Engineering One Bloor West

Canada's First Supertall Structure

Toronto | Canada

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Steel Supplier: ArcelorMittal
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This technical leaflet has been created to provide detailed insights into the solutions implemented in the structural design of One Bloor West Toronto. It outlines the key engineering approaches, materials, and technologies used to ensure the building's stability, offering a comprehensive understanding of the technical considerations behind its construction. This document was prepared by [RJC Engineers], [Walters], and [ArcelorMittal].

One Bloor West's slender tower, rising 85 stories and over 300 meters tall, is Canada's first "supertall" structure (see Fig. 1). Primarily a residential tower, this mixed-use development also incorporates hotel levels above premium retail and event spaces.

Located at 1 Bloor Street West, One Bloor West stands at the intersection of Yonge and Bloor Streets - one of the country's most prominent intersections. The site sits near Toronto's busiest subway station, handling over 200,000 passengers on an average weekday, and is adjacent to the Mink Mile, an upscale fashion district.

For these reasons, One Bloor West's original design brief called for an exceptional, column-free retail space at the base, free of corner columns, to capitalize on the high-traffic location. The Development Team envisioned creating Canada's tallest building to complement this iconic site.

Designed by internationally renowned architecture firm Foster + Partners, the structure was initially conceived as a nearly 380-meter-tall building with an 18:1 aspect ratio and a steel diagrid exoskeleton. However, site challenges—including a narrow footprint, a parking ramp occupying one-third of the site, and the need to integrate residential, hotel, amenity, commercial, and parking spaces—necessitated modifications.

Fig. 1: One Bloor West in Toronto under construction

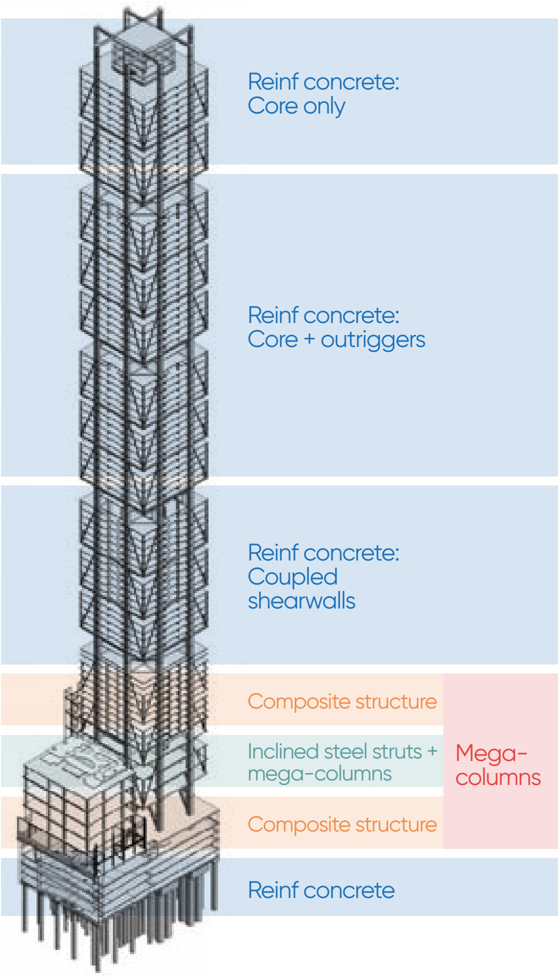


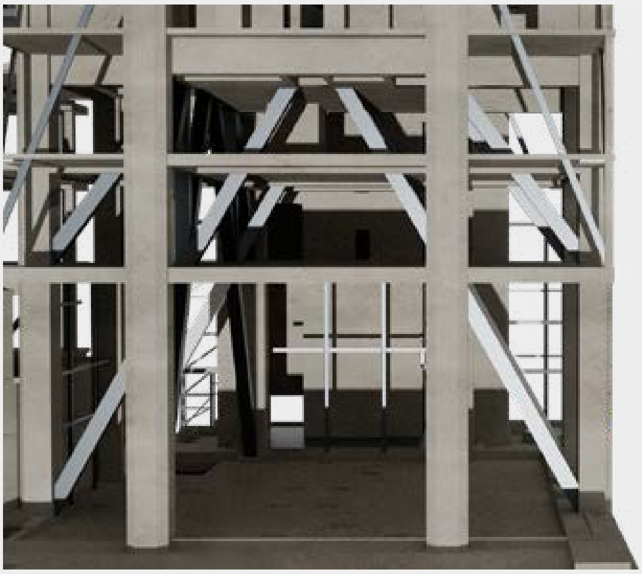
Fig. 2: Final structural diagram of One Bloor West

Various heights, shapes, aspect ratios, and structural systems were studied. While the steel diagrid was initially favored, it was deemed cost-prohibitive for Toronto's market. However, a fully concrete system could not achieve the column-free retail space at the base, leading to the adoption of a composite structure.

The final structural design (see Fig. 2) features a square tower optimized to reduce wind loads. While most Toronto towers use conventional concrete systems, including slabs and central cores, One Bloor West's design transfers loads above the retail levels to large, inclined steel struts resting on composite mega columns at grade. This eliminates the need for interior columns or a concrete core in the retail space.

