DOI – http://dx.doi.org/10.4322/1809-7197.2020.99.0005

Engineering the supertall and superslender 111 West 57th

FATIH YALNIZ
WSP

RESUMO

Apresenta-se em linhas gerais a concepção arquitetônica, os elementos e componentes da fundação, o sistema estrutural, bem como alguns aspectos das análises estruturais e das especificações de projeto, do edifício 111 West 57th, localizado em Nova York, nos Estados Unidos, um dos mais altos e esbeltos do mundo

Palavras-chave: *projeto e análise estrutural de edifícios, sistema estrutural para edifícios altos, resistência a esforços horizontais, ensaio de túnel de vento.*

I. INTRODUCTION

Located just south of Central Park, the most slender high-rise building in the world was topped out in 2019 in the heart of Manhattan, NYC among the other new supertall, superslender recently built buildings. The soaring 111 West 57th Street, with a height of 1428 ft. (435m), and a width of only 58 ft. (17.5m) holds the world record slenderness ratio of 1:24. Another new development 217 West 57th street, also completed in 2019, holds the title of tallest residential building in the western hemisphere by the height of 1550 ft. (473m).

Since the completion of the first supertall 157 West 57th street in 2014—a slender residential tower rising 75 stories from a small site, every new development in that area challenges the engineers to go higher while providing unobstructed views and world class comfort expected from a luxurious building. These new generation, small footprint structures reaching the new heights require unique engineering solutions.

▶ **Figure 1**
View of the NYC skyline; the Empire State Building and 53W53 together with 111W57th under construction

111 West 57th street presented engineering conditions on multiple levels. A super-tall, super-slender tower in the middle of New York City to be merged with an existing landmark building, created unique challenges for the team. Limited construction space compounded the challenges. Throughout the project, every design solution was supported by multiple rigorous analyses and design procedures. Structural solutions were developed to become one with

the architectural intent, leading to a successful and unique new icon for the New York City skyline (Fig. 1).

2. PROJECT DESCRIPTION

Located on 57th street between 6th and 7th Avenues, 111 West 57th is the latest installment of supertall, superslender buildings on "Billionaire's Row" (Fig. 2). The superslender structure has a total of 68 residential floors and includes 60 condominium apartments, an indoor lap pool, amenity spaces and terraces. By completion, it will stand as a world-class model of innovative building technologies, luxury, energy efficiency and environmental sustainability.

The tower was conceived by Developer JDS Development and designed by SHoP Architects. The project combines the original landmarked Steinway building designed in 1925 by Warren & Wetmore, and the new tower addition. In addition to the new feather-like slender tower, the project involved renovating and retrofitting the landmarked Steinway Building. Design team envisioned a tower that would extend classic 1920 style onto the skyline while the other towers nearby adapted contemporary approaches.

The tower's structure creates floor-to-ceiling windows that offer views of Central Park to the north and Midtown to the south while eastern and western elevations are ornate with distinctive terracotta and bronze façades.Two levels of below grade space rise to the surface and soar 95 stories above street level. The total height of the project is 1428 ft (435 m), including 160 ft. (48m) of steel crown that also houses the Building Maintenance Unit. As a distinctive feature of the building there are a series of open floors and multiple setbacks on the south side of the building creating an elegant profile.

Figure 2
View of the slender 111W57th rising with Central Park in the background

3. FOUNDATION SYSTEM

One of the initial challenges of the project design and construction was the foundation. A major challenge was the necessity of working around the existing Steinway building foundations combined with the limited footprint and demands of the new structure. The design and construction process required intensive coordination within a tight schedule. It was helpful however, that the midtown area of Manhattan has good quality substrate, with bearing capacity of 60 tons-per-square-foot.

The foundations of 111 West 57thconsist of concrete mat and footing foundations with thicknesses ranging from 6 ft. (1.5m) to 13 ft. (4m) founded on a medium to hard (Class 1A to 1B) 60 tons-per-square-foot rock. The new foundations are adjusted around the existing Steinway building foundation with the intent of minimizing the amount of interruption of the existing structure. To address the overturning effect from lateral forces, close to 200 Rock anchors/tie downs were also placed. The extent of the rock anchors/tie downs into the rock ranged from 50 ft. (15m) to approximately 80ft. (25m).

