Title:	**Supertall, Super Slender Tower with a Multitude of Constraints: 220 Central Park South**
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Subjects:	Architectural/Design Building Case Study Structural Engineering Wind Engineering
Keywords:	Damping Residential Slenderness Structural Engineering Structure Supertall
Publication Date:	2015
Original Publication:	Global Interchanges: Resurgence of the Skyscraper City
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. **Conference proceeding** 4. Unpublished conference paper 5. Magazine article 6. Unpublished

Supertall, Super Slender Tower with a Multitude of Constraints: 220 Central Park South

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Abstract

220 Central Park South is a 950' (292m) ultra-luxury residential tower located in New York City. At only 53' (16m) wide, the tower has an impressive 18:1 aspect ratio. With a negotiated maximum height and a desire to build above 200 feet, the project required the development of several unique structural solutions. The total project floor area had to be built within a 750' tall band starting 200 feet above grade and ended at the roof. Mechanical systems were driven into the lower 200 feet of the building as MEP floors were not to be placed within the band. Belt walls were also prohibited and the 1,100 ton required damper was "squeezed" into a 25 foot volume. This case study shows how the design team overcame the engineering challenges of working against multiple constraints.

Keywords: Damping, Residential, Slenderness, Structural Engineering, Structure, Supertall

New York City is the capital of the world. And while owning New York City real estate comes with some cache, it is also among one of the most secure and profitable investments in the world. Property Rights or Freeholder laws in the United States are the best in the world. A stable economy, solid banking system, and transparent monetary policy have driven foreign investment in the US market to record levels. While the Foreign Investment in Real Property Tax Act (FIRPTA) still hampers foreign investment particularly from sovereign wealth funds- the EB-5 Visa program has encouraged individual real estate investment by foreigners.

Many of the US' own billionaires prefer to make New York City their home and primary investment. The most innovative companies, both old economy and fresh startups alike, call New York home. Additionally, the city has a multitude of world renowned cultural organizations and a flourishing social scene. More importantly, all of this is packaged in the safest large city in the world. The "Safe Streets" initiative started under the Giuliani administration and continued to this day encourages residents and visitors alike to be out and about. It has been said that Manhattan has gotten "larger" as more and more neighborhoods once considered off limits are now in vogue. Hell's Kitchen and the Lower East Side of Manhattan are two great examples of how "Safe Streets" have led to gentrification.

Figure 1. Tower Massing Options for Testing (Source: DeSimone Consulting Engineers, PLLC)

Furthermore, the financial crisis has had a profound effect on real estate development. Banks have tightened lending requirements significantly. Banks are no longer offering non-recourse loans and they require developers to have significantly more equity in every deal. While one would expect this to have a chilling effect on development it has had quite the opposite effect. Only the strongest and largest developers have the financial means to develop in this environment. Additionally, in this zero interest environment many investment funds are searching for returns in the real estate market. Only the blue chip real estate firms are capable of attracting investment dollars from these well managed funds.

All of this has set the stage for the development of some of the most luxurious and expensive real estate in the world. Superlatives are not new to the luxury market. "Supertall", "super luxury", are phrases used to describe this latest crop of residential developments and foreign buyers are snapping them up in droves. Many of the wealthiest US individuals including celebrities and hedge fund managers are all chasing the next big thing as well. Exclusivity is essential. While the demand seems endless how is this demand met? What are buyers in this strata typically looking for? More importantly how can the design team assist the developer in creating a truly unique product that is differentiable from the rest of the market? The team behind 220 Central Park South had to consistently keep all of these questions in mind while creating the world-class luxury building while also competing with the new crop of supertall luxury towers along Central Park.

The Challenge

The old adage in real estate, location, location, location is still true to this day. While neighborhoods in New York such as Tribeca and the Meatpacking District are considered the trendiest, properties located adjacent to Central Park still command the highest prices. Fifth Avenue, Central Park South and Central Park West continue to be the most desirable addresses in New York. The recently developed 15 Central Park West is now one of the most sought after new developments in decades. This "new" building was designed to be evocative of the Grande Old Dames located along the Park. The project raised the bar and proved to many that while trends come and go, the big money was to be made on the park.

220 Central Park South is the next generation of super tall, super luxury, located on the park. While there has been a proliferation of super tall luxury buildings 220 CPS aims to raise the bar. One57 and 432 Park are both additions to the park view lineup and each comes with its own differentiator. While 220 CPS will be unique in many ways the most important differentiator is that the project is actually located on the Park. While many of the new developments aim to capitalize on their adjacency to the park, they are all actually located one to two blocks south.