Tower Transfer

The retail space required a 30x30m clear, open space and a 12m clear height volume. This cathedral-like space (see Fig. 3) was achieved by creating a composite transition above the commercial space, while transferring the tower's gravity and lateral structure onto structural steel struts.



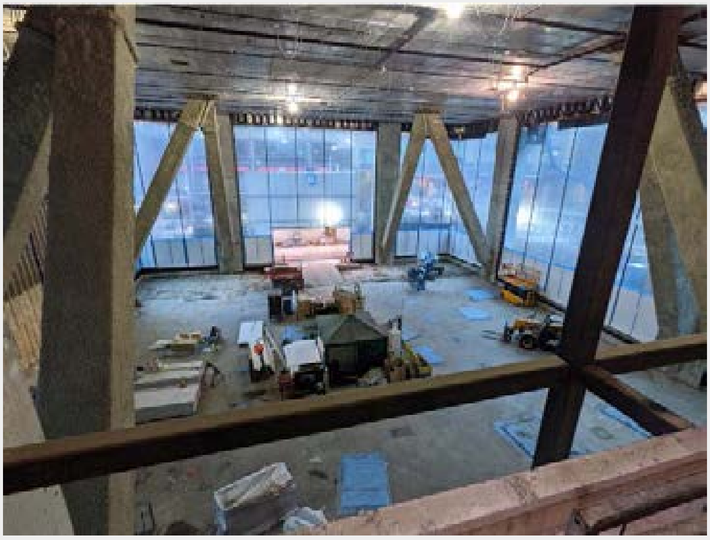


Fig. 3: Completed retail, 30x30m cathedral-like volume at the ground floor, extending up to level 3

Despite the building's height, the general weight of the structure is configured to keep all elements (except diaphragm ties) in compression for connections. For wind-governed buildings like One Bloor West, mass generally helps to reduce dynamic accelerations and resist overturning forces.

Earthquake forces are low relative to the wind loads and can be resisted elastically by the mega struts (see Fig. 4). Moreover, the composite levels from floors 5 to 9 act as an outrigger. The struts have sufficient capacity such that no weak storey is created from the core above.

A major consideration for this transfer was how to detail nodes for members that would have large tension forces in multiple directions. These forces are difficult to achieve with a typical built-up plate due to the combined compression, local bending and bidirectional tension forces.

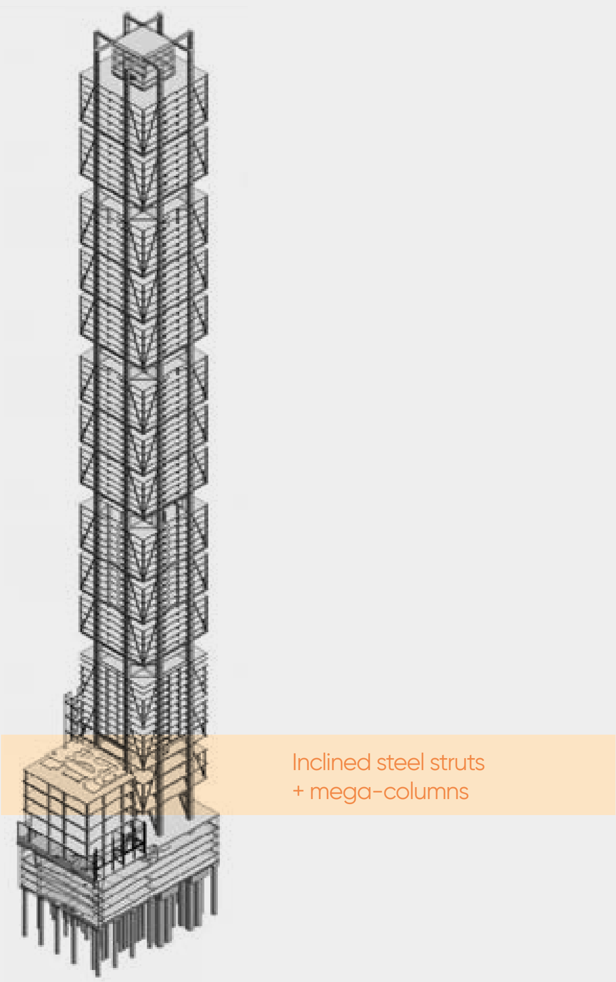


Fig. 4: Erection of mega struts to Level 3 from the ground-floor slab

A seemingly simple solution was to connect all elements to large, solid steel nodes (see Fig. 5). This was deceptively simple; it is difficult to create these sections while maintaining full through-section properties, weldability and high strength (450MPa), all while remaining insusceptible to lamellar tearing. The design team collaborated with local engineers for CastConnex High Integrity Block (HIB) product and Walters Group's engineering experts to design "nodes" that would meet all of the design criteria, yet be practical for fabrication and installation on site. These blocks, hot forged and specially designed and cast, were combined with ArcelorMittal's HISTAR ASTM A913 high-strength steel (65 ksi, 450 MPa) wide flange sections - creating nodes and sections that can be erected fully finished at site. Final nodes and struts weighed between 30-50 tonnes.