4. SUPERSTRUCTURE

111 West 57th is a reinforced concrete building with 160 ft. (48m) of steel crown. The gravity system is composed of cast-in-place concrete flat-plate slabs supported by reinforced concrete columns and shear walls. The uppermost 160ft. (48m) of the tower, the "crown", is steel construction consisting of concrete on composite metal deck supported on steel beams. Steel construction is chosen due to limited space and multiple setbacks at the crown. Lateral resistance of the steel crown is provided by steel braces. The crown is intended to be functional and accommodates various mechanical equipments, including a Building Maintenance Unit.

The tower structure is composed of a robust concrete core with multiple outrigger floors and reinforced concrete columns. Outriggers are horizontal rigid systems connecting the main core wall to the columns. Lateral loads are not only resisted by the bending of the core alone, also by the axial tension and compression of the exterior columns connected to the core. Placing outriggers in the mechanical floors increases the effective depth improves the stiffness of the structure. The reinforced concrete core wall system acts as the main spine throughout the tower, providing support for gravitational loads as well as resistance to wind and seismic forces while containing the elevator and stairs of the building's main circulation. The concrete shear wall sets back as the tower sets back in the south of the building. The concrete strength and the thickness of the concrete core decrease along the height of the building. The shear walls are interconnected over the core access openings using concrete link beams, and where required, steel embedded concrete link beams. The core wall thickness varies along the height of the tower while link beam widths match shear wall thicknesses. To accommodate the limited space, multiple setbacks, and resulting transfers at the south side of the building, several columns that would have typically been located at the south of the building are replaced by a deep concrete beam, leaving only two columns at the north side throughout the building.The typical residential floor slab thickness is 12 inches (30.5 cm), supported by shear walls and only two columns allowing a column free layout for the interiors.

The tower's record-breaking slenderness imposed stringent demands on the overall strength and stiffness of the structure. The design team carefully investigated several options to increase the stiffness while respecting the functionality of the space. One of the ways to increase the stiffness of the building, 4 outriggers are added at mechanical floors throughout the building. There is a total of 10 mechanical floors in the tower and the location and number of the outriggers at selected floors are based on structural efficiency criteria (Fig. 3 a/b). Each addition of the outrigger floor is coordinated with the other trades, allowing continuous functionality. The mechanical equipment at each outrigger floor is accommodated by the mechanical openings provided.

Although the building is designed for both seismic and wind forces, the building's design is governed by wind load. Due to the nature of the towering, slender structure, the design team performed multiple wind tunnel tests to accurately determine the wind pressures and wind-induced vibrations early in the design process. To achieve

