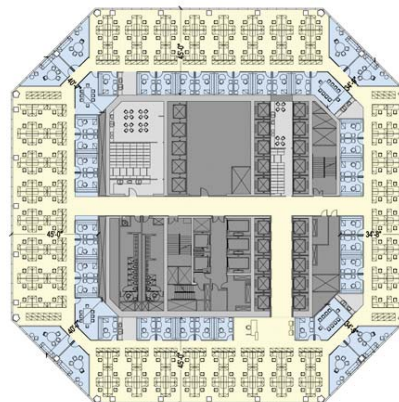
“From past experience, we learned that in high-strength concrete, the value determined using ACI expression for modulus of elasticity can be exceeded,” explains Yoram Eilon. “Accordingly, we specified dual requirements for the shear walls’ concrete: a modulus of elasticity of 7,000 ksi and corresponding concrete compressive strength of 12,000 psi and 14,000 psi. This contributed to the stiffness of the tower without the premium of calling for even higher strength concrete. The introduction of dual requirements allowed us to specify a 14,000 psi concrete mix and benefit from concrete stiffness that is comparable to over 15,000 psi concrete mix.

The key factor to successful and consistent results is the tight monitoring and quality control of the concrete mix components and the use of local materials that are readily available.”

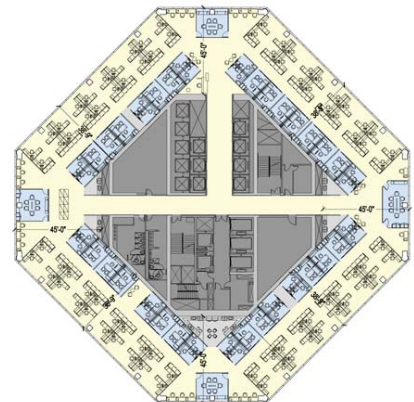
The use of a hybrid system of high strength concrete core and structural steel moment frame at the tower perimeter results in an efficient structure. Additionally, the fact that the tower tapers as it rises coupled with the chamfered corners on the floor’s footprint forms an aerodynamic and structurally efficient shape (see Figure 4). In New York City, skyscraper structural design is usually governed by wind loads. The geometrical shape of the tower reduces exposure to such loads, as well as the amount of structural steel needed, and, thus, the demand on the lateral system of the tower.



Typical Low-rise Floor Plan



Typical Mid-rise Floor Plan



Typical High-rise Floor Plan

Figure 5. Typical floor plans © SOM

Project Modeling

Reconciling the engineering, scheduling, procurement, etc. was expedited with Building Information Management (BIM) tools. Back in 2003, when SOM began work on 1WTC, the firm chose to coordinate and document the infrastructure's complexities using BIM software. The tool proved valuable enough that the architects modeled the entire tower this way, which facilitated the design process and ensured on-time completion of the bid documents. This project represented one of the earliest uses of BIM on a project of this scale. In order to ensure success, the software developer and the architect formed a close partnership, at times with the software engineers residing in the architect's offices to address issues in real time and develop new software tools required for a project of this complexity. Many of these tools and processes became part of the software package in subsequent releases. This tool and a variety of other programs were used to inform and build the overall building model. This allowed the application of available tools and talent to best effect during design, coordination and documentation.

Safety Design

Seven World Trade Center, the first rebuilt structure near Ground Zero, was completed in 2005. The 52-story, 226-meter (741-foot) tower provided an opportunity to enhance the original tower's pure form with precision detailing. Simultaneously, we integrated the next generation of life-safety standards subtly into the infrastructure. The structure incorporates enhanced fireproofing for the structural steel that exceeds current codes. Its core is enclosed by up to three feet of reinforced concrete. There are dual interconnected fire standpipes and extra water storage to allow for high capacity sprinkler heads. If a standpipe is cut or broken, the interconnecting valve automatically cuts off water supply to that standpipe and redirects it to the other standpipe, ensuring that every other floor has sprinkler protection. Pressurized fire stairs are 20% wider than code and are fully pressurized, equipped with emergency lighting with both generator and



Figure 6. West Plaza © SOM

battery back-up, in addition to photo luminescent exit markings. 7WTC is thus now a precedent for new construction in New York, influencing building-code reforms, green building standards and informing the design of 1WTC.