HISTAR A913 steel, developed by ArcelorMittal, is a high-strength, low-alloy steel widely used in tall building construction for its excellent mechanical properties and economic benefits. Its exceptional yield strength, combined with high ductility, allows for thinner and lighter structural elements without compromising safety or performance. This reduces material usage and increases efficiency. Additionally, HISTAR's unique production process ensures consistent quality and better weldability, making it ideal for complex designs like composite mega columns. In the case of One Bloor West, the higher yield strength not only served to satisfy the strength demands, but the lighter section sizes also helped to alleviate pick weights for the crane.

Use of these sections allowed for the creation of a light and airy space which was a key feature of the architectural design.

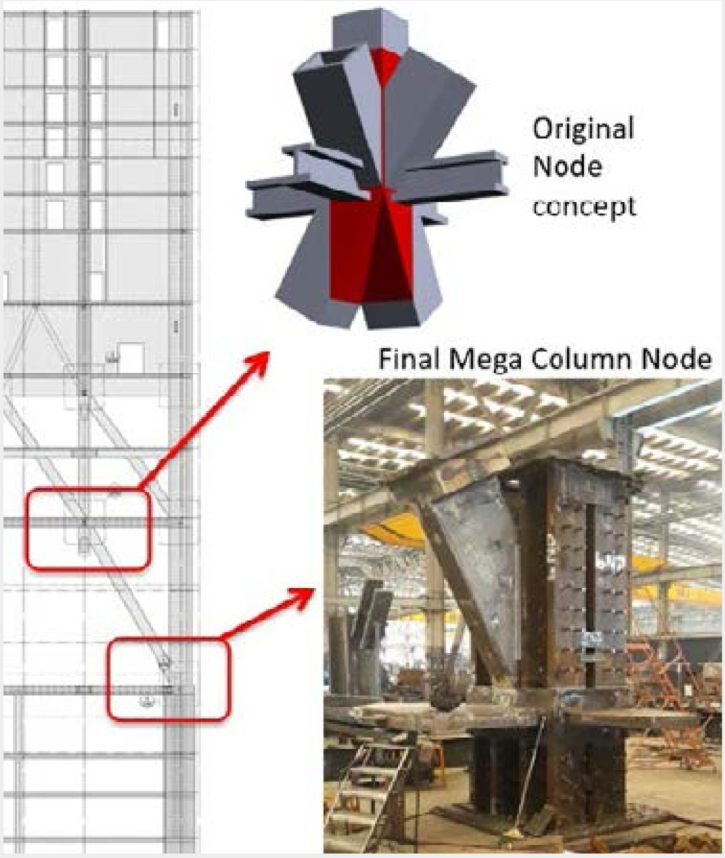


Fig 5: Mega nodes

Fig. 7: Composite Mega Column in the fabrication shop

Mega Columns

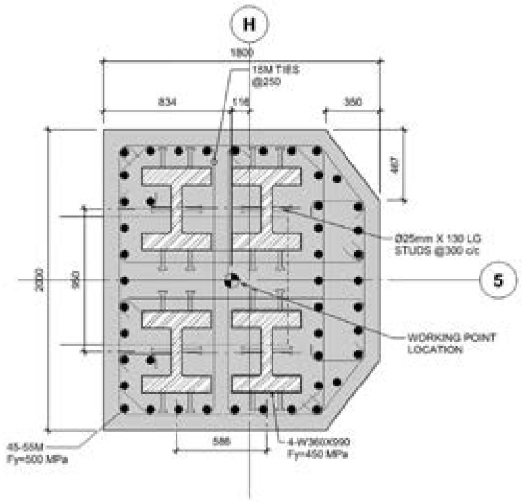


Fig. 6: One Bloor West's Ground-Level Mega Column

From the P2 level to Level 9, the Mega Columns (see Fig. 6) utilize a composite design to optimize strength and save space, while simultaneously facilitating connections to the structural steel mega struts. Composite Mega Columns are defined as vertical structural systems with more than one hot-rolled steel section, longitudinal rebar and ties embedded in concrete, and they are subject to significant vertical loads and secondary bending moments. They are a convenient solution in terms of structural behavior, cost and constructability for the design of tall buildings, including towers over 300m tall.