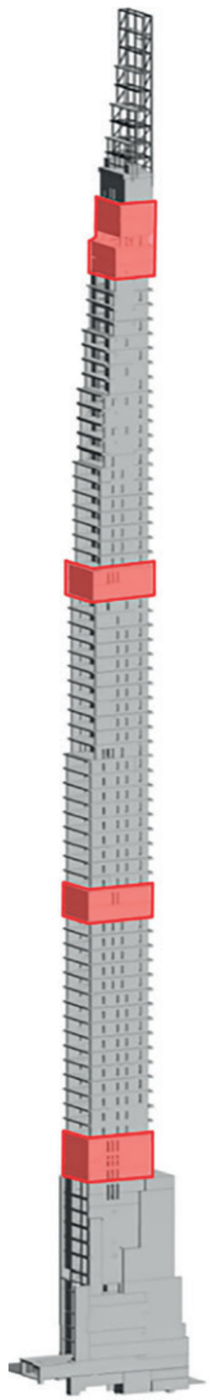

Figure 3a
Section showing the outrigger locations

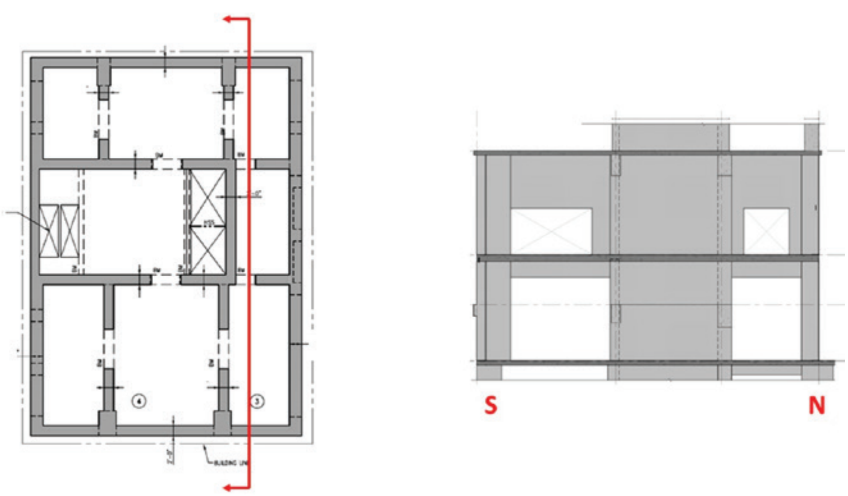

Figure 3b
Typical outrigger floor plan and section

industry-recommended comfort criteria for different return periods for residential buildings and reduce overall wind loads, a three-pronged approach was taken. First, open floors were introduced (Fig. 4). Open floors help to mitigate the vortex shedding phenomenon that is typical of slender structures. Numerous alternates for the open floors were studied throughout the tower's development process including wind tunnel tests, resulting in three open floors effectively. Second, the mass at the top of the building was increased to reduce the accelerations. Increasing slab mass effectively at the top of the building increased generalized mass, reducing the demand from the damper. Finally, a project specific 800-ton Tuned Mass Damper was placed at the top of the tower (Fig. 5 a/b). Tuned Mass Damper is an effective tool to control accelerations for the residential buildings which has more stringent criteria compared to office buildings. Taking the steps above ensured occupancy comfort for different return periods. Building response was closely monitored during the construction to ensure Tuned Mass Damper will perform within the design range.

The utilization of high strength concrete of up to 14.000 psi (95,6 MPa) is imperative in achieving a building such unprecedented height and slenderness. Concrete strengths range from 14.000 psi (95,6 MPa) to 8.000 psi (55,2 MPa) for the foundation, columns, and shear walls, and 10.000 psi (68,9 MPa) to 6.000 psi (41,5 MPa) for slabs. A concrete mix design test program with the concrete producers was established to create the appropriate mix designs to achieve desired concrete strength and Modulus of elasticity. This was seen as a crucial element in the structural design of the building, and work on the concrete mix design was undertaken at the early design phase. In order to obtain required Modulus of Elasticity, coarse aggregate type and volume were critical and thus they were specially reviewed.

