High Rise by the High Line

Designing for speed and efficiency

by Ramon Gilsanz, Jennifer Lan, and Petr Vancura

Avalon West Chelsea is a new 588,000 ft^2 (54,600 m^2), multi-family residential development located in the prime Chelsea Arts District of Manhattan, New York. Programmatically, this "L-shaped" building consists of two distinct components: Avalon West Chelsea, a 31-story tower featuring 309 luxury apartments, and a 14-story mid-rise that extends from the tower at the west to the High Line Park at the east, housing 405 units geared toward a younger demographic (Fig. 1). The LEED Silver certified property also includes 142 affordable housing units, rooftop terraces, green roofs, rear yards, a fitness center, lounge areas, a 140-car parking garage, and retail space at street level. The upper floors have views to Midtown, Downtown, and across the Hudson River.

The project was developed, constructed, and is owned/managed by AvalonBay Communities. SLCE Architects served as Architect of Record; Fogarty Finger was the Design Architect; MG Engineering was responsible for mechanical, electrical, and plumbing (MEP) design; and Mueser Rutledge Consulting Engineers provided geotechnical services. Gilsanz Murray Steficek LLP (GMS) provided structural design services for the new building and its foundations. GMS was responsible for the design of all reinforced concrete and structural steel and provided special inspection services for the cast-in-place and precast concrete, as well as welding, bolting, and steel erection.

Fig. 1: Rendering of Avalon West Chelsea

An Efficient Design

Avalon West Chelsea is a reinforced concrete flat-plate structure. This system offers a combination of lower costs and higher speed of erection when compared to other structural systems, so it is the most common slab structural system for high-rise residential construction in New York City. Flat-plate construction allows for an irregular column layout, maximized usable floor-to-ceiling space, and flexibility in the layout of the interiors. As the slab is flat, minimal ceiling finishes are required over living and sleeping areas. Like other concrete systems, flat-plate construction is inherently fireproof and is less susceptible to vibration than steel systems. Shear walls are located around the elevator shafts and egress stairs to minimize their architectural impact and to provide structurally sound and fireproof enclosures.

The size of the building alone created complexity for the structural design. The building's primary structure comprises cast-in-place flat-plate concrete floors supported by seven sets of shear walls in addition to almost 200 columns. The columns and shear walls are supported by more than 1000 piles (Fig. 2).

Fig. 2: Pile cluster for the core foundation walls. Over 1000 piles were required to support building columns and shear walls. The piles are tied together by a foundation slab

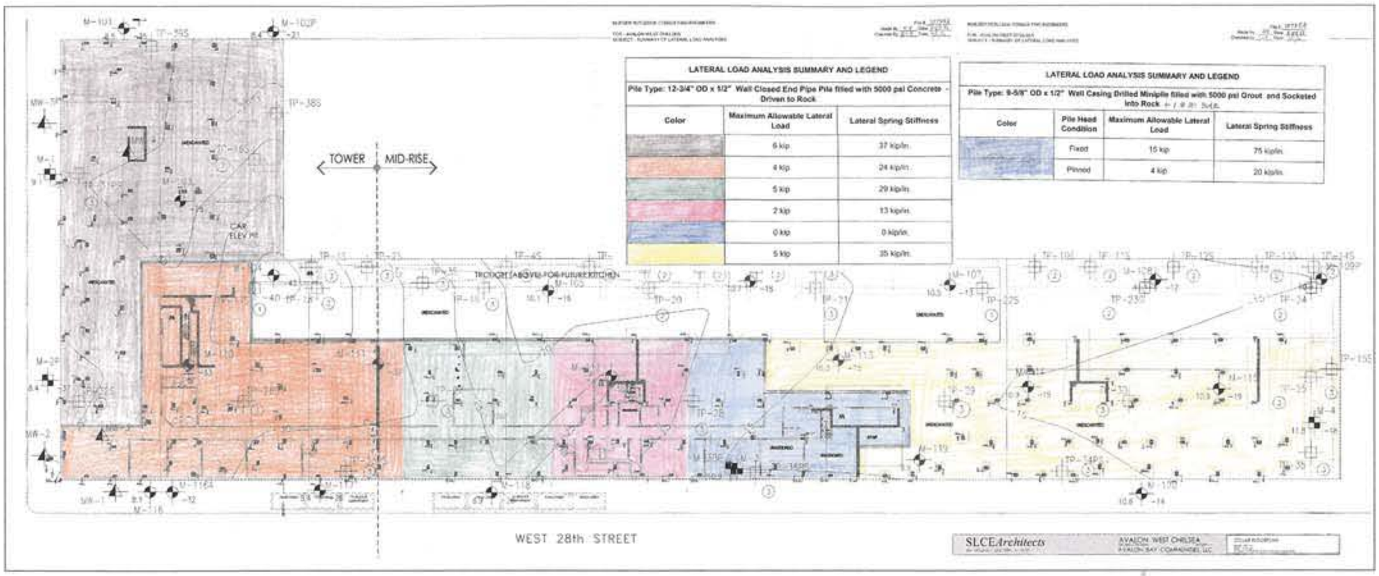

Fig. 3: The geotechnical engineer assigned strength and stiffness values to the piles based on length and diameter. The variation was accounted for in the structural design through soil-structure analysis