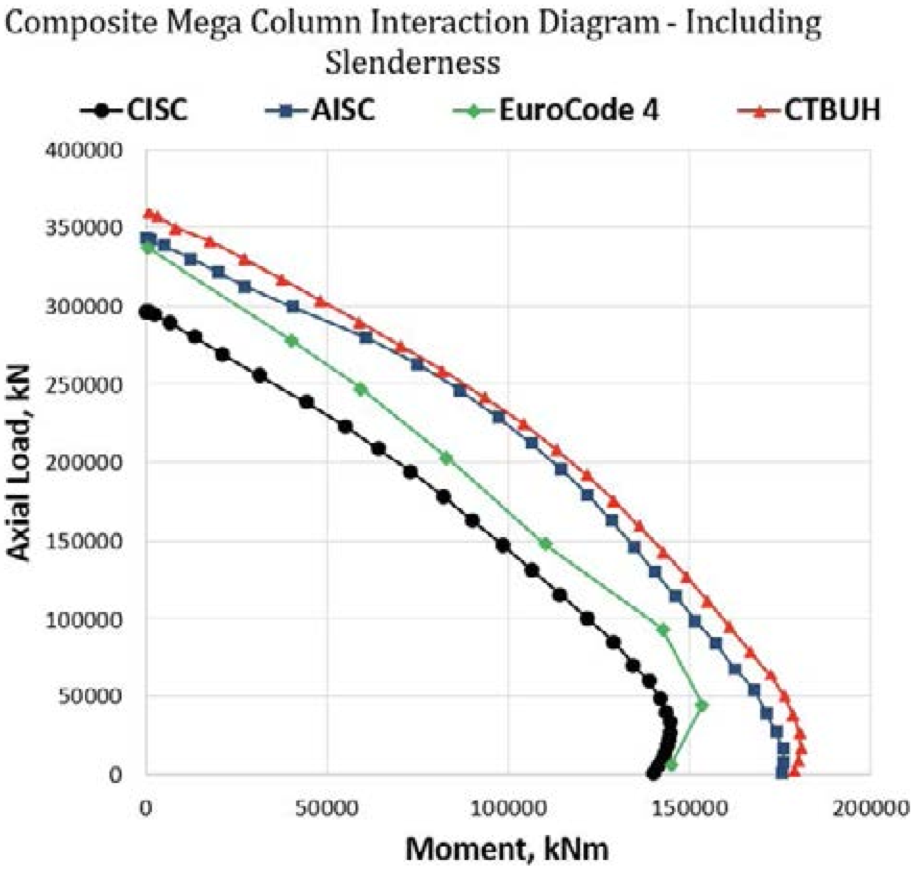


Fig 8: A comparison of interaction diagrams across different standards

Due to the height of the building, the struts and Mega Columns need to be very stiff and also strong enough to resist large loads. Steel and rebar were used to achieve this strength, in addition to high-performance concrete. This included grade 500 rebar, grade 450 structural steel, and 75 MPa self-consolidating concrete, which achieved a tested Modulus of Elasticity (MOE) of 45 GPa, exceeding the specified 38 GPa. Below Level 9, these transition to large reinforced concrete columns with plan dimensions of 2.8x3.1 meters, each bearing a load of approximately 290 MN.

At the time of design in 2017, the use of both the HISTAR hot rolled steel sections and composite Mega Column design was novel. To create these sections, the provisions of different codes and industry publications were compared. In particular, the Canadian Institute of Steel Construction (CISC) code had limits on the strength of concrete, steel and rebar; 55, 350 and 400MPa, respectively. As a result, the design was justified using base CISC standards, without the imposed limits, and a comparison with other standards and design references (Fig 8).

Further, although codes and specifications do consider composite structural elements, they do not offer specific provisions on the design of composite sections with two or more encased steel sections. Experimental tests and numerical models were conducted by the Council on Tall Buildings and Urban Habitat (CTBUH), ArcelorMittal, and their partners in 2015. From this, a simplified design approach was developed that was validated against global standards. The full research report (including the design methodology) can be found here:

Connection Design, Detailing and Fabrication

The magnitude of the compression forces in the struts and columns, and the tension forces in the horizontal tie elements required careful planning to ensure the forces could be transmitted efficiently. This required careful consideration by Walters construction team of how these elements would be fabricated, shipped and erected on site, not least of all was ensuring the weight of the different assemblies was within the capacity of the large tower luffing crane on site.

The implementation of the CastConnex HIB, along with standard plates, allowed for optimization of the nodes while maintaining the required structural performance and simplifying fabrication and erection (Fig. 9).

Another significant optimization introduced by Walters engineering team was converting the horizontal ties from double wide-flange material to single large plate ties. This simplified connection design, detailing, fabrication, welding and installation on site.

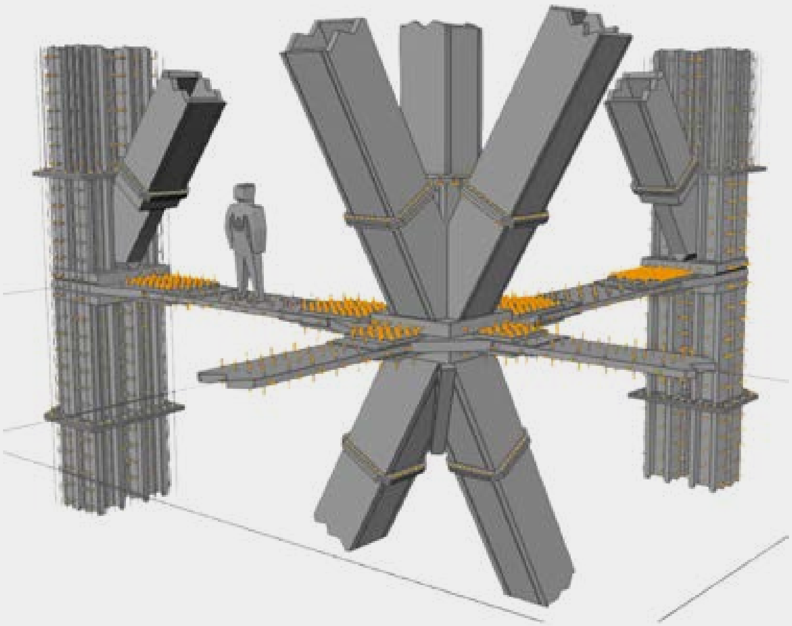


Fig. 9: Optimization of nodes using CastConnex HIB and standard plates, ensuring structural performance and simplifying fabrication and erection

