Vancouver House

By Geoff Poh, P.Eng

Picture yourself standing at the base of a 515-foot-tall high-rise tower looking up to the sky with the side of the building being only as wide as you are tall. Looking up, you see the tower gradually grow out to one side above you, consecutively with each floor, seemingly without any columns supporting the tower as the floor plate expands in width by 16 times and doubles in area.

This was the challenge faced by the design team on the Vancouver House project in Vancouver, British Columbia, Canada. Now topped-off and nearing occupancy, the playful curve of the tower is causing a stir and turning the heads to all those who walk near it.

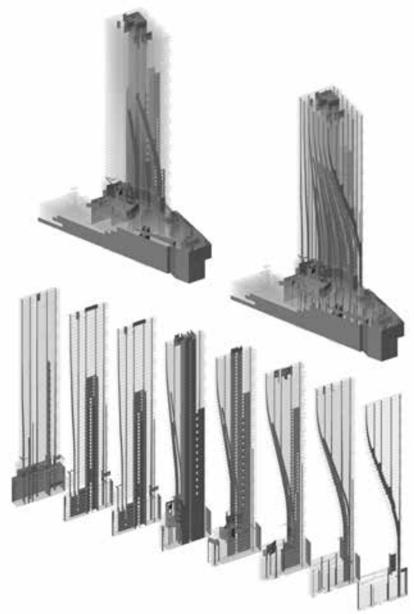
Topped-out Vancouver House tower north view (left) and south view (right).

Spatial Limitations without Compromise

Vancouver House is a unique building that required unique solutions from all disciplines. The design philosophy originates from the air-space clearance requirements surrounding the Granville Street Bridge. Needing to maintain at least a 98-foot (30-meter) safety offset from the bridge, the design architects at Bjarke Ingels Group sculpted the outline of the tower around these constraints without compromising the usage of the space, taking the shape of what Bjarke Ingels describes as a curtain being drawn aside.

Geometric Induced Structural Demands

The top of the building is rectangular, standing at nearly 100 feet wide (30.5 meters) and 13,200 square feet (1,226 square meters) in area. As you descend the building, the floors narrow and transform at the north end of the tower to a triangular shape nearly half the size of the roof at only 6 feet (1.8 meters) in width at the north end and 7,800 square feet (725 square meters) in area at the north end.



Vancouver House model views. Core only (top left); Full structure (top right); Full structure exploded section view (bottom).

Post-tensioned reinforced concrete flat slabs stack the tower at each of the 60 floors above ground. 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).

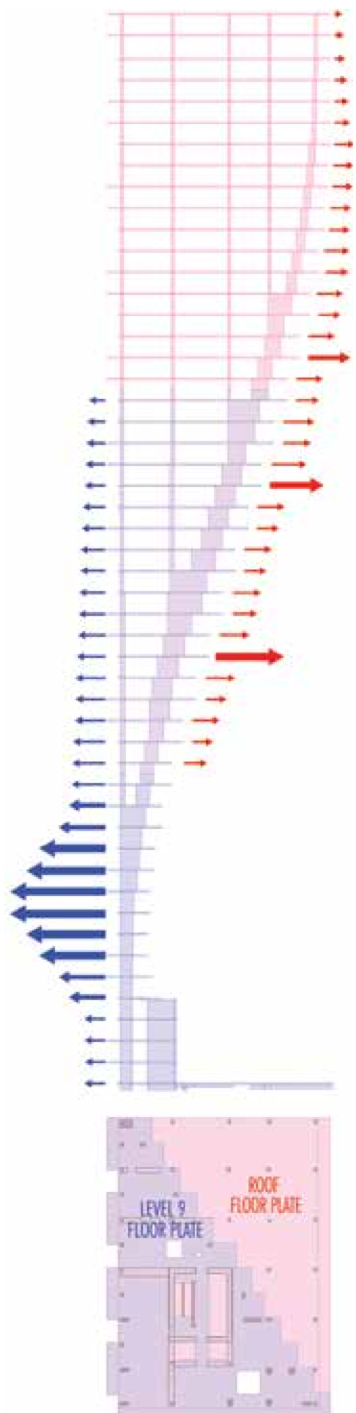
Overlaying the rectangular floor onto the triangular shape below, the elevator-and-stair core – the consistent vertical layout of the building – is located off-center, pushed southwest from the center of the rectangular building above. With both principles of the walking columns and the offset core, the tower is subject to sustained lateral and torsional forces under its own gravity loading, resulting in a permanent elastic lateral displacement up the height of the tower.

