ASSOCIATION OF CONSULTING ENGINEERING COMPANIES | CANADA

AWARD SUBMISSION

Port Lands Bridges

TORONTO, ON

ENTUITIVE

1 PROJECT SHEET

PORT LANDS BRIDGES (PLFPEI PROJECT)

TORONTO, ON

The Port Lands Flood Protection and Enabling Infrastructure (PLFPEI) Project is Waterfront Toronto's multi-year land development enabling ecological resiliency. Its primary objectives are comprehensive flood protection for the Port Lands, and the creation of crucial infrastructure supporting economic growth on massively underutilized land.

Central to this $1.25B revitalization are four futuristic bridges designed and engineered by Entuitive. The bridges were fabricated in Halifax and delivered to Toronto's shores via the St. Lawrence seaway – the steel weighing between 400 and 1,200 tonnes for each bridge.

The signature Port Lands Bridges (Cherry Street North & LRT Bridges, Cherry Street South Bridge and Commissioners Street Bridge) are steel-tied arch structures using open steel plate/shell elements curved in two directions. The bridges have all been designed to meet high aesthetic requirements with significant focus on the importance of the public realm aspects of the bridges. Since arriving in 2022, the bridges have reflected the future-forward nature of the PLFPEI Project.

Year Completed
2022

Entering Company
Entuitive

Contact
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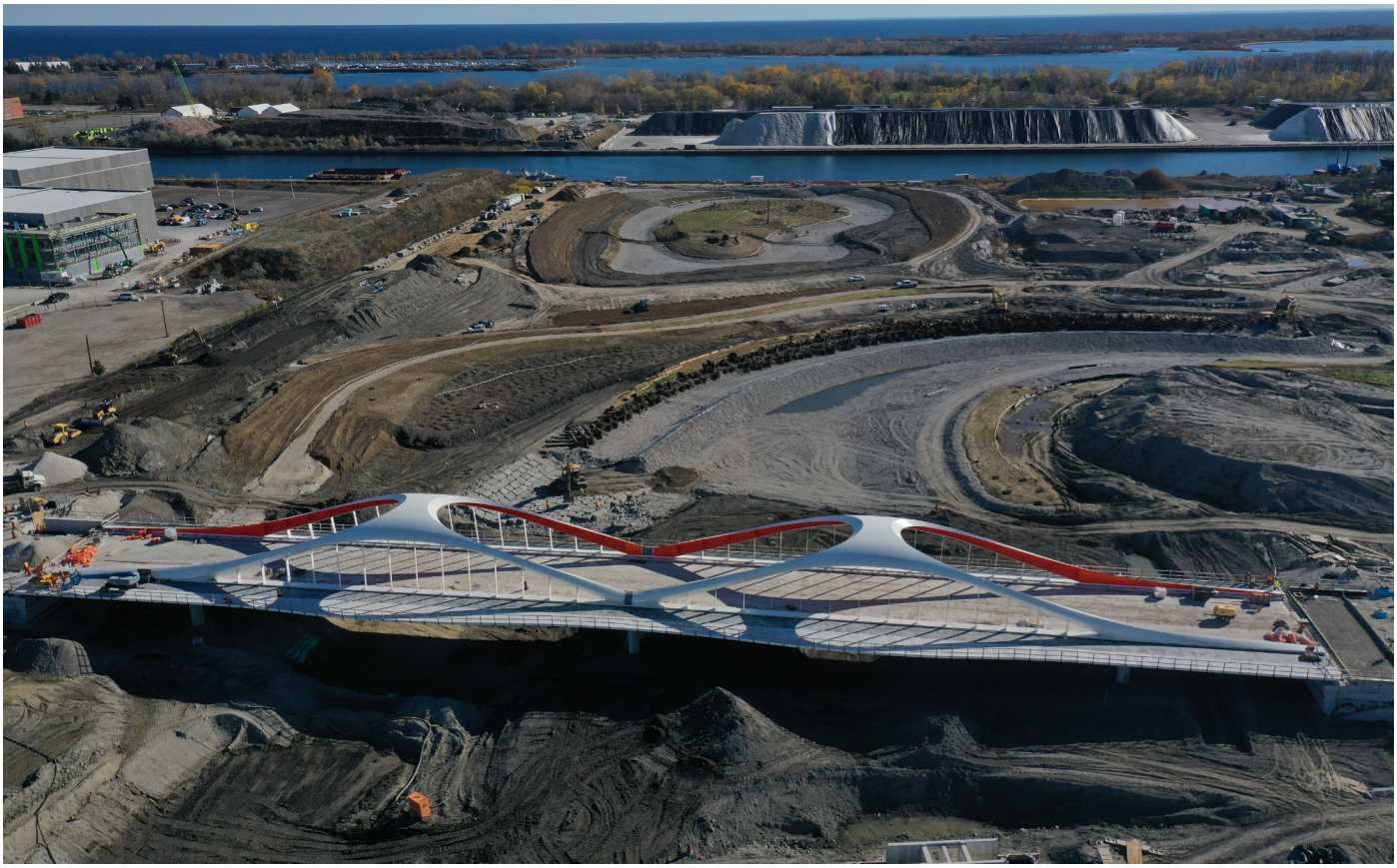
PROJECT OBJECTIVES, SOLUTIONS, & ACHIEVEMENTS