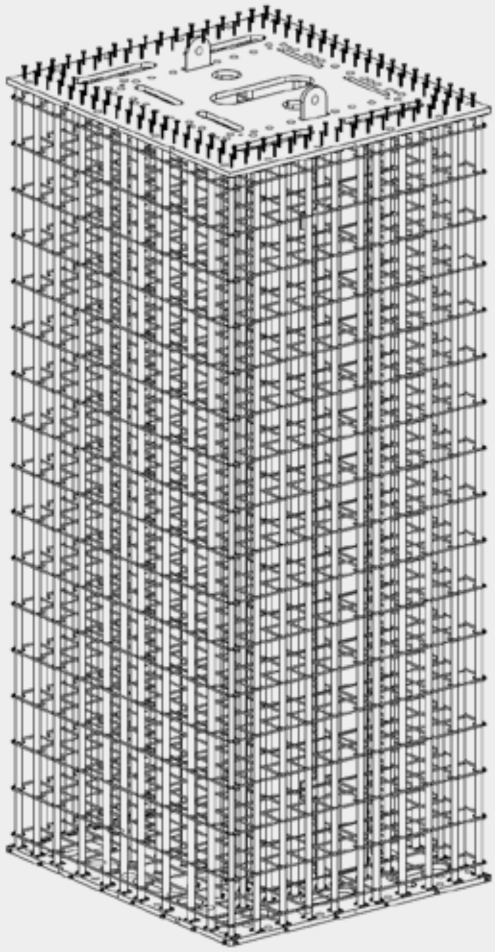
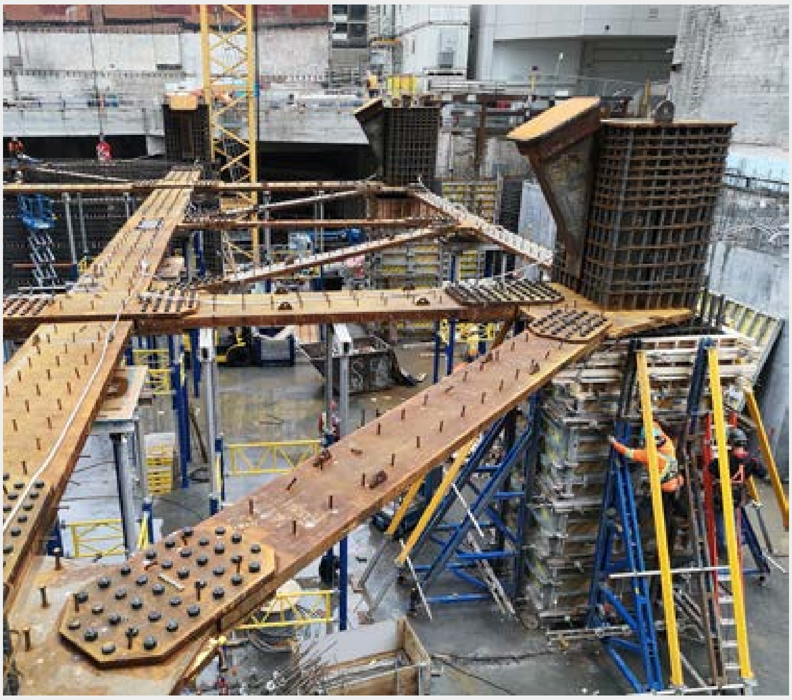


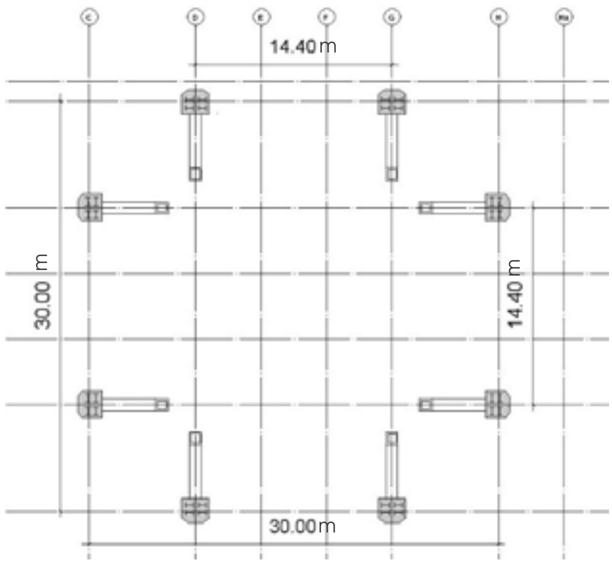
Fig. 10: Walters Inc. patented modularized columns were utilized for ease of fabrication, shipping and installation. High-strength reinforcing steel was pre-installed in the fabrication shop for significant schedule and cost savings.

For the mega-columns, a now patented Walters Group innovation (Canadian Patent No. 3,042,494; United States Patent No. 12,203,269) was developed to modularize the columns into assemblies that could easily be fabricated, shipped and installed on site complete with all of the high-grade reinforcing steel pre-installed in the fabrication shops, see Figure 10 below. This provided significant value to the client and saved many months off the construction schedule.



