

INSPIRING INNOVATION

One King West Tower

By Agha Hasan P. Eng et al.

The task of successfully merging historical grand décor with sleek modernism is a challenging one. One King West Tower in Toronto, which marries the historic to the progressive through technical innovation and functional inspiration on a grand scale, is an example of how that challenge can be met to create a striking landmark structure. One King West Tower merges the turn of last century's stone masonry Dominion Bank Building with a slender, contemporary high-rise, concrete tower. The award winning, mixed-use residential structure in 2005 became the tallest residential building in all of Canada.

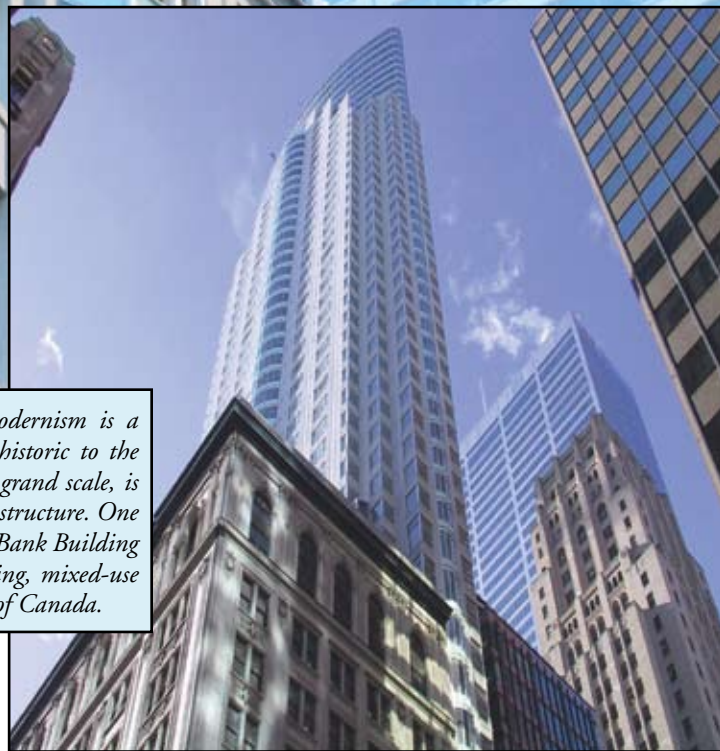
Background

One King West Tower is situated in the middle of the busy downtown business district in Toronto, Ontario, Canada. The tower sits on a small compact site adjacent to the Dominion Bank building, an architectural stalwart of the city built in 1914. Because this historic structure was to form part of the new tower, and because the remaining open site was limited to just over 26 feet wide, the location demanded innovative solutions and approaches throughout the design and construction process. This extremely thin piece of land had to support a tower program that included over 500,000 square feet of supported floor area, 570 luxury residential suites, and 100 parking spaces. Stanford Downey Architects was charged with not only making this space elegant and inspiring, but also to have a profound impact on the Toronto skyline. The property owner's goal was to attract high profile clients with a taste for grandeur. Working closely with the Halcrow Yolles structural engineers, and after many months of design coordination, an innovative structural system was devised that enabled a new, slender tower to merge with the existing Dominion Bank Building.

Inspired Innovation: The Slender Tower

The result of many design meetings was a 610-foot (measured from foundation to rooftop) high residential concrete tower that is sandwiched between the Old Dominion Bank building and the adjacent property. To accomplish this height, the tower slenderness ratio (total height divided by width) would need to be around 23 at its narrowest width. This slenderness ratio is arguably one of the world's largest for a high-rise building at the time construction began.

The biggest challenge for the structural engineers was to design a lateral resisting system that would meet this slenderness ratio and satisfy the base overturning forces, drift due to wind loads, comfort acceleration criteria, and also keep the building economically feasible from a construction point

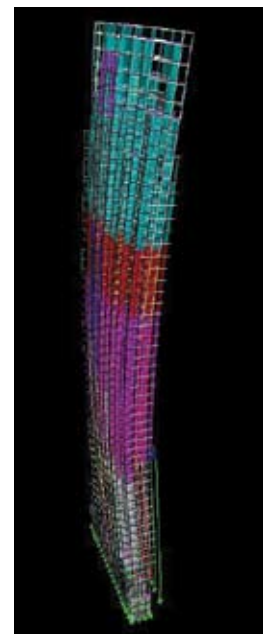


The One King West Tower is 51 stories of private luxury condominiums located in the central business district of Toronto, Ontario, Canada. The tower was constructed integrally with the Dominion Bank building in the foreground. Courtesy of ©Drew Hauser.

