

Architect Jean Nouvel's concept for 53W53 - a super-slender tower of pyramidal form with northern and southern façades gradually sloping away at two distinct angles from $54^{\text {th }}$ and $53^{\text {rd }}$ streets, respectively - is founded on the aesthetics of exposed elements arranged in an asymmetric, almost random pattern on all façades of the building. Given the number of inclined members forming an unorthodox lattice, these patterns have been termed diagrids. The structural solution envisioned by WSP USA smoothly merged with the architectural intent by using the elements of the diagrid as a continuous system, providing support not only for the building envelope but also adequate in terms of stability and strength for the entire structure.

## Foundation System

The geotechnical composition of the site presented an interesting engineering challenge. While the Midtown area of Manhattan is typically associated with good quality substrate, with bearing capacity up to 60 tons-per-square-foot, the geotechnical surveys and studies performed for the 53W53 tower showed evidence of an old stream towards the west side of the site. The continuous presence of water linked to the stream was attributed to the gradual deterioration of the mechanical properties of the rock, which were evaluated to be only eight tons-per-square-foot. To prevent excessive settlements to the neighboring buildings, and in consideration of the adjacency of the South perimeter of the site to existing facilities of the New York City Metropolitan Transit Authority (MTA) along $53^{\text {rd }}$ Street, the foundation system required the implementation of measures aimed at preventing adverse effects to neighboring underground structures. More than thirty reinforced concrete drilled caissons, each 3 feet in diameter, were required to extend a minimum of 30 feet below the subcellars. In selected locations near the MTA tunnels, the caissons reached 70 feet deep, matching the elevation of the subway track.

## Superstructure

The superstructure of the 53 W 53 tower is based on a unique dual-purpose system. In traditional high-rise projects, focus on efficiency and typical construction sequence results in the provision for two separate systems to carry gravity loads and lateral loads. However, the architectural intent of 53W53 required a uniquely different approach. A single, exterior structural system matching the geometry of the diagrid was developed having the ability to carry both vertical loads and those associated with wind and seismic demands. This approach, while efficient from a structural standpoint, presented numerous engineering challenges which were solved with a combination of rigorous analysis and innovative solutions.


53W53 Project 3D Rendering. Courtesy of Hines.


## Installation of Node 4R-6.

The original structural concept considered forming the diagrid with steel members only. A value engineering study resulted in both financial and constructability advantages to using a reinforced concrete diagrid system consisting of vertical columns, inclined elements or braces, and horizontal spandrel beams. This structural solution allowed for the maximization of unobstructed interior spaces in the majority of floors.

Perhaps the most challenging aspect of creating a reliable and resilient structural diagrid system was the conception, testing, and implementation of highly specialized nodal connections at almost every intersection of the diagrid. At least three dozen nodes required the interconnection of four structural members or more. On a given node, not only are there multiple diagrid members intersecting, but these elements might also be located on multiple planes and oriented at different angles. Take, for example, the first node installed on site, located on the North face of the sixth floor and the largest in the tower. Node 4R-6, as it was referred to in reference to grid lines and elevation, is the intersection of six major structural elements at various angles, all of which support a significant portion of the tower above.
The most efficient solution to address the congestion of reinforcement and realignment of forces at the nodes was to develop a steel core assembly with special connectors to which the high-strength reinforcement, consisting of No. 20 ( 2.5 inches in diameter) bars, was anchored. The steel core served as the ideal transition element between various layouts and directions of steel reinforcement present throughout the building. The contractor was required to create a full-scale mock-up prior to the actual construction to validate the feasibility of this innovative solution. The outcome of the mock-up was satisfactory in terms of both quality control and reliability for on-site execution.
Considering the client's request for the lower floors of the tower to be used for additional gallery space for the Museum


Installation of Node 3A-10 showing a $K$-frame geometry.


Detail of top (left) and bottom (right) of Node 3P-31 before concrete casting operation.
of Modern Art, shear walls and interior columns were relocated to the periphery, allowing for a highly flexible floor layout. Steel trusses over these large, unsupported spans were used to pick up the loagds delivered by the few interior columns and to transfer them to the east shear wall core.
Another structural engineering challenge was the need to span over the existing ConEdison emergency generator servicing the Museum of Modern Art, which required a 24 -foot long overhang cantilevered from the tower's northeast corner. The overhang was integrally connected to the exposed members of the diagrid.
The required lateral stiffness and strength of the tower was accomplished by placing outrigger walls, effectively connecting the central shear wall core to the exterior diagrid system at Levels 35,36, and 37, which created the effect of a "belt floor" approximately at mid-height of the structure. These outrigger walls were added to the structure with negligible impact to the marketing plan, as these floors housed the mechanical rooms required to handle the distribution of the building services at that elevation.
As the many façade planes converge at different locations and elevations of the building, small pyramids or apexes were created. To minimize the impact of these volumes on interior spaces and to facilitate their construction, it was determined that the five clearly delineated vertices of the building be constructed of steel framing. This solution allowed for the possibility of prefabricating portions of the frames to be erected after the surrounding concrete structure had been cast.

## Wind Tunnel Testing and Structural Analytical Modeling

This intricate structure required complex analyses including full three-dimensional sequential construction analysis, with consideration to time-dependent changes in material properties and loading demands, which were used to estimate the required elevation and position compensations to be implemented during construction.
In addition to analytical models, a series of comprehensive aerodynamic tests to accurately determine the wind pressures and wind-induced vibrations were performed by RWDI Consulting Engineers. A two-prong approach was necessary to achieve the industry-recommended comfort level for human occupancy in terms of vibration and acceleration due to wind. First, the structural
mass was increased towards the top of the building by using a slab thickness of 20 inches at the $73^{\text {rd }}, 74^{\text {th }}$, and $76^{\text {th }}$ floors. Second, a 650-ton Tuned Mass Damper was placed at the double-height space between the $74^{\text {th }}$ and $76^{\text {th }}$ floors.

## Integrated Buildings SMEP Design

WSP USA provided not only the services for structural design, but was also responsible for the engineering of building services including mechanical, eleetrical, plumbing, fire protection, telecommunications, and others. This allowed for a very close and effective collaboration among the design and construction teams and good interaction between engineering disciplines.

## Construction Progress

Foundation construction was completed at the end of 2015. At the time of this publication, the superstructure work has reached the $40^{\text {th }}$ floor, which is approximately 500 feet above street level. As the tower tapers and reduces its footprint towards the top, construction progress is expected to be a 4- or 5-day cycle per floor, standard in New York City's construction environment. The project is scheduled to top out in the summer of 2018. The installation of curtain wall began in 2016 and will be completed by the beginning of 2019.-


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