Efficient on-site installation of nodes, ties, and compression struts due to extensive pre-planning by the steel construction team

Installation of the nodes, ties and compression struts was executed very efficiently on site given the extensive pre-planning efforts by the steel construction team.



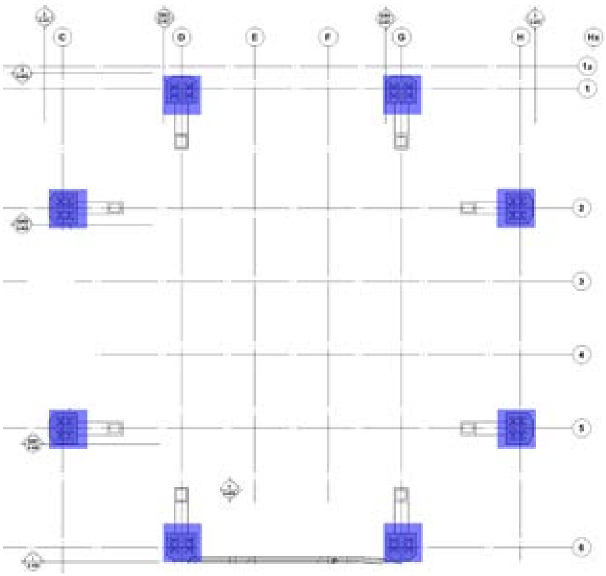


Fig 11. Equivalent RC column sizes overlayed on composite mega columns at the ground level

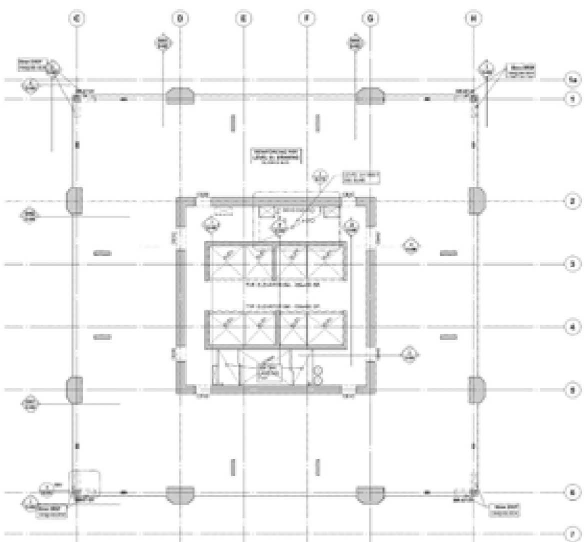


Fig. 12: Typical floor plan above the retail levels showing the core that was transferred

Gaining Floor Area

While the Mega Columns and steel struts allowed for the structure free retail space at the base of the building, the Mega Columns also presented other spatial advantages.

The Mega Columns have a consistent geometry from levels P2 to 9 of 1800x2000mm. An equivalent (i.e. with the same structural capacity) reinforced concrete column would measure 2500x2500mm at the ground level and 2300x2300mm at levels 3 and 4. This results in a floor area gain of 2.65 sq. meters (28.5 sq. feet) per column or 21.2 sq. meters (228 square feet) over the ground level (Fig. 13). Similarly, the floor area gain for levels 3 and 4 totaled 13.5 sq. meters (146 sq. feet) per floor. When considering all three levels, the size of the Mega Columns relative to reinforced concrete columns led to a floor area gain of 48.2 sq. meters (519 sq. feet).

Further, the transfer of the core via the Mega Columns and struts also had spatial benefits. The elimination of 60 linear meters of core wall led to further floor area gains in addition to flexibility in space planning and occupancy.

When considering these benefits over the lifespan of the building, and coupled with the fact that this is one of Toronto's highest rent districts, the gains in floor area and flexibility with occupancy and tenant leasing result in significant financial benefits to the owner.

Caisson Foundation

Bedrock in Toronto is generally strong and close to the surface. However, as this site sits at the northern edge of the downtown core, the bedrock is about 40m below the surface. Early concepts considered an excavation to rock, but a 20m deep, five-level basement was selected with the structure using large diameter caissons for bearing. Below-grade levels are taller than typical for the back of house, hotel arrival and stacked parking.

To enhance understanding of the bearing capacity, an Osterberg Cell (OCell) test was conducted. This means a sacrificial caisson with an embedded jack was constructed and caisson skin friction was used to push down on the rock. Through this test, a design based on 12 MPa ULS/ 8 MPa SLS end bearing and 800 kPa ULS / 620kPa SLS was created. Caisson sizes were also optimized with the trade. Due to presence of large caisson drilling rigs in the area amid ongoing transit development and the international Gordie Howe Bridge, 3.0m diameter socket caissons were chosen, extending 2m into sound bedrock.

Fig. 13: Caisson is ready to be installed from the base of excavation into the lined shaft to the rock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Corner Hangers

One of the architectural requirements for the retail space was a column-free interior and no corner columns. Additionally, there was a strong architectural desire to express the structure while creating mass breaks up the tower. The selected solution was to create hung corner columns, featuring two steel corner hangers, thus bringing the gravity load back to the mega columns.