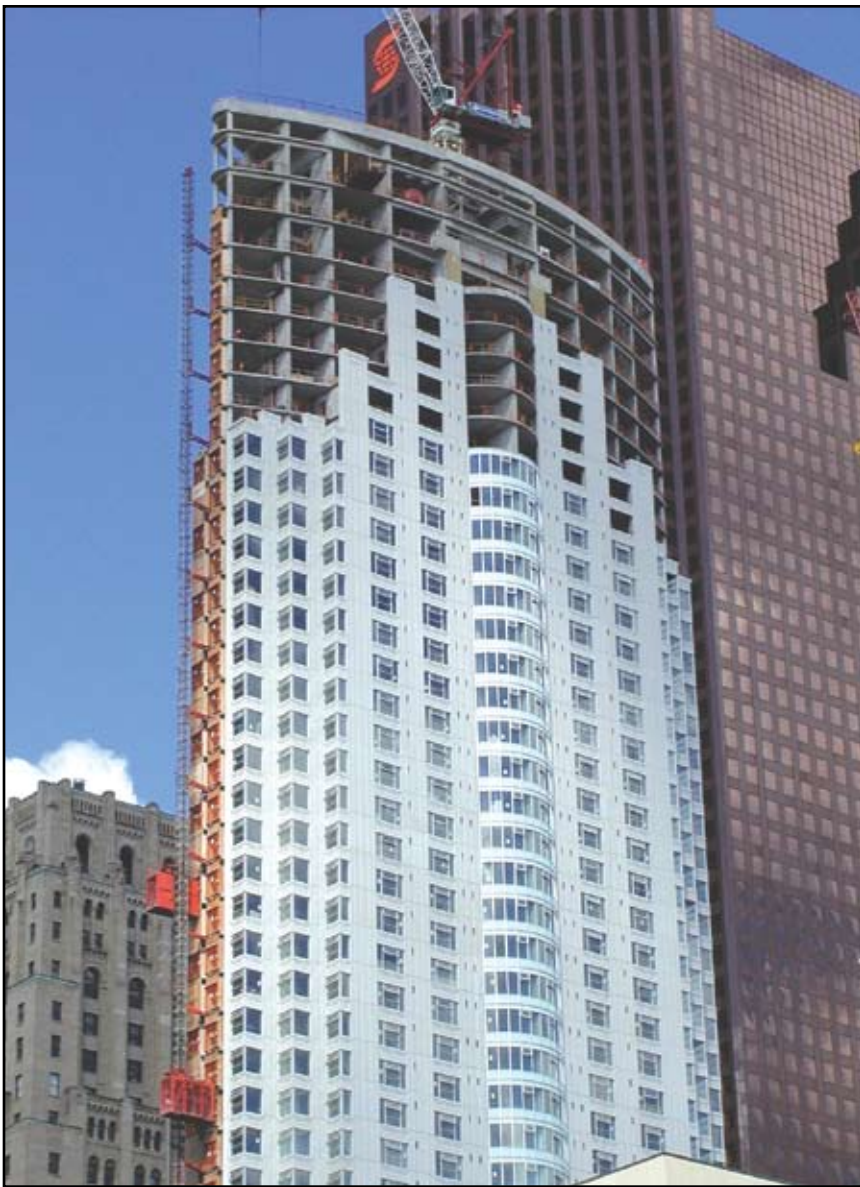
of view within this extremely narrow project site in the middle of an urban financial district. The overriding concern during design for all these technical design issues was the building's 26-foot (at its narrowest) East-West dimension.

The lateral system ultimately chosen for this building was a typical concrete shear wall with some unique structural innovations that were implemented in selected locations. The first innovation was to use outrigger concrete walls at the lower levels (Floors 14 through 16) supported on jumbo outrigger structural steel columns. These steel columns were subsequently embedded with surgical precision through a portion of the existing Dominion Bank building. This maximized the width of the building at its base to just over 46 feet, reducing the overall building slenderness to just over 13:1, still large, but more economical. While this expansion of the overall lateral force resisting system base width was helpful, tremendous uplift forces remained and needed to be resisted within the building foundations.