For the design of 1WTC, 7WTC was used as a precedent, but went well beyond it. In addition to a concrete-enclosed core, the tower includes a protected tenant-collection point on each floor and a separate stairwell for first responders. From an architectural perspective, all of these features are integrated into the design without lessening efficiency or constructability. The building incorporates highly advanced state-of-the-art life-safety systems that exceed the requirements of the New York City Building Code and that will lead the way in developing new high-rise building standards. Such careful planning permeates the entire tower from the base through the office floors to the observation deck and mast. At the same time, care was taken to avoid the perception of the tower feeling like a fortress.

The reinforced-concrete tower base occupies a 61-by-61-meter (200-by-200-foot) footprint (see Figure 5), which are the same dimensions as the original Twin Towers. The 57-meter (186-foot) tall base is monolithic, penetrated by large entrances on all four elevations.

While the building incorporates unprecedented security, the perception is one of openness and accessibility, which will be a humanizing element for the five million annual visitors expected when the adjacent park opens in 2013. Designed in collaboration with landscape architects Peter Walker and Partners, the collective vision is to connect the tower with nearby neighborhoods and allow views and access into the memorial (see Figure 6).

Architectural Design

Entrances, identified by glass canopies and highly transparent glass cable-net wall systems, penetrate the base on all four elevations. The main lobby wraps around the central core and is filled with daylight entering through the entrances and clerestory windows in the north and south walls. As ↗

...human scale

“The story goes that a student once asked the architect, ‘O master, why did you build two 100-story buildings instead of one 200-story building?’ And he answered, ‘Ah, to keep the human scale’.”

Gael Greene, a restaurant critic, depicting Minoru Yamasaki's conversation with a student about the Twin Towers. From "The Most Spectacular Restaurant in the World," Insatiable Critic, May 31, 1976

the tower rises from the base (see Figure 7), it tapers and its square edges are progressively chamfered, thereby transforming the square into eight tall isosceles triangles in elevation (four that point up and four that point down, alternating). At the halfway point up the tower, the tower forms a perfect octagon and then culminates in a square, glass parapet rotated 45 degrees from the base. The resulting crystalline form will capture an ever-evolving display of refracted light. As the



Figure 7. 1WTC under construction © Tansri Muliani

sun moves through the sky or onlookers move around the tower, the surfaces will appear like a kaleidoscope, changing throughout the day as light and weather conditions vary. The office floors are topped by a rooftop observation deck at 415 meters (1,362 feet) with a glass parapet extending to 417 meters (1,368 feet) – the heights of the original Twin Towers.

The curtain wall begins at the 20th floor and continues to the observation deck (see Figure 8). Based on a 1.52 by 4.06 meter (5 by 13.3 foot) module, the panels are floor-to-floor, high-performance, insulated units weighing in as much as 2,720 kilograms (6,000 pounds) each. The Manitowoc cranes that positioned the structural steel sections were again called into service to hoist them into place. The units at the 20th floor are the heaviest due to blast-resistance requirements which make them thicker (with laminated inner lights) and, therefore, heavier than the other units.

For the curtain wall, a thermally broken unitized wall system was developed that incorporates insulated glazing units (IGUs) of a new monumental scale that is capable of withstanding the wind pressure experienced by a supertall building while also meeting stringent security requirements. The IGUs, fabricated by Viracon, are a single light of glazing, spanning 4.06 meters (13.33 feet) floor to floor (see Figure 9), using the largest production line IGU's manufactured at the time. These units are typically made up of low-iron glass with a 95-millimeter (0.375-



Figure 8. Typical section © SOM

inch) outer light and a 64-millimeter (0.25-inch) inner light. There is a high-performance low-e coating (Viracon's VRE) on the third surface. The coating reduces the amount of UV and infrared heat and energy (solar heat-gain coefficient entering the building), while maintaining maximum visible light transmittance and neutral color. The metal spandrels are painted a pewter color and are positioned slanting inward. The result is a curtain wall designed for maximum daylight, while reinforcing the tower's monumentality.