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 at Glotman Simpson Consulting 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 utilizing 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 feet 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.

Wing walls outrigger 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 DYWIDAG threaded rods counteracting the primarily unidirectional loading of the tower, pulling the building back to near verticality.



Floor plans and lateral loading.

Limiting Cracks and Ensuring Performance

Concrete cracks are a result of the inherent nature of the material as it cures and is stressed. While shrinkage and flexural cracks quite commonly occur on reinforced concrete buildings, it is much more important to fully understand the performance and sensitivity of a tower with this level of complexity and scrutiny. Glotman Simpson's expertise in non-linear performance-based design in high-rise concrete structures along the west coast of North America was invaluable in assessing the requirements for the Vancouver House structure.

Models of the structure with post-yield structural element properties were created using PERFORM3D and run against selected ground motions tailored to the project site (1.0x Maximum Credible Earthquake – or MCE). Strain compatibility and stresses of critical elements were checked under this level and then increased to 2.0x MCE. It is essential to understand the cumulative crack widths at the core walls and post-tensioned concrete flat slab diaphragms, the sum of which will propagate the lateral displacement of the tower. The design of the system followed the analysis to limit the cracks at these critical elements. Ultimately, the residual set of the structure was analyzed to confirm near elastic performance under 1.0x MCE and vertical stability and safety under 2.0x MCE. Both service level gravity and seismic load cases were also evaluated.

Success in Design Coordination and Planning

"Every unit is custom-designed." This aspect of the project was genuine and not just a marketing tactic. Easily as complex as the structural challenges, the coordination of the building façade and all other services around a moving structure in construction was a tall order for the executive architects at DIALOG.

Mechanical and electrical services supporting the daily use of the building were required to do similar gymnastics up its height. Centralized in one single location just north of the concrete core at the base of the tower, the services branching out to the outer extremities of the building were like the branches of a tree.

The cumulative stresses onto the post-tensioned reinforced concrete slabs meant significant limitations on the allowable concrete embedded services. The mechanical HVAC and electrical services were removed from within the depth of the flat slabs – moving to coordinated ceiling drops – leaving only a handful of special lighting features and mechanical lines at each floor to be meticulously coordinated into the structure.

An industry built around static structures under gravity required a new approach to coordination leading up to the construction of the building. All secondary components completing the architectural aesthetic of the tower were designed with additional movement tolerance and adjustability to move with the building's lean and twist for years to come.

Construction Monitoring Proving Performance

If constructed using traditional methods, at the point of structure top-off, the elastic movement at the upper height of the tower would have displaced nearly 10 inches towards the east relative to the base. To bring the tower design back to near verticality and account for long-term creep, Vancouver House was deliberately constructed vertically out of plumb (tower cambering) at each floor following directly opposite to the final displaced shape of the tower. The upper floors of the tower were cambered to offset the slopes formed by building rotation and column shortening.

The engineers at Glotman Simpson worked diligently with the construction team from ICON West Construction, both in the planning leading up to construction and for the duration of construction activities, to monitor the verticality of the tower through each floor construction sequence. Movement surveys of the tower at every second floor were performed for the duration of construction up to one year after topping off the building. Survey data collected followed closely with the calculated movement of the tower during and after construction; there was no better way to confirm the calculated performance of the building well into the long lifespan of this world-class tower.

An Icon for the West Coast of North America

Creativity, innovation, and meticulous design and coordination led to the success of this project. Performance-based-design with the use

Wide-flange coupling beams in construction.

Vertical post-tensioned high-strength DYWIDAG threaded rods in construction.

Vancouver House in construction.

of the latest technology in non-linear analysis developed the possibility for a tower like this to exist. Collaborative work to develop construction staging and sequence analysis turned the tower from paper to reality. The level of scrutiny placed on this project made it essential for efforts above and beyond any other project to develop a practical, constructible design. Vancouver House topped off in July 2018 and will always be a catalyst for creative architects and engineers.▪

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Project Team

Developer: Westbank Corp.
Design Architect: BIG (Bjarke Ingels Group)
Executive Architect: DIALOG
Structural Engineering Consultant: Glotman Simpson Consulting Engineers
Landscape Architect: PFS Studio
Mechanical Engineering Consultant: Integral Group
Electrical Engineering Consultant: Nemetz (S/A) & Associates Ltd.
Building Envelope Consultant: Morrison Hershfield
General Contractor: ICON West Construction