Assemblage of the development site at 220 CPS took several years. After the developer purchased the last remaining parcel, a single "hold out" remained. As it turned out, a rival Extell Development had a lease for the garage located under the last building. While the terms of the deal remain confidential one of the stipulations negotiated was that the developer of 220 CPS, Vornado Realty Trust would not develop a building greater than 950ft in height. As it turns out, Extell was planning another super tall development directly to the south and was concerned about their views being blocked. The assembled site consisted of a through block lot with frontage on both Central Park South and 58th Street. 220 CPS is actually a two building development comprised of the Villa located directly on Central Park South and the Tower, located to the south on 58th street. Zoning on Central Park South limited the building height to no more than 220ft. The development of the Villa to the north created a self-inflicted hardship on the south tower in that the views to the Park (North) were now blocked below 220ft. Marketing studies had concluded that the value of the tower units with obstructed views would be significantly diminished. As such the developer called on the design team to develop a scheme whereby all of the product for sale in the tower would be super-elevated above 220ft. As the tower height was limited to 950ft an interesting typology was created. The floor area in the tower had to be fit within the zone of 220ft to 950ft. Zoning setbacks and a marketing requirement for higher floor to floor heights was also an imposition. Layering all of these restrictions created a unique quandary in that any mechanical floors or structural out rigger floors would take away from salable space within that predetermined building volume. The design team needed to develop a solution as the loss of each salable floor would result in the potential revenue loss of almost $75 million.

All of the mechanical equipment including cooling towers was dropped down and located within the lower 220ft of the building. Express ducts and risers were required as well as supplemental fire pumps.

The Solution

The Villa building to the north was governed by zoning which resulted in the restricted building height of 220ft as well as street wall setbacks. At 220ft the structural solution was obvious and straightforward. A concrete flat slab was proposed as is typical for most residential projects in the Metropolitan region. Cast in place flat slabs are supported on concrete columns. Shear walls resist lateral wind and seismic forces.

The Tower building was governed by zoning restrictions but more importantly the previously negotiated height restriction of 950ft. The resulting building form was a near perfect rectangle extruded vertically. In order to accommodate the required zoning restrictions particular to the site resulted in a tower 53ft wide by 128ft long with a plan area of approximately 7,500ft^2. At 950ft tall the resulting aspect ratio exceeded 18 to 1. From previous experience the team was well aware of the potential impact from vortex shedding and / or buffeting from existing adjacent and planned adjacent high rise towers. The first step in the design process was the development of a concept model. The choice of system was less important at this stage. The structural properties were developed to determine building periods and densities. A wind tunnel study was immediately undertaken to determine what if any site specific aerodynamic anomalies may exist. Additionally, the architect was studying several variations to form that included setbacks and a cantilever.

Wind Tunnel Testing

It was determined that three models would be tested. At this initial stage a force balance model was utilized with the understanding that an aeroelastic model may be utilized at a later date. The three forms initially tested were as follows:

A basic massing resulting from a strict

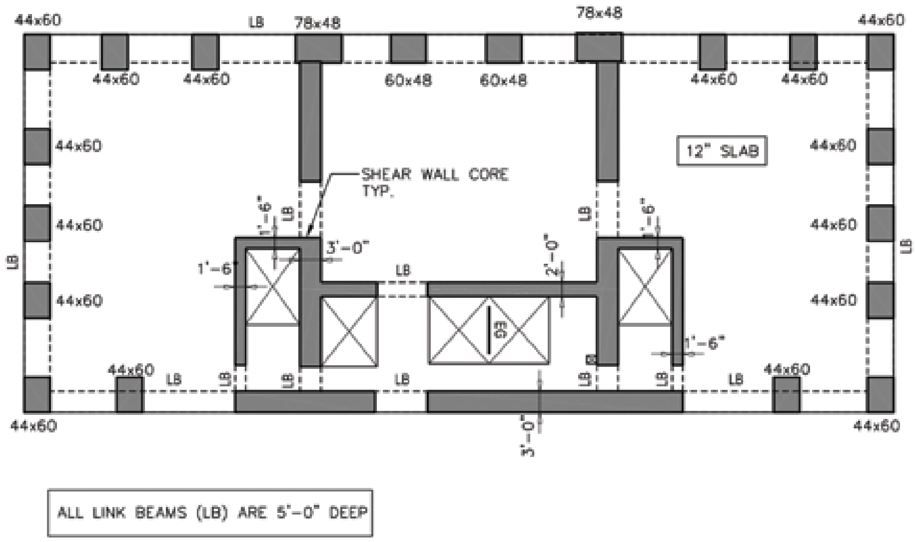

Figure 2. Lower Podium Floor (Source: DeSimone Consulting Engineers, PLLC)

