ANDREW VOTH
Ph.D., P.Eng., Associate
RJC Engineers

TD TERRACE

Collaborative steel solutions for a sculpted skyscraper

BY :: ANDREW VOTH, PH.D., P.ENG., ASSOCIATE, RJC ENGINEERS (AVOTH@RJC.CA, WWW.RJC.CA)

The City of Toronto's already dynamic skyline has once again been enhanced with the addition of a new sculpted and sloped skyscraper: TD Terrace.

Located at 160 Front Street West at the corner of Front and Simcoe Streets, the newest space for TD Bank is a 47-storey, 240-metre-tall sloping steel-framed commercial tower that adds approximately 1.2 million square feet of Class A office space to Toronto's financial core. Along with the incorporation of a six-storey masonry heritage building façade, the building offers four levels of below-grade parking and bike storage with a dedicated underground PATH connection and a four-storey podium with tenant amenities, set to be occupied in 2024.

From its beginning, Adrian Smith + Gordon Gill Architecture designed the tower's unmistakable sculpted silhouette to be a response to the local environment. By orienting the main axis of the building parallel to the site's prevailing winds and tapering the building at both the top and bottom, the wind's lateral loads on the structure are minimized. The shape of the building also had a significant impact on the pedestrian realm by minimizing wind effects at grade and creating a spacious landscaped area in stark contrast to the compressed neighbouring sidewalks. The irregular shape, the client's vision and the demanding structural requirements of this unique building also created many challenges that could only be overcome with the use of innovative steel solutions and significant collaboration between RJC Engineers and Walters Inc.

Advanced Steel for Complex Geometry

Developer Cadillac Fairview with Adrian Smith + Gordon Gill Architecture and B+H Architects began working on the project over 10 years ago with key features in mind, including state-of-the art façade, sustainable strategies, efficient use of space and speed of construction, among others.

The use of structural steel had significant advantages to addressing some important requirements of the project. A hybrid structure approach with a concrete core, structural steel framing (approximately 9,500 tonnes) and structural steel outriggers has a significant advantage for speed of construction over a conventional all-concrete structure.

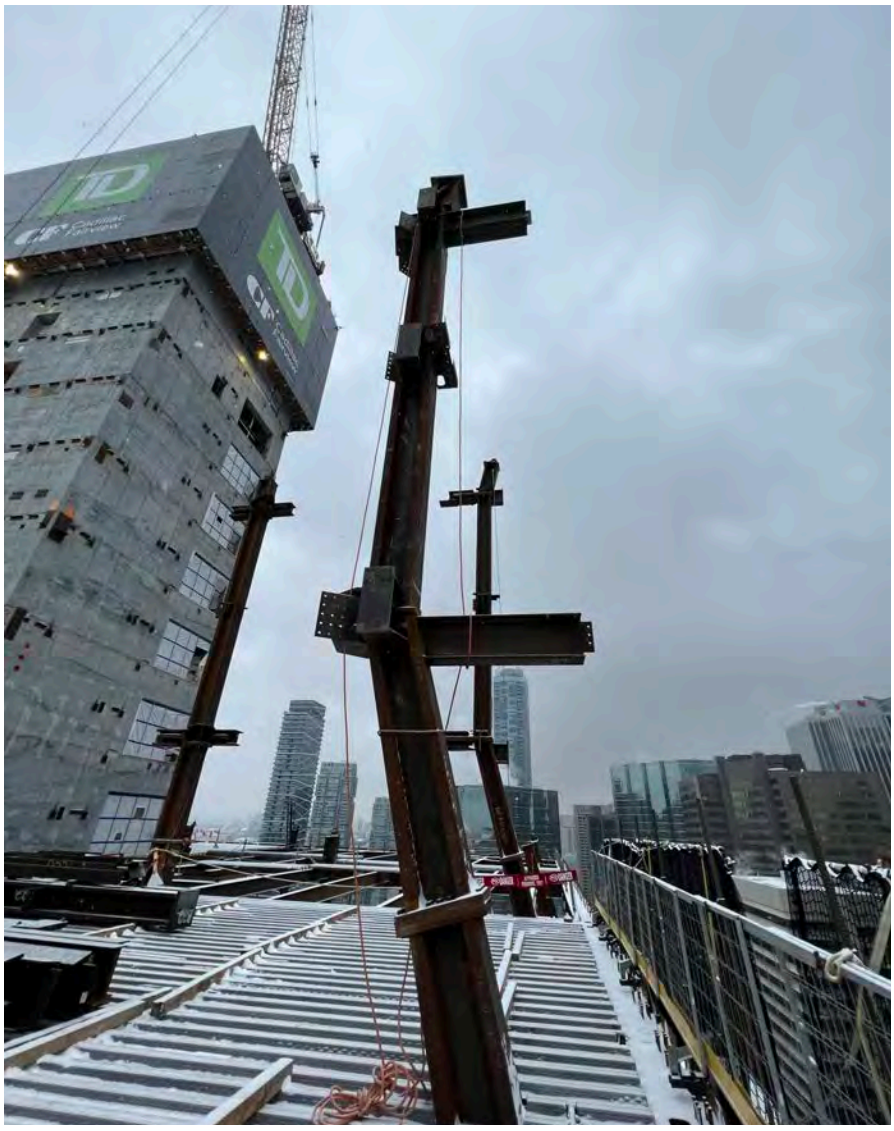
Structural steel also provides the ability to create large column-free spaces by allowing long floor plate spans between the concrete core and the perimeter façade. Spans between 13 metres and 15 metres varied over the height of the building and were important to form the complex sloped geometry of the building, and also to provide efficient tenant spaces. Structural steel, because of its high strength-to-weight ratio, was also important in keeping the structure as minimal as possible, including keeping column sizes relatively small compared to concrete construction.