To counter these large uplift forces, the main foundation for the tower consisted of a 3-foot thick concrete strip footing grid-work that included over 100 rock socketed



The finite element model for One King West Tower under gravity and wind sway deformation. The color changes denote different concrete strengths.



One King West Tower under construction.

anchors drilled to a depth more than 30 feet into rock. More than 50% of these anchors (including all of the anchors installed within the existing Dominion Bank building) were pre-stressed into place in order to activate them to resist uplift even during construction.

Next, engineers performed a rigorous finite element model of the tower concrete shear wall lateral system. Historically, tall buildings exhibit “cross wind” effects that magnify the short direction dynamic properties and wind sway of a building. However, for buildings with large planar aspect ratio, the cross-wind vortex shedding along building length is poorly correlated due to wind flow reattachment. This was confirmed in wind-tunnel analysis which concluded that the along-wind buffeting governs the vibrational response of the building

Through years of experience with high-rise design, Halcrow Yolles engineers have developed proprietary design aids in order to calculate the loss of stiffness in concrete shear walls under the combined effect of wind and gravity loads. Using these relationships, the engineers on One King West Tower diligently calculated stiffness loss at every level and applied these values when analyzing the building under gravity loads, lateral loads, and dynamic effects. Because gravity load sway played a major role in building lateral displacement, different wall cracking parameters had to be adopted for easterly and westerly winds. This resulted in creation of two independent models for wind and gravity load analysis for easterly and westerly wind cases.

High-rise buildings must also be evaluated for occupancy comfort when undergoing wind induced oscillations. This is done by first modeling the dynamic properties within a finite element program, then verifying these dynamic properties with wind tunnel testing. One simple method of determining occupancy comfort is to measure the acceleration at the top floors of the building under the worst wind induced dynamic condition. Usually an acceleration value under 15 milli-g is considered acceptable for residential buildings. For One King Street Tower, along its narrow East-West dimension, the accelerations were originally reported to be as high as 17 milli-g by the wind tunnel. In order to reduce the accelerations economically, Halcrow Yolles along with Boundary Layer Wind Tunnel Laboratory (BLWTL) implemented a tuned liquid damper that was installed at the top of the tower. This damper used water filled tanks to a specific height within roof-top concrete tanks to counter the wind induced dynamic effects. The tuned liquid tuned damper (TLD) may be tuned to the individual building frequency of concern by adjusting the height of the water in the tanks. For buildings in this acceleration range, for which wind resonant effects are substantial, the implementation of dampers may lead to overall wind force reduction, and corresponding savings in material building costs. Further evaluation of tuned liquid tuned dampers are being monitored under a long-term plan aided by a Canadian government grant.

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Construction of the liquid tuned dampers at the top of One King West Tower.

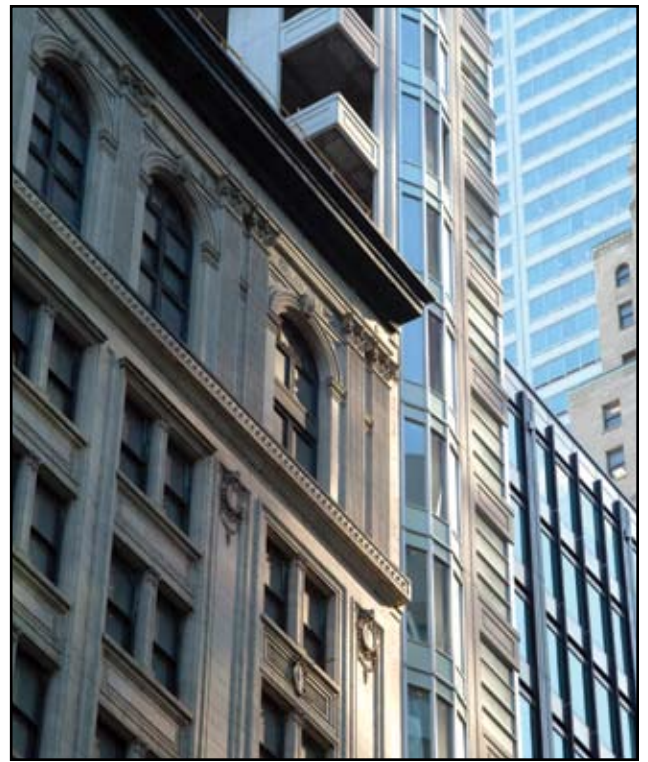
Past and Present Are Tied Together: Dominion Bank Building

The existing Dominion Bank building was originally constructed in 1914 to act as the bank headquarters. At the time of its construction it was one of the tallest buildings in Canada. The renovation would turn the office levels into additional residential suites, add a dining hall, and add private meeting rooms where the original main bank hall was located.