This solution had several structural advantages. It allowed for a distributed transfer system, never becoming too bulky at one level and allowing for a large reduction in typical corner column sizes.

This ultimately removed corner columns on premium suite levels, enabling massing breaks that are advantageous for wind load reductions. Further, as the megastructure is sized for stiffness, continuously transferring gravity load back to this system optimized the structure's load utilization.

The two hangers per corner column also provide redundancy of the load path. Should a failure occur, this allows for more than one way of load to travel.

Fig. 14: Left: A corner hang is installed. Right: A massing model shows the hangers

Aerodynamic Improvements

Original architectural concepts had more subtle massing breaks. In collaboration with Foster+Partners and wind consultant RWDI, the aerodynamic impact of various mechanical floor envelope configurations was studied. The ability to create these changes was supported by the corner hangers, enabling greater setbacks on the mechanical levels. Creating a more broken surface on the tower reduced vortex shedding, disrupting or 'confusing' the wind. This results in reduced sway, fewer wind motions due to dynamic effects, and a lower demand for supplemental damping.

Three major design options were studied, all of which included perforations in the facade system: square, rounded and full chamfered corners. These reduced damping demands by 7%, 12% and 15%, respectively. The fully-chamfered design was selected as the final design, resulting in cost savings hovering around $1.2 million on the Tuned Mass Damper.

Fig. 15: Studied options for massing breaks

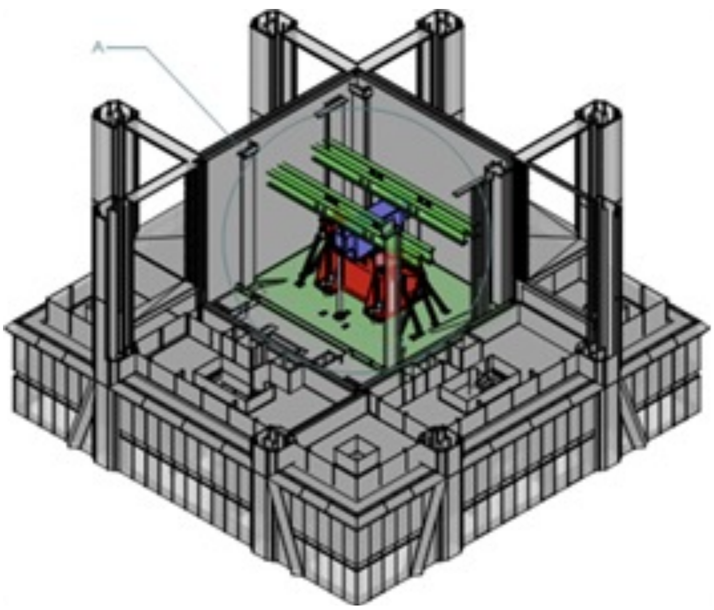

Fig. 16: Location and configuration of the TMD courtesy of RWDI

Tuned Mass Damper

Buildings over a height of around 30 storeys will typically be governed by wind in the Toronto climate. At this height, the displacement of the building due to wind will often control wall thicknesses to limit the inter-storey drift—impacting the exterior envelope and interior finishes. However, once buildings reach a height of 60 storeys or 200 meters, the need for supplemental damping to ensure occupant comfort can exceed structural requirements for drift control.

Comfort is typically measured by the level at which building occupants will notice movements, either by acceleration or building twisting, also known as torsional velocity. Different standards exist, typically for 1-in-1 and 1-in-10-year wind events, as well as residential versus office occupancy. Drift and acceleration can even impact the placement, design, or suitability of pools at the tops of tall buildings.

One Bloor West is no different. Early in the structure's design, it was known that a supplemental damping system would be required. Due to the height of the building, a higher performance system was required, so a Tuned Mass Damper (TMD) was selected.

Unique Forming and Construction

A tower of this height and complexity called for more adaptive forming and construction techniques than typical Toronto construction. An automated climbing system (ACS) is used to form the main structural core. Like commercial office construction, the center elevator banks trail behind and are constructed as the ACS passes. The corner slabs also trail behind. A variety of construction techniques were reviewed for the corner hangers. Ultimately, the construction team decided to allow for corner steel hangers to be erected in one lift with concrete slabs constructed after the hangers were in place.

Fig. 17: Exterior view of the tower early in construction showing the ACS at the top, hanger columns and envelope progress above the ground floor retail. The RCS system was not yet installed in this photo

A rail climbing system (RCS) is used around the perimeter of the tower to facilitate envelope installation. Due to the structure's height, it was determined that traditional fly tables (truss formwork) would be unsuitable for expected high winds, so a knock-down deck forming system which travels between levels on the ACS was selected.

Large-tower cranes are used for the early, heavy-steel erection. A larger-than-typical exterior climbing tower crane is also used to facilitate the construction of the steel crown and TMD.

Outrigger Design and Building Creep

Three effective outrigger levels are present on the tower with connections from the main core to each Mega Column. The first is the outrigger created by the continuous walls and transfer from Levels 5-38. The second two are on the upper mechanical tranches at Levels 56-59 and 76-79. The outriggers work to engage Mega Columns as part of the lateral system and increase tower stiffness. They also support distributed transfer beams which pick up interior columns every 21 floors, optimizing mega-column utilization.