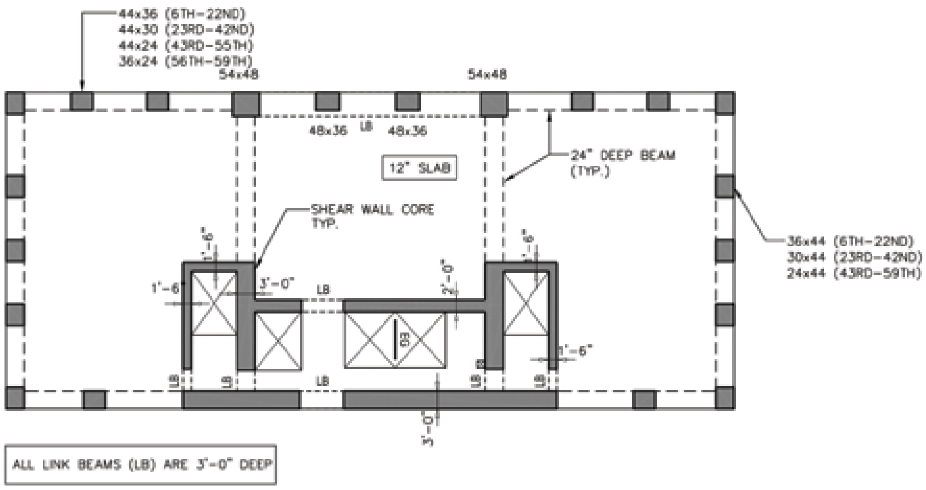

Figure 3. Tube Scheme (Source: DeSimone Consulting Engineers, PLLC)

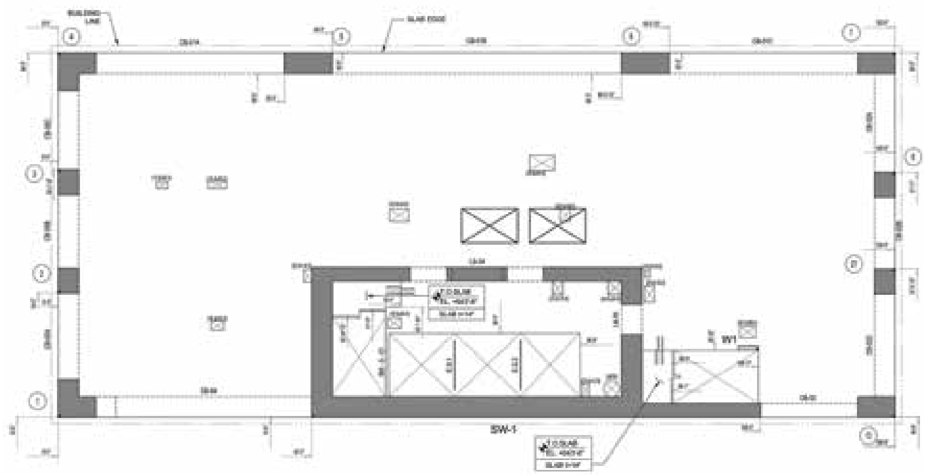
Figure 4. High Rise Tower Plan (Source: DeSimone Consulting Engineers, PLLC)

interpretation of the zoning requirements. This would become the baseline. The second and third models were forms presented by the architect, and approved by ownership that were qualitatively determined to be superior from an aerodynamic standpoint from a multitude of other proposed forms. The base line case was compared to the other two forms so it could be determined what benefit or penalty existed for the various shapes (see Figure 1). This process would help inform the determination of the final building massing.

Based on the building exposure and aspect ratio the need to use supplemental damping was assumed and the space required integrated into the building massing. Based on the height constraints it was determined that 25ft would be allocated for the damper. This height restriction eliminated the possibility of using a simple pendulum damper. Based on our previous experience and reassurance from RWDI we were confident that we could fit a compound action damper within the allotted height.

For the purposes of this initial study we assumed a maximum damping potential of 6-6.5% of critical. The target accelerations, at 2% of critical were established at 32-34 mG with the assumption that 6% damping would yield a resulting acceleration of 17-18 mG. At this stage the primary focus was to determine if it was even possible to develop a scheme that could meet established acceptance criteria in a form that would satisfy the various site constraints.