Eventual tenants will be educated on building infrastructure, from simple, metal walk-off grilles at major entrances to MERV 16 high-efficiency particulate filters and gas-phase filtration to serve the outside-air intake system and air-handling units on each



Figure 9. Typical curtain wall © SOM

floor. Ultimately, written guidelines and an exemplar space will help tenants incorporate sustainable strategies in their fit-outs. For example, individual electrical-supply meters will encourage tenants to reduce energy consumption and meet the building's goal of a 25% reduction in energy consumption. In addition, strategies for using low-emitting materials – paint, adhesives, wood, fabrics, and carpet – are outlined. The tower will be partially powered by 12 hydrogen fuel cells, expected to generate 4.8 megawatts of power for 1WTC and other buildings on the site.

Natural Resources Defense Council (NRDC) Green Lease Forum and the Mayor's Office of Long-Term Planning Sustainability brought together a group of real estate and energy efficiency experts to develop new commercial lease language that allows tenants and owners to share the costs, as well as the benefits, of energy efficiency improvements. Mayor Bloomberg expects this initiative to set a precedent for commercial leases. The ambitious goal is to transform the city into the nation's first carbon-neutral metropolis.

Spire

The spire will perform multiple functions, most of which will involve broadcasting and digital communication. It's a hybrid structure, consisting of two major components: a 137-meter (450-foot) spire and a three-level communications platform ring (see Figure 10). At the base of the spire, the circular lattice ring will support point-to-point microwave dishes, steerable Electronic News Gathering antennas, and whip-type radio communication antennas. To add more support against wind, eight radio-frequency (RF) transparent Kevlar guy cables will be connected from the mast back to the ring. Large helical channels, called strakes, are built into the geometry of the radome and wrap around the antenna to direct wind up and away from the structure. Window-washing equipment will also be incorporated into the ring structure. Because of the circular shape of the ring, the building can be serviced with only three maintenance units. The ring and mast structures were created in conjunction with structural engineers from the Stuttgart firm of Schlaich Bergermann und Partner.

The spire is an antenna encased in an eight-sided tetrahedral paneled radome (radar dome) – a structural, weatherproof enclosure that protects it from the elements, while being transparent to radar or radio waves. The steel mast will have eight sections stacked vertically and decreasing in width, while the radome will be a modular, fiberglass and foam sandwich panel system arranged in an octagon. This folded-plate enclosure structure is the first of its kind to be used in antenna construction. The geometry of the radome shell is based on a repeating modular system that allows for easy replacement and erection and also creates a protected maintenance area that is unique in the antenna industry.

Perhaps the most symbolic and resonating feature of the spire is not its symbolic height. Near the top of the spire, xenon lamps will light a sweeping beacon, which will flash the letter N in Morse Code – dash/dot. The idea originated with the desire to create a beacon reminiscent of the code light ships a century ago flashed to identify their port, as ships

entered their harbors – B for Boston, N for New York, and so on. More than a symbolic gesture, the beacon recalls New York's maritime past and beams a safe-harbor welcome that will be seen as far away as 26 miles. In its subtlety alone, it signals a resurrection. ■

Project Data

Completion Date: 2013
Height to Architectural Top: 541 m (1,776 ft)
Stories: 100
Total Area: 320,980 sq m (3,455,000 sq ft)
Primary Use: Office
Project Developer: The Port Authority of New York & New Jersey
Architect: Skidmore Owings & Merrill LLP
Structural Engineer: Schlaich Bergermann und Partner; WSP Cantor Seinuk; Leslie E. Robertson Associates
MEP Engineer: Jaros, Baum & Bolles
Main Contractor: Tishman Construction
Project Manager: The Port Authority of New York & New Jersey
Wind Consultant: RWDI
Elevator Consultant: Jaros, Baum & Bolles



Figure 10. The Spire © SOM