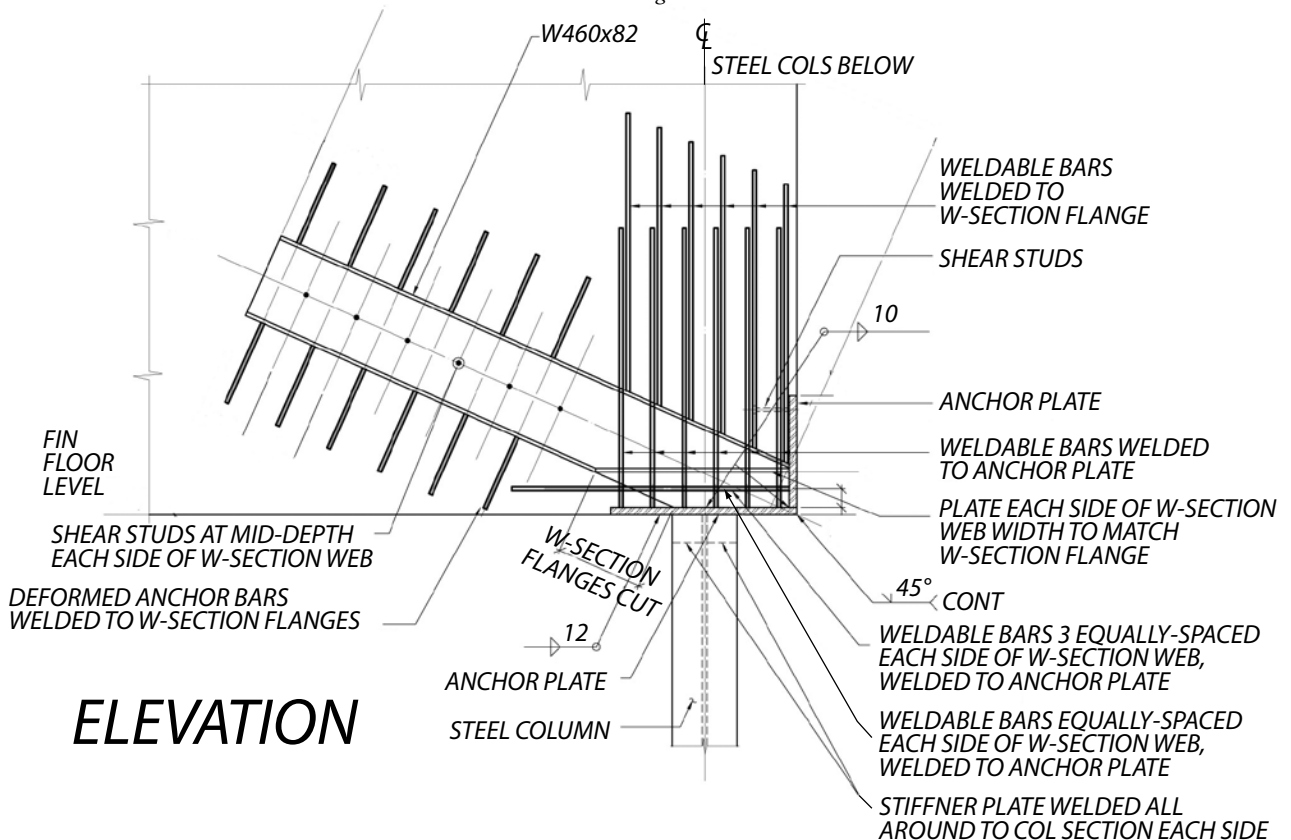
The original bank vault was retained in the basement of the building and restored as part of a private club called the Dominion Club. The vault now may be reserved for private meetings or meals where business may be conducted in an intimate setting that is “protected” from all manner of distractions.

The existing Dominion Bank building was constructed of unreinforced stone masonry that was considered adequate during its age, but no longer meets code performance requirements. Furthermore, it was crucial to provide compatible lateral sway between the Dominion Bank Building and the new tower, because of their intimate proximity to each other.