To simplify the construction process, the design team strived for uniformity and repetition. In the resulting design, about 80% of the pile caps and 80% of the gravity columns have the same cross sections and reinforcing areas. To avoid increasing the column and reinforcing areas in the lower half of the tower, the concrete strength is increased. All slabs have continuous top and bottom mats of typical reinforcement. Additional reinforcement is specified to be the same diameter at each floor, and the majority of the bars are specified in two standard lengths. GMS also worked with the architect and the developer to minimize the number of column transfers to preserve the uniformity of the design. The final design achieved an average reinforcing steel weight of 7.5 lb/ft^2 (36.6 kg/m^2) of gross floor area.

Initially, seismic considerations governed the design of the lateral force-resisting system. A site-specific response spectrum analysis was performed by the geotechnical engineer to more accurately assess seismic effects, and through this analysis, the design seismic loads were reduced to similar magnitudes as the wind loads. Torsion was observed in the governing dynamic mode of the building, and the inherent capacity of the gravity columns was used to restrain the movement to an acceptable level.

As previously indicated, building columns and shear walls are supported by about 1000 piles. While these elements were designed with pinned supports at the top and bottom, the large quantity made it feasible for the design team to take advantage of the lateral resistance of the piles and avoid the need for additional foundation elements. Varying rock and soil conditions were encountered over the large site footprint of 67,000 ft^2 (6200 m^2), however, so the geotechnical engineer performed a detailed analysis to assign pile strength and stiffness for each portion of the site (Fig. 3). Because approximately one-third of the site has a very shallow rock stratum, some piles were deemed to provide no lateral resistance. A foundation slab was used to tie all the piles together.

The floor slabs were designed without expansion joints so that the tower structure could cantilever laterally from the significantly stiffer mid-rise portion of the structure. A construction sequence analysis was performed to understand the effects of self-straining forces on the 575 ft (175 m) long slab. Crack-control reinforcing was added at column exteriors, shear wall corners, and re-entrant corners, where high stresses were observed.

Concrete Construction in New York City

The tower portion of Avalon West Chelsea was constructed using the 2-day cycle, a concrete construction method in which one level of superstructure is constructed every 2 days. The process was developed in New York by Joseph DePaola of DIC Concrete in the 1950s[1] and was improved on in the following decades. This construction method requires a skilled and experienced labor force as well as stringent inspections. As the 2-day cycle entails a specific sequence of events to occur for the work crews to be able to move to the next floor, a delay in any single step will delay all subsequent steps, thus resulting in a setback of an entire work day.

With the advent of computer-aided analysis and design, building designs are more complex, less repetitive, and less conservative than they were in the 1950s. High-performance buildings today also hold many more systems and services, so there are more trades and more congestion on the construction site. As a result, building with a 2-day cycle today is more challenging than it was a half century ago.

In a typical cycle, placement begins at daybreak. Concrete is placed one quadrant at a time; meanwhile, lathers install reinforcing bars one section ahead of the placement crew.

After the placement, the fresh concrete is given several hours to harden. Around midday, layout crews start locating columns and walls, and they are followed by carpenter teams that position vertical forms and shoring. By the end of the day, formwork for the next floor is substantially complete. The following morning, reinforcing bar cages are placed and secured for columns and shear walls. At the same time, carpenters, plumbers, and electricians place blockouts and sleeves for slab openings required by their trades, followed by lathers who then position bottom-bar layers. Electricians follow behind the bottom-bar lathers to install conduits that are to be embedded within the slab, and the top-bar lathers follow behind the electricians to complete the reinforcing bar placement. In the afternoon of the second day, concrete is placed at columns and shear walls. By the end of the day, the first portion of the subsequent slab is ready for the next morning placement (Fig. 4).

The biggest challenge of a 2-day cycle is not the speed of the work itself, but the fact that multiple trades must mobilize and perform their tasks within the same physical space. A 1989 study by Pennsylvania State University researchers showed that congested workspace and restricted access may result in up to 65% and 58% losses of efficiency, respectively.[2] If installation conflicts are not coordinated and resolved immediately, then work cannot continue and the placement is delayed.