The Port Lands Flood Protection and Enabling Infrastructure (PLFPEI) Project was designed as a comprehensive plan for flood protecting southeastern portions of downtown Toronto from a provincially-defined Regulatory Storm event – including parts of the Port Lands, South Riverdale, Leslieville, and south of Eastern Avenue, equaling approximately 230 hectares of urban land in Toronto.

The PLFPEI Project's primary objectives were comprehensive flood protection for the Port Lands, and the creation of crucial infrastructure supporting economic growth on an under-utilized, post-industrial waterfront land mass. Upon completion of the Port Lands in 2024, a new re-naturalized river outlet will be extended south from the juncture of the existing Don River and the Keating Channel. This new river outlet will form a new Island in Toronto to be named Villiers Island.

The new Port Lands Bridges, established in 2022, form a family of four signature bridges that will connect the mainland to Villiers Island once it is formed. Two of these bridges cross the Keating Channel at the new Cherry Street, one for the road (Cherry Street North Road Bridge) and one for Light Rapid Transit (LRT) traffic (Cherry North LRT Bridge), both with spans of 56.1 m. The other two bridges, Cherry Street South Bridge has a 70 m main span and 20 m end spans and the Commissioners Street Bridge with four spans has middle spans of 56.1 m and end spans of 19.8m. The Bridges were designed in accordance with the Canadian Highway Bridge Design Code CAN/CSA-S6-14 (CHBDC)



TECHNICAL EXCELLENCE & INNOVATION

The superstructures of the four Port Lands Bridges are composed of structural steel using a tied arch structural system. The arches and domes are made from steel plate curved in two directions and welded together to form open non-prismatic sections. Closed steel box sections are used for the tie girders. Steel variable depth I-beams support the reinforced concrete deck from the tie girders. Steel plate hangers transfer load from the tie girders to the arches at each deck beam grid point.

The double curved steel plates making up the arches and the domes were formed in the Netherlands and then fabricated with the rest of the steel superstructures components in Nova Scotia, before the fully assembled superstructures were transported by barge to Toronto.

The poor soil overburden conditions of the Port Lands, irregular bridge configuration, and Major Route Category of two of the bridges also made it necessary to complete a seismic assessment using Elastic Dynamic Analysis. Detailed vehicle-induced vibration has been completed for the bridges, including design for provisional tuned mass dampers.

The Port Lands Bridges can be further classified as slender, non-uniform, symmetrical arches subject to asymmetrical vertical loading. The nature of the arches and loading conditions results in the need to consider arch stability. Various design approaches were used to analyse the arches including second order analysis using Finite Element Analysis (FEA) as well as approximate manual methods.

A variety of design software programs were used to model the complex superstructure geometry of the bridges. During both the conceptual design and detailed design stages, Grasshopper and Rhino3D software was used. First, at the conceptual stage to algorithmically determine the shape of the arches and shell elements, and later during the detailed design stages to generate a suitable refined mesh for the surfaces of the entire superstructure.