Engineers solved these inherent deficiencies and incompatibilities by simply allowing the existing Dominion Bank building to be tied laterally or “lean on” the new tower.

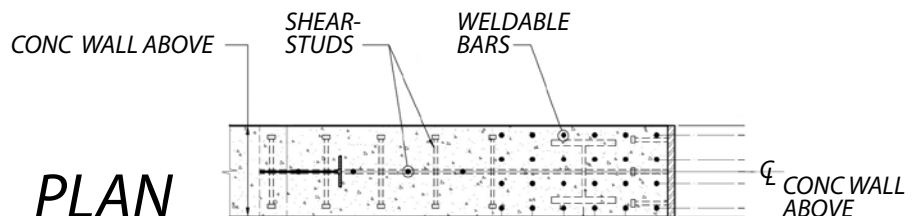


One King West Tower is only 23 feet wide at its base. This narrow gap makes the 610 foot tall One King West Tower one of the most slender high rises in the world.



ELEVATION

The shear wall outrigger connection detail. This detail shows how Halcrow Yolles engineers connected the interior concrete core walls to the exterior steel columns that were surgically placed within the Old Dominion Bank Building.



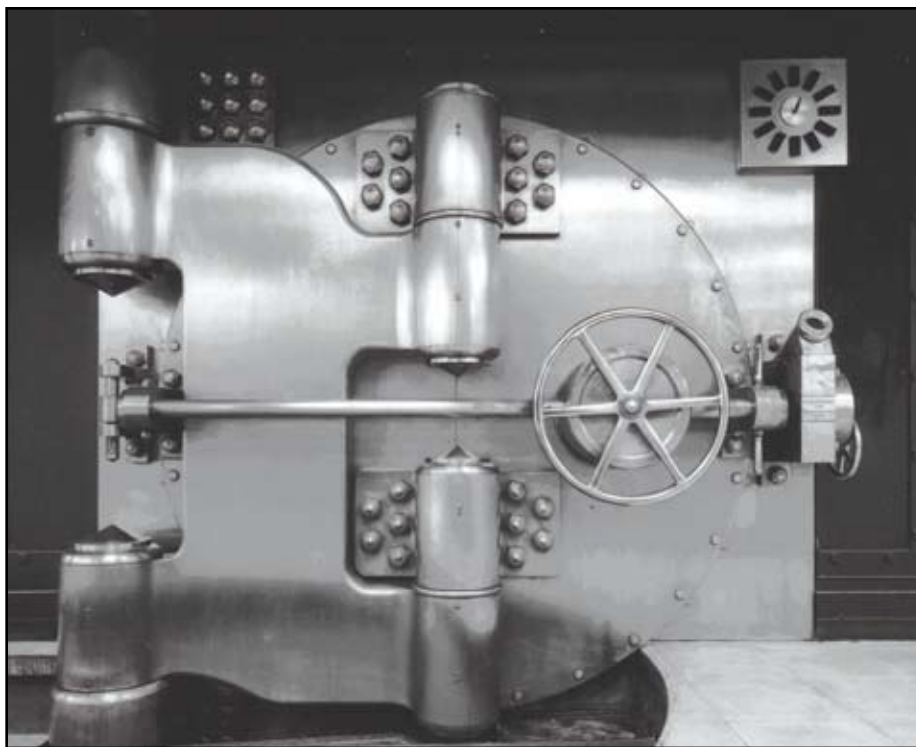
PLAN

The connection included a vertical slot so that additional gravity loads were not collected by the Bank Building, and prevented vertical shrinkage incompatibilities with the tower. By using the tower lateral system in this manner, no additional money was necessary to upgrade or modify the existing building's lateral system. The architect was able to spend this money on preserving and re-creating the grandeur of the existing Dominion Bank interior.

Summary

By taking the simple concrete shear wall and adding innovative features such as; rock anchor foundations, outrigger columns, sophisticated wall stiffness analysis, precision wind-tunnel studies, and using tuned liquid dampers to reduce accelerations, One King West Tower is an example of how the past can be improved with the right touch of modern ingenuity.■

Agha Hasan, P.Eng is a Principal with Halcrow Yolles in Toronto, Ontario. He has over 30 years of experience with analysis and design of tall buildings with special emphasis on wind and seismic effects. He may be reached at Agha.Hasan@halcrowyolles.com.



The Dominion Building bank vault. Currently the vault is being used as a private dining room for special occasions.

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