At a site like Avalon West Chelsea, about 150 union workers were employed every day. Based on the local prevailing wage at the time, a 1-day delay would result in a cost add of over $100,000 for labor alone. Additional costs, such as equipment rental and remobilization expenses, would make the delay even more expensive. Simultaneously, the owner also would incur opportunity costs related to interest on construction loans and delayed revenue streams (according to the New York City Department of Finance assessment of the completed building, a hypothetical 1-day delay would represent $86,000 of income that the owner would not be receiving). Consequently, the contractor is under pressure to proceed with scheduled placements and incur the costs associated with fixing errors after the fact, rather than delaying the construction cycle for coordination.

Field Coordination during Construction

Embedded conduits

Placing electrical conduits within the thickness of a structural slab provides numerous advantages over installation below the slab. In-slab conduit can be thin-walled PVC pipe rather than more expensive galvanized steel, and doesn't require expensive and labor-intensive concrete anchors and conduit straps. Embedded conduits also do not encroach on occupied space, thus allowing for maximization of floor-to-ceiling heights within apartment units. At Avalon West Chelsea, however, the lower 14 levels typically contained 57 apartment units per floor, which resulted in conduit congestion (Fig. 5). This required a high degree of coordination

Fig. 4: By the end of day two of a 2-day construction cycle, the first portion of the subsequent slab section is ready for the next morning's concrete placement

Fig. 5: Close coordination was required to avoid conflicts between the electrical conduit and reinforcing bars

between the structural and MEP trades, as electrical drawings typically show only the points of entry and output, leaving the conduit layout to the field electricians.

While structural engineers are familiar with limits on conduit diameter and center-to-center spacing specified in ACI 318-11,[3] electrical contractors are rarely aware of these requirements. As conduit layout is not typically done during the design phase, all coordination must occur during the shop drawing phase. When detailed shop drawings are not submitted or when they are not provided to the structural engineer, as is frequently the norm, coordination between electrical and structural systems has to occur in the field.

Because of the constraints created by the architectural layout and the floor plate geometry at Avalon West Chelsea, the conduit layout had to be engineered. The prescriptive requirements of ACI 318-11, which incidentally are no longer included in ACI 318-14,[4] would not have worked. During the first week of superstructure erection, the structural engineer defined a set of rules for the electrician to follow that were specific to this project. This gave the contractors a better understanding of the structural impacts of their work and reduced the number of nonconforming conditions that had to be fixed after conduit placement. For the typical floors, GMS produced a diagram showing zones where conduits were not permitted and zones where conduits could be placed at a specific spacing. In some zones (middle spans of smaller bays), GMS determined through analysis that it was acceptable to place conduits at a closer spacing than what was prescriptively specified in ACI 318-11.

Other field coordination items

Whereas conduits run between top and bottom layers of slab reinforcement, riser penetrations run through the slab and displace reinforcing bars. Typically, MEP drawings remain schematic throughout the design development phase and are usually not finalized until construction documents are 100% complete. These trades are therefore not fully coordinated during design and must be coordinated during shop drawing review or in the field. When MEP subcontractors are brought on board, they propose substitutions that may change opening sizes and/or locations which impact the structural design. Any conflicts not picked up during the submittal review process will need to be resolved in the field.

Some construction logistics, such as temporary equipment and installation space requirements, never appear on drawings reviewed by the structural engineer. This is particularly significant at very tight construction sites with limited space for storage and staging. Contractors often ask for temporary slab openings when they cannot get enough clearance within the building to move materials around. These are typically last-minute requests and they require coordination in the field to relocate displaced bars and conduits.

Another condition encountered in high-rise construction is that all construction materials have to be lifted to the highest floor using the tower crane. As all trades share the crane, the wait time between crane lifts can be significant. If material is accidentally left out in one crane lift, it may not make it to the working deck prior to concrete placement. In these instances, the deck crew has to improvise with the materials available on the deck to remediate the situation. Engineering judgment is necessary to determine whether or not the completed substitutions are acceptable.

Excellent Execution

Given the complexity of the project and the quick response time required for the 2-day cycle, the engineer's presence is essential for maintaining the schedule and minimizing errors in the field. At Avalon West Chelsea, GMS had a continuous presence at the site because the company was engaged as both the structural engineer and the special inspector. Solutions would be worked out directly with the contractor, and when the issue involved other trades, other parts of the design team would be engaged as well. There was an open and direct line of communication between the construction team and the design team.

The mid-rise was the first portion of the development that was completed and it opened its doors to its first tenants in December 2013. The tower portion opened near the end of 2014. The combination of innovative approaches for simplifying structural systems and a highly efficient construction process delivered a superior product to the client within budget and on time. Together, excavation and foundations cost about \$12,000,000 and the superstructure was completed at a cost of just over \$27,000,000, or about \$46/ft^2 (\$495/m^2) of superstructure.

While structural engineers are often lauded for achieving wild architectural forms, the engineering and inspection team on this project instead presented value through thoughtful structural design, by simplifying the construction processes, and by bringing a straightforward production process to a potentially overwhelmingly unwieldy project.

That's engineering!

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Selected for reader interest by the editors.

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