To account for plate buckling and buckling of the arch, the entire shell structure was modelled using quadrilateral elements with applied imperfections. A non-linear analysis was completed to account for second order effects and to verify that stresses were within acceptable limits.

As noted to the left, the arches of the Port Lands Bridges can be classified as non-uniform, slender arches with asymmetric loading due to their built-up open cross-sections and rotated orientations in relation to the deck and due to the moving vehicular loading.

In terms of project management, taking a collaborative approach was pivotal to the successful design, engineering, and placement of the Port Lands Bridges. As the Prime Consultants delivering a complex structural engineering work, Entuitive worked alongside Waterfront Toronto, the Construction Manager (Ellis Don), the City of Toronto, the TTC, Ports Toronto and other stakeholders to ensure successful project delivery. Close coordination with consultants working on other aspects of the overall PLFPEI Project was also necessary.

From their sheer presence and sleek design, the Port Lands Bridges have been exciting Torontonians visiting the Port Lands, while motorists and cyclists already enjoy reconfigured roadways, a redesigned section of the waterfront, and a palpable sense that much-needed change is on the horizon.

The Port Land Bridges stand for more than a collection of signature steel bridges: as land development and surrounding construction continues, the four Port Lands Bridges feature prominently within the context of a more sustainable future for Canada's largest city, and a sign of things to come.

In addition to the engineering and design achievements listed above, The Port Lands Bridges for the PLFPEI Project have achieved the following:

- Featured in the keynote address, logo, and delegate tour for the 11th International Conference on Short and Medium Span Bridges (SMSB)
- Awarded Special Jury Award for Catalytic Infrastructure at Toronto Urban Design Awards
- Awarded three CISC 2022 Awards for Excellence in Steel Construction:
  - Bridge Projects
  - Erection – Ingenuity – Constructability
  - 2022 Favourite Project

LEVEL OF COMPLEXITY & PROJECT CHALLENGES

Entuitive experienced numerous challenges during the design, construction, and fabrication stages, described in detail below, but was still able to conduct investigations and formulate solutions remotely during COVID shutdowns.

As with many projects completed in the last year or so, the creation of the Port Lands Bridges was initiated prior to COVID with fabrication and assembly taking place remotely (with steel bending in the Netherlands, and fabrication in Nova Scotia). The feasibility of site visits was further diminished based on travel restrictions but addressed on this project with regular virtual site visits conducted with an Ellis Don rep on site in Nova Scotia. A number of in person visits were also completed where permitted by COVID restrictions.

The complex geometry of the steel superstructure is the first challenge that comes to mind with these bridges. Structural modelling and drawing representation of the bridges are all complicated by this geometry. As has been discussed above, 3-D modelling tools along with algorithmic and paramentric design where used throughout the project. The fabricator was also given access to the 3-D models which were particularly important for the fabrication of the bent plates.

In addition to the superstructure complexities, the foundations at the bridges where quite poor, since the site consists fill materials on the old lake bed. In some cases the ground materials were liquifiable, which required rigorous seismic analysis.

The slender hangers for the Cherry Street North LRT Bridge were developed first and found to be quite sensitive to even relatively small compressive strains induced by weld shrinkage of adjacent hangers during the fabrication process. Through collaboration amongst the design engineers, fabricator, and construction engineers, a hanger welding sequence was developed that used simultaneous welding of hangers in sets along with selective application of heat. The sequence was verified through staged Finite Element Analysis (FEA), testing and measurement of weld shrinkage in a mock-up, and instrumentation and monitoring.

After the welding and cooling of the first set of hangers in the center of the bridge, the hangers were observed to be plumb. After repeating the same on the symmetrically adjacent hangers, some out of plate bending was noticed in some of the first set of hangers. As subsequent hangers were welded, the condition worsened on the original hangers and new ones started exhibiting out of plane bending. A small gap was also noticed between the tie girders and the temporary support blocking. Having followed normal welding practices, this was not an expected outcome, so all welding was halted while the root cause was investigated.

