VANCOUVER HOUSE
Vancouver, BC

POST-TENSIONING INSTITUTE ®

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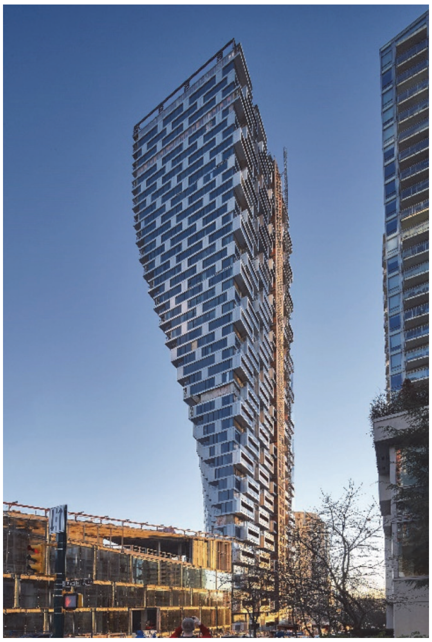

Fig. 1—Vancouver House.

An iconic welcoming gateway to the city (Fig. 1), Vancouver House is a visually remarkable, honeycomb glass tower consisting of a total of 652,000 ft^2 (60,600 m^2) within 52 floors. Located in close proximity to the Granville Street Bridge entrance to downtown Vancouver, the unique design was specially adapted to allow for significant redevelopment of an area with limited buildable land while complying with setback requirements from the bridge ramps. With an ultimate height of 515 ft (157 m), Vancouver House is the fourth tallest tower in downtown Vancouver.

The tower, which starts off with a slender base, torques up from its limited 7500 ft^2 (700 m^2) triangular footprint and gently cantilevers as it ascends, allowing the tower to reclaim efficiency as it twists from a triangular shape into the optimum rectangular shape, increasing the tower's floor area as it rises.

The building structure[1] consists of 53 structural levels above grade of post-tensioned reinforced concrete flat slabs 8 in. (200 mm) thick in the tower. Concrete strengths on the tower range from 5000 to 9400 psi (35 to 65 MPa) for the different concrete elements. Supporting concrete columns to each of the floor slabs walk along the curved silhouette of the building following the northeast edge. The offset nature of the columns shifting each floor pulls the tower floor slabs towards the bridge (eastward), collecting the vertical gravity load of the concrete structural system and the superimposed loading. As the vertical columns gradually walk down the height of the building, they merge together. As the north tip of the building tapers to the width of a single column at the base of the tower, they push against the floor slab in the opposing direction (westward).

The non-symmetrical design of the cast-in-place concrete building posed considerable structural challenges that were addressed by many key experts. Achieving the desired vertical alignment of the cantilevered floors required diligent management of the deflection as there were very few typical floors throughout. As the floors extend further out over the triangular half of their rectangular site, their loads are transferred back to a branching system of tension columns and shear walls through the use of horizontal post-tensioned cables and vertical post-tensioned rods. The concrete core is strengthened with vertical post-tensioned threadbars encased in the concrete (Fig. 2), enabling the transfer of loads from the wider upper floors of the tower to the core and columns.

Gravity-induced lateral design in a high-seismicity region

Adding to the complexity of the structural design, the high seismicity of the west coast of North America compounded the challenge for the structural engineers. The summation of both gravity and seismic forces onto the system necessitated a rigid vertical spine that is both flexurally and torsionally robust to stabilize the building. Vancouver House employs a reinforced concrete core using innovative systems that have never been used in the local residential high-rise construction industry.

At the entrance to the elevator lobby, heavy wide-flange beams embed 5 ft (1.5 m) into the concrete walls at both ends directly above as you enter and exit the core, connecting the two 'C' shapes of the core and closing it into a torsionally strong box section. Rather than traditional yielding link beams, these heavy steel sections remain elastic under gravity and cyclic seismic loading.

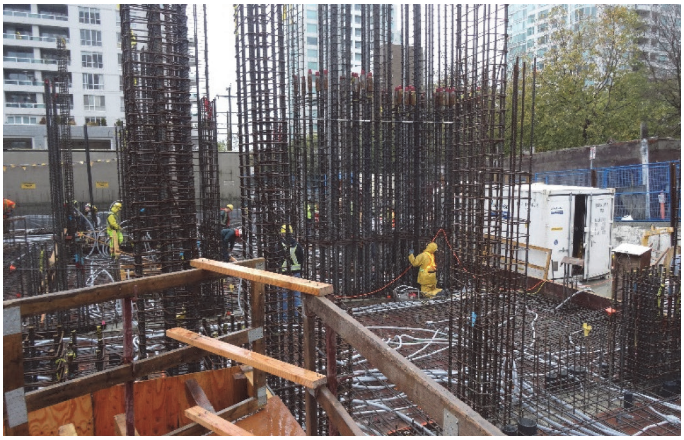

Fig. 2—Vertical post-tensioned threadbars.