A challenging design aspect was bounding the design of the outriggers. Non-linear creep and shrinkage models were run to review the impact of these time-dependent effects. Additional bounding was completed on the expected material properties. The concrete stiffness varied by 18% from design values. Furthermore, cracking within the outriggers had to be compared to assumptions made for wall, coupling beam, and even slab cracking, as slab coupling can account for 5-10% of global lateral stiffness in tall towers.

Due to this concrete property uncertainty, it was found that Mega Column stiffness is effectively decreased by about 20% when accounting for creep and shrinkage with a conservative model. Adding on, the outriggers were designed assuming full-gross section stiffness. This bounding approach was incorporated to govern the design of mega struts.

Finally, a fatigue-level analysis was completed on outriggers and steel mega struts to check for potential fatigue issues or strength degradation from cyclic loading. Outriggers are critical in shear strength, which can degrade under cyclic loading and high-stress reversals. Generally, no decrease in strength was found.

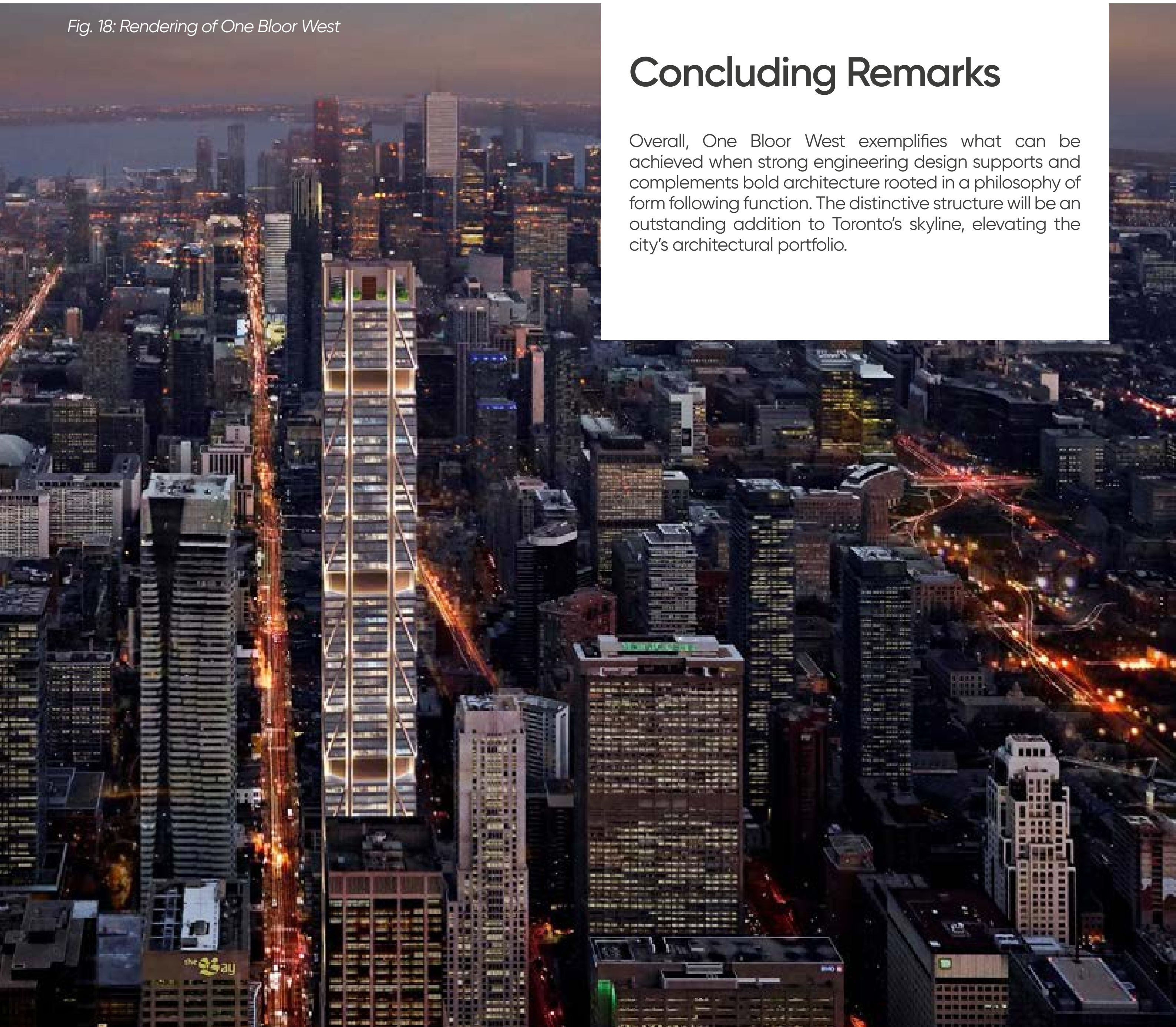

Fig. 18: Rendering of One Bloor West

Concluding Remarks

Overall, One Bloor West exemplifies what can be achieved when strong engineering design supports and complements bold architecture rooted in a philosophy of form following function. The distinctive structure will be an outstanding addition to Toronto's skyline, elevating the city's architectural portfolio.

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