An investigation was conducted, and it was determined that the hangers had buckled due to the shrinkage experienced at the full penetration welded joints at the tops and bottoms of the adjacent hangers where they connect to the arches and tie girders, resulting in compression stresses in the hangers. An analytical review was completed for the hangers to determine the displacement required to cause buckling and the expected shrinkage due to welding. The results showed that the expected shrinkage due to welding was much greater than the displacement required to cause buckling in adjacent hangers. In addition to the fabrication challenges this also meant that locked in residual stresses might be a concern for the hangers during service and ultimate load conditions.

To gain a better understanding of the specific Port Lands Bridges hanger reaction as a result of the welding process, a staged construction model was developed in CSiBridge to mimic the proposed welding steps. Since weld shrinkage is so important to the results, it is important to have a good approximation of the actual weld shrinkage. To help with this, the fabrication team completed a weld shrinkage test on a mock-up using the same plate thickness, weld preparation and procedure being used for the hanger welding. Infrastructure at Toronto Urban Design Awards

Based on the weld shrinkage test and the finite element modelling, it was concluded that weld shrinkage would need to be mitigated to reduce hanger distortion. It was determined that a series of heating and cooling steps could be used to achieve this result. Other factors taken into consideration when developing the hanger welding sequence, included:

- maximum number of hangers that could practically be welded simultaneously,
- symmetry of hangers selected per set,
- adaptability of the sequence with the remaining Port Lands Bridges.
- The steel on the bridges has all been designed and fabricated to meet Architecturally Exposed Structural Steel (AESS) requirements based on the CISC guidelines. Implementing these requirements for the complex geometry of the Port Lands required frequent discussion with the fabricator as well as careful inspection and feedback on the fabricated steel.

CONTRIBUTION TO ECONOMIC, SOCIAL, AND/OR ENVIRONMENTAL QUALITY OF LIFE

The Port Lands Bridges serve as part of the beautifully designed path to, and around, Waterfront Toronto's rejuvenated Port Lands. The PLFPEI Project will usher in the next generation of sustainable waterfront developments, define new relationships between nature and cityscapes, humans and wildlife alike, and also includes the restoration of original Indigenous landscapes and ecological systems to the area.

The Port Lands Bridges are already acting as readily identifiable and unique symbols of this new area of the City of Toronto. With their highly aesthetic and sculpted forms, along with their generous sidewalks, bike lanes and viewing areas, the bridges will become destinations for foot traffic not just a means to cross the waterways.

While the bridges are highly aesthetic, the aesthetics are achieved through expression of the structural engineering form characterized by the use of a steel tied arch, shell elements (including a dome that acts as a lateral brace for the arches), plate hangers and more traditional deck beams on the below deck structure.

Having designed the Cherry Street North and LRT bridges, as well as Cherry Street South Bridge and Commissioners Street Bridge, the social and economic development and reimagining of Cherry and Commissioners streets alike is ushered in by the Port Land Bridges at the outset. Cherry Street is poised to take on an entirely new urban identity, and will act as an extension of downtown Toronto into the Port Lands. It will feature curated and formalized hardscape areas and softscapes, variable planting and enough pedestrian clearway width to suit surrounding uses, all with the goal of creating a sequence of exterior rooms for pedestrians along the street.

Meanwhile Commissioners Street's newly cultivated park identity will serve to feed some of the social infrastructure featured in the Port Lands. When moving eastbound along Commissioners Street towards Commissioners Street Bridge (whether by foot, bicycle, vehicle or public transit), River Valley Park, passive-use lawns, access to the waterways and more programming spaces will be found.

From an environmental standpoint, the bridges and connecting roadways encourage bike lane and foot traffic throughout the Port Lands leading to newly developed parks and a designed river valley. The popular Don Valley Trial will also be reconnected to the eastern region of the Port Lands, serving to extend city cycling and hiking routes. These spaces are already ripe with planting efforts which will lead to around 5,000 new trees, 77,000 shrubs and over 2 million new herbaceous plants.

It's undeniable that the PLFPEI Project is helping Ontarians reimagine—and rebuild—our cities, with green infrastructure and resilient communities at their heart, and the Port Lands Bridges designed by Entuitive have come to symbolize the progress that Waterfront Toronto has achieved so far in its vision.