The results were rather close with only slight differences between the variations.

With the shape, height and volume established it was now time to further develop the structural system that met with the owner and architects approval.

As previously discussed, the residential portion of the project was to be super elevated to improve views to the north. Mechanical equipment was pushed into this volume. It was decided as a structural strategy to stiffen this base significantly with the idea that we could reduce the "effective" height of the building by constructing the tower on a very rigid base (see Figure 2). Working with the architectural team several core schemes were developed with the goal of maximizing plan efficiency and salable area. Some twenty three options were developed and tested. Ultimately it was determined that putting the core on the south face of the tower would enable all of the residential units to be oriented entirely to the North. As the owner was expecting to sell the majority of the building as full floor

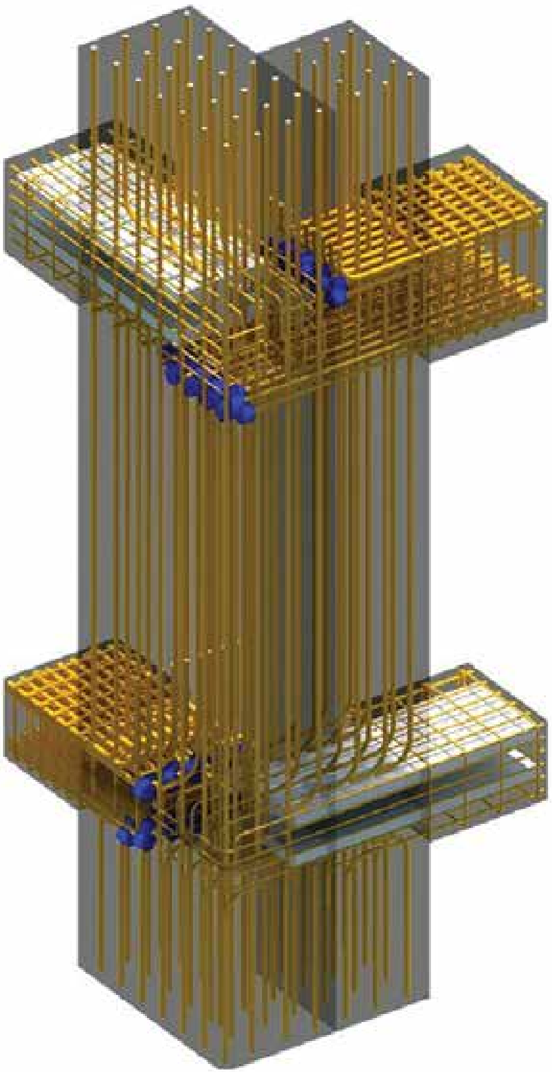

Figure 5. Composite Beam Details (Source: DeSimone Consulting Engineers, PLLC)

Figure 6. Composite Beam Details (Source: DeSimone Consulting Engineers, PLLC)

units, flexibility was key. As building mass was important to reduce response and eliminate tension, interior columns were eliminated and an 11" slab was utilized to span from core to building perimeter. The lower tiers of the building were programmed to be multi-unit residential floors. The higher partition density provided ample opportunity to locate shear walls between unit demise walls.

While most of the competing towers in the vicinity of the park were all modern, glass curtain wall buildings, the developers of 220 CPS decided to take a different approach. Instead of creating another reflective glass megalith, the developer wanted to create a very contextual yet modern version of the glorious older buildings that line Central Park. In lieu of glass they opted for limestone. Hand set limestone or even precast was unsuitable for a building of this height so a limestone curtain wall system was developed. While the design presented unique challenges it also presented unique opportunities as well. Unlike a traditional curtain wall system the glass component of the design was not "floor to ceiling". Instead the limestone façade surrounded the windows of the living spaces creating "picture frames" through which the occupants could look out onto the park below. This architectural feature provided us with the opportunity to locate spandrel beams around the entire building perimeter. Coupled with the shear walls the spandrels greatly enhanced the stiffness and torsional response. The resulting structural system is a hybrid that varies vertically, consisting of shear walls with perimeter moment frames at the base and moment frames alone at the upper portion (see Figure 3).