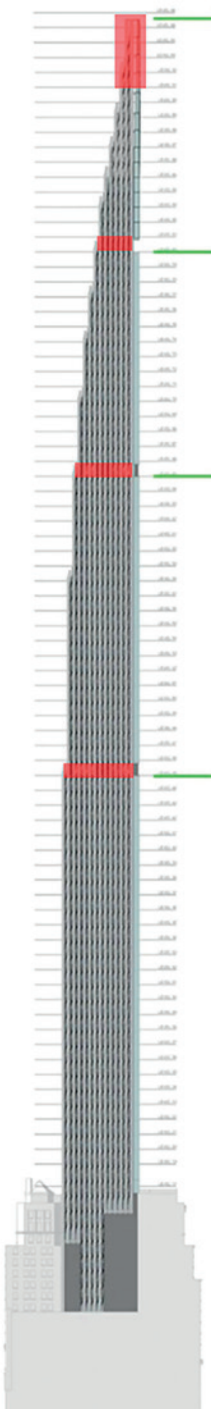

Figure 4
Section showing the open floors

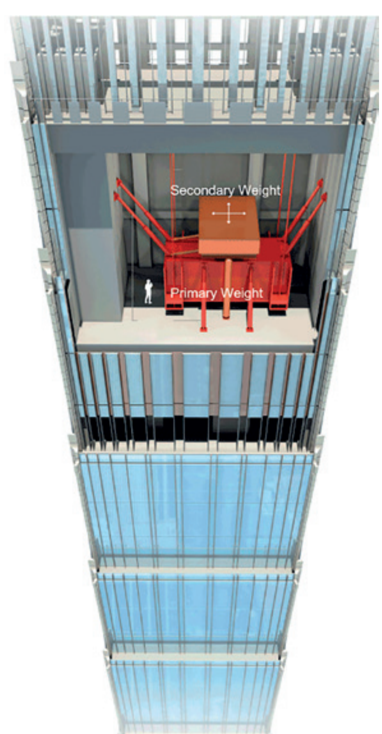

Figure 5a
TMD detail

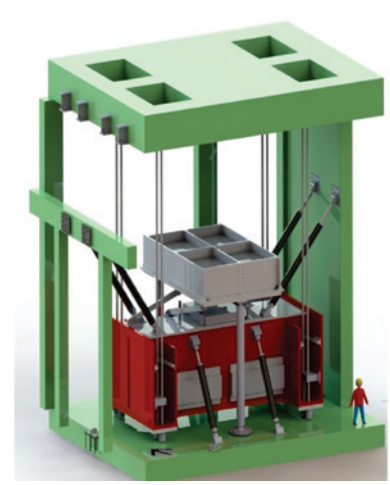

Figure 5b
TMD detail

Figure 6
3D analysis model

In addition, the high strength concrete used for the thick concrete walls, defined as mass concrete, required a particular concrete mix to meet the most stringent of demands.

Industrial by-products such as fly ash, granulated ground blast furnace slag cement and silica fume were used to replace more than 50% of the cement content to reduce and slow the heat of hydration. Self-Consolidating Concrete (SCC) was used for all concrete requiring strengths greater than 8.000 psi (55,2 MPa). Due to the high density of reinforcing steel at the base of the building, most of the (SCC) mixes were consolidated with internal and external vibrators. During the construction, concrete was regularly sampled and test results were documented.

The increase in concrete strength resulted in a significant reduction in the overall size of structural elements while providing greater stiffness. Furthermore, high strength reinforcing steel, spliced by means of mechanical connectors, was utilized in columns and shear walls at the lower portion of the building. Utilizing high strength reinforcement in lower floors minimized the reinforcing congestion while reducing the construction effort. Reinforcement, preassembled outside in cages, was transferred to construction site.

Axial shortening due to changes in structural members as a result of elastic, creep and shrinkage effects over time, is an important consideration in super slender buildings. Appropriate calculations were performed by using three-dimensional sequential construction analysis taking into consideration the different scenarios (Fig.6). Based on the construction schedule, multiple models were developed to accurately estimate the required elevation and position compensations to be implemented during construction. The building was regularly monitored during the construction for axial deformations.

5. WIND TUNNEL TESTING

Wind Tunnel tests are an important part of the design process, performed with varying surrounding considerations. Establishing the wind climate, understanding wind's behavior at different strata, direction and frequency of occurrence, understanding the building's aerodynamic and aeroelastic response and making subsequent adjustments to the building's geometry to mitigate wind effects were key measures taken for a successful project. The studies regarding structural engineering, architecture and wind tunnel testing of the tower were very closely intertwined throughout the development of the project (Fig. 7).

Figure 7
Wind-tunnel testing

Comprehensive and project-specific wind tunnel tests were performed at the Rowan Williams & Irvin (RWDI) wind tunnel facilities to determine more accurate wind loading and wind response of the tower with respect to human comfort criteria.

High Frequency Force Balance (HFFB) and Aeroelastic tests were performed at different stages of the design. Results guided the team in the design, including determining the most efficient location of the open floors.

The acceleration results at the highest occupied floor for different return periods meets the criteria of human comfort for residential buildings after placement of a project-specific 800-ton Tuned Mass Damper. Although ISO addresses accelerations only for 1 year return period, TMD is designed to meet the acceleration criteria for 1 month and 10 years return periods.

6. SUMMARY

111 West 57th incorporated numerous advanced engineering solutions to achieve the luxury, height, and slenderness ambitions of the project. This unique building has pioneered new frontiers of engineering to emerge as the world's most slender building, while embracing a classic architectural design style. From early on, it was of the utmost importance for the team to foresee the challenges, and develop procedures and innovations supported by multiple rigorous analyses.

A unique and challenging building like 111 West 57th enables the engineering team to apply the accumulated knowledge gained through previous experience enhanced with forward thinking advances in structural practice.

The combination of structural engineering with exacting wind tunnel testing, and the collaboration with the architect and development team intertwined harmoniously throughout the trajectory of the project. The result is a highly complex, innovative and elegantly proportioned tower. The aspirations of the entire project team have added a new and unique grand icon to complement the New York City Skyline.