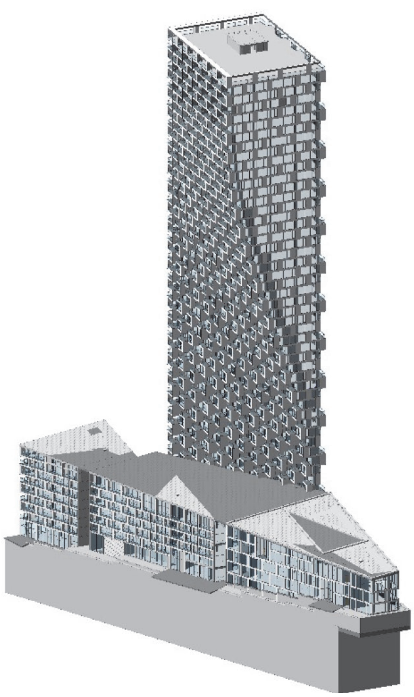

Fig. 3—Structural model used to analyze structure.

Wing walls are rigged out from northwest and southwest corners of the offset core, staggering their openings between the two walls on every floor.

At the extreme ends of the wing walls and the furthest location from the core stand 11 post-tensioned high-strength threaded bars counteracting the primarily unidirectional loading of the tower, pulling the building back to near verticality. Vertical post-tensioning was used to compress one side of the building's core to counter the vertical tension created by the structure's lean, while the horizontal post-tensioning countered the tendency of the floors to twist as the structure leans with the construction of each floor as it rises. Each floor was constructed offset from a vertical plumb line by a set amount opposite to the buildings' lean so that after completion, the building will lean back to the plumb line (Fig. 3). The amount of lean was calculated using nonliner time-history analysis of the building, taking into account concrete cracking and creep shrinkage. The lean was calculated for each stage of construction using multiple sets of variables for a range of properties to provide an upper and lower bound of expected movement. The building was continuously surveyed throughout construction to monitor actual movements against calculated movements. The measured deflections show that the use of post-tensioning along with prescribed offsets during construction has resulted in building movements within the envelope of calculated values.

Vertical post-tensioning is not used often and this structure required 11 prestressing threadbars (Fig. 4), each 2.6 in. (66 mm) nominal diameter, to be anchored in the foundation and extend up the core to the 36th level. The tendons are installed in a corrugated sheathing and coupled when required. There were two intermediate stressing locations to help overcome the overturning moments of the cantilevered floors above during construction. At level 26, four of the 2.6 in. (66 mm) threadbars were transitioned to 1.8 in. (46 mm) threadbars through the use of special machined transition couplers.

The tendons at the intermediate points were stressed using a small-diameter, high-pressure ram (Fig. 5) to fit within the constrained space of the core reinforcing steel. This operation took a lot of coordination with trades and detailing in the area to make sure there were no bars impeding the insertion of the ram into the area.

Particular attention was paid to the grouting details to make sure the tendons would be completely grouted without voids and to ensure the grout could be injected and pumped to the top of the tendons. The bottom anchorage is located 11.5 ft (3.5 m) below the bottom parking slab, creating an area of concern for water collection. Prior to construction, various grout mockup tests (Fig. 6) were performed to select the appropriate mixture and prove the injection details and positioning of grout injection ports. After the mockup testing was completed, a method was determined to make sure any standing water was displaced from the bottom anchorage. The coupler locations were another area of concern to make sure the couplers had room to travel during stressing and to make sure the grout would not get constricted. Additional ports were installed above and below the couplers in case problems were encountered so that there were options to stop grouting

Fig. 4—Stressing of vertical threadbars.

Fig. 5—Stressing of tendons at intermediate points.

Fig. 6—Grout mockup testing.

and continue later without having to drill into the core wall. During the grouting operation, none of the backup measures were required, as the mixture determined during the mockup test and equipment selected performed perfectly.

The use of post-tensioning in this project increased the building performance, as it reduced deflection and vibration, allowing for better predictability and control of movement within the structure. The longer spans which were enabled by post-tensioning cut down on the number of columns required and allowed for innovative building design in a way that other construction methods could not, as it gives greater flexibility to the changing floor plans throughout and provided openness and stability to the structure. Creativity, innovation, and meticulous design and coordination led to the success of this project.

REFERENCES

1. Poh, G., "Vancouver House," *STRUCTURE Magazine*, Jan. 2020.

TEAM

Owner: Westbank Corp.
Architect: BIG (Bjarke Ingels Group) and DIALOG
Structural Engineers: Glotman Simpson Consulting Engineers
General Contractor: ICON West Construction Corp.
PT Supplier: DYWIDAG-Systems International
Other Contributors: PFES Studio, Landscape Architect; Integral Group, Mechanical Engineering Consultant; Nemetz (S/A) & Associates, Electrical Engineering Consultant; Morrison Hershfield, Building Envelope Consultant