While the resulting structural system provided adequate stiffness and a building response within acceptance criteria the developer insisted on something more. Amongst other things they were selling park views and they wanted the structural system to be less obtrusive. The interiors of the building, like the exterior were very traditional and as such the structure was to blend in as opposed to being part of the architecture like 432 Park Avenue. Unlike 432 Park, the developer did not want columns marching across the façade at 16ft intervals. This insistence lead to the development of a revised cellular, megaframe concept. At a total width of 128ft the building plan was divided into three equal "cells". The area of the perimeter moment frame columns was "lumped" into four locations across the north building face. Lumping the column area into only four columns greatly increased the individual column sizes. From a forming efficiency standpoint this greatly reduced overall vertical column formwork. The resulting clear span became close to 40ft creating a truly unique view experience (see Figure 4).

The elimination of the perimeter columns resulted in an increase in the beam span and decrease in beam stiffness. In order to increase the beam strength and stiffness structural steel shapes were integrated into the spandrel beam design (see Figure 5 and Figure 6).

Figure 7. Damper (Source: DeSimone Consulting Engineers, PLLC)

With the structural system refined, the optimization process was undertaken. Various studies were conducted to verify and improve stiffness assumptions. Structural member cracking properties were calculated at various load levels. Seismic Performance Based Design techniques were also utilized to further refine stiffness calculations. Moment curvature diagrams were developed for various members up the height of the structure to account for varying load levels and the contribution of reinforcing steel to member stiffness. High strength reinforcing steel was utilized to minimize congestion. A performance based approach was utilized for the concrete mix design. While strength was important, modulus was equally important. Working with the concrete supplier and contractor, several mixes were developed and tested to verify strength, modulus and workability. Ultimately, concrete performance mock-ups were performed to verify field strength, modulus, and workability. The mixes were batched and loaded into several concrete trucks. The trucks followed their anticipated route to the site and concrete was placed into column mock ups. While there was initially some resistance to this exercise it became obvious that important information was to be gained from this exercise.

The final damper design was performed by RWDI in conjunction with their Motioneering division. After the final design was completed, the wind tunnel results were regenerated. While there was much give and take along the design process the overall behavior of the building changed minimally. The solution proposed was an 1,100 ton compound action damper (see Figure 7).

Using time history analysis it was determined that the damper was capable of achieving 6.5% damping which brought the overall building response to within acceptable levels at varying wind speed recurrence intervals.

Conclusion

The design of 220 Central Park South adds another supertall, super luxury building to the Manhattan skyline. The building's design represents a furthering of the field of wind engineering and concrete high rise design. The building design is a result of the close collaboration between developer, architects, and engineers. More importantly, the design was guided by an understanding of the particular development issues confronting the site and the underlying economic model as opposed to any preconceived notions in regard to structural optimization and cost. The building design has been extremely well received with sales exceeding expectations.

The Details

The gravity load resisting system is comprised of the reinforced concrete structural slab, which is supported by the moment frames and shear walls, and lastly transferred to the foundations. In general the thickness of the slab ranges between 10" to 12", with concrete strengths not exceeding 10ksi. Gravity loads around the perimeter of the building are higher than average due to the use of handset limestone at the lower floors and limestone curtain walls at above floors.

The lateral load resisting system for the tower is comprised of reinforced concrete core shear walls and perimeter reinforced concrete moment frames. Shear wall and column concrete strength range from 10ksi to 14ksi utilizing reinforcement steel as high as grade 75 #11 and grade 80 #20.

The seismic design for the building was based on the requirements for a shear wall frame interactive system with ordinary concrete moment frames and ordinary reinforced concrete shear walls.

Wind loads were found to govern the design of the building over earthquake loads, with the wind engineering services and loads provided by RWDI.

The foundation system consists of three 8ft thick concrete mats comprised of more than 2,200 cubic yard concrete sitting on class 1a bedrock. Excavation of the bedrock to more than 50ft below grade required a combination of rock hammering and controlled blasting. Excavation was complicated by the surrounding historic landmark buildings immediately adjacent to the project site to confirm and ensure the structural integrity of those buildings was not affected by vibrations of the explosions or rock hammers.

To resist overturning in the tower, 142 rock anchors with 615kips tension capacity were drilled more than 50ft into the bedrock and installed within the mat foundations. The top and bottom reinforcement within the mat is comprised of up to eight layers (four running in each direction) of grade 75 #11 bars.

The Development Team

Developer: Vornado Realty Trust

Design Architect: Robert A. M. Stern Architects

Executive Architect: SLCE Architects

Interiors Architect: The office of Thierry W. Despont, Ltd.

Structural: DeSimone Consulting Engineers

Curtainwall: Heintges & Associates

M/E/P: Cosentini Associates

Wind Tunnel: RWDI Consulting Engineers

Geotechnical: Langan

Construction Manager: Bovis Lend Lease