Beyond the more typical reasons why steel was the best material for the TD Terrace, structural steel was critical in making the complex building geometry possible in three areas: the sloping geometry of the building façade, the architectural feature "inlets" and the curved crown volume at the top of the structure. The structural challenges of the building's complex geometry also led to fabrication and connection challenges, where a close collaboration between Walters and RJC Engineers was essential to make the project a reality.

A Team Approach to a Challenging Design

No project is without design challenges, but 160 Front was unlike any other that required close collaboration between engineer and fabricator to make the architectural intent a reality.

The tower's sculpted sloped shape required that the perimeter steel columns were sloped for the entire building height. Column geometry changes occurred at approximately every three floors and spliced one metre above the floor (as opposed to at floor level) to allow for better erection accessibility. With each change in column slope the structural steel floor plates resolved the unbalanced "kick" force back to the concrete core. Very early in design, working points of the change of inclination of the columns were coordination between the architects, Walters and RJC to ensure the splice locations minimized the structural impact, lifts were within crane restrictions and splices were in locations well suited to fabrication, all while still maintaining the architectural intent.



Developer: Cadillac Fairview
Architect: Adrian Smith + Gordon Gill Architecture & B+H Architects
Structural Engineer: RJC Engineers
Steel Fabrication and Erection: Walters Group
Constructor: PCL Construction

An extreme set of inclined columns was required at the tower inlet floors: an architectural feature where the building face steps back on the east and west sides of the tower to create a mid-tower terrace. The significant column-cranked offset of 2.5 metres over two floor levels creates a significant axial force in the steel floor diaphragm and, eventually, into the concrete core. This combined with differential movement between the structural steel columns and the concrete core creeping over time required innovative steel connections. Two details were developed to ensure efficient axial force transfer, and also to limit significant bending on the shallow axial members created by the differential movement.

The high axial force connection between floor diaphragm and the concrete core required pre-stressed Dywidag rods embedded in the core walls. The design team determined that a "true pin" connection between the rods and the structural steel was the best approach to limit member bending due to vertical core movement and to develop the large axial force connection – a connection that could only be realized in steel. The pin detail and the Dywidag stressing sequence was also an iterative process, with Walters and RJC Engineers working through connection clearances, dead and live stressing end locations and the best configuration of the pin itself – a challenge that could not have been overcome without collaborative design and planning and the use of a structural steel system.

Top It All Off

The iconic tower is topped with a 45-metre-tall curved structural steel volume that is home to a 23-metre-tall glass architecturally exposed atrium with exposed CastConnex Diablo connections, a building maintenance unit including a 12-metre wide operable sliding door and the mechanical penthouse levels. Beyond the curved structure being geometrically complex where only structural

steel is really an option, the space is also home to a critical part of the building's lateral system: a series of inclined outriggers at the top of concrete core that help control the lateral drift of the building.

To ensure that the columns that were a part of the outrigger system did not pre-compress by being pushed down by the shrinking/loaded core, the outriggers were axially released to be locked in six months after the core topped off. The location of the release was modified to ensure that the locking in could take place effectively, understanding that the top portion of the outriggers were exterior, and bottom portion were positioned in a tight mechanical level with equipment fully in place. PCL and Walters' sequence played a large role in determining the best approach with RJC.

The outrigger system included embedded steel sections in the core walls, and very detailed BIM modelling from Walters (down to the couplers) was done to minimize the clashes with the preferred connections, reinforcement and climbing formwork system jack locations. A significant challenge where collaboration was key to success.

Collaboration: Key to Success

160 Front's exterior elegance has a complex structural system skeleton that could not have been possible without the use of structural steel and significant collaboration from the whole project team. Collaboration relies on a culture of willingness to collaborate and work through challenges at various points in the life of a project, and also looking for opportunities over the course of a project. TD Terrace is a wonderful example of how an innovative, collaborative structural steel design can produce an iconic, inspiring project in reality. AS