Canadian Consulting Engineering Awards

2012

East Hamilton Waterfront Link Multi-Use Pedestrian Bridge

May 8, 2012

PROJECT HIGHLIGHTS

The East Hamilton Waterfront Link – Pedestrian Bridge is a new landmark for the City of Hamilton in its prominent location at the mouth of the Red Hill Valley Creek. At 220 metres long, it spans a restored, natural wetland and the 12-lane Queen Elizabeth Way (QEW) Expressway. The new crossing enhances the connectivity of Hamilton's recreational trail system, providing pedestrians, cyclists and in-line skaters with safer, barrier-free access and a direct connection from the valley to the Lake Ontario waterfront, linking hundreds of kilometres of trail in Southern Ontario.

McCormick Rankin (MRC) was retained by the City of Hamilton to complete the design and contract administration for the new signature pedestrian bridge, which completes the final link of a continuous trail system that connects the Bruce Trail to the Lake Ontario Waterfront Trail.

A valuable contribution to Hamilton's public realm, representing a true integration of structure, architecture and landscape coming together, the Bridge establishes a strong sense of place and civic pride. Its contemporary design features an elegant tilted steel arch that spans 85 metres over the Red Hill Creek and provides a dramatic focus to the overall structure. The signature span with its "fireweed red" hue and dramatic night-time lighting is viewed by thousands of people daily.

The Bridge is the final connection of the Red Hill Valley Trail to the well-developed Lake Ontario trail system across the Red Hill Creek and the QEW between the Red Hill Valley Parkway and Burlington Street. The $240-million Red Hill Valley Parkway opened to traffic in the fall of 2007. It connects the QEW with the City of Hamilton's southeastern development area on the Hamilton Mountain. The parkway project, which constitutes the City's largest ever infrastructure project, winds through the environmentally sensitive Red Hill Valley and includes a trail system that connects to the Bruce Trial.

Complexity and New Application of Existing Techniques/Originality/Innovation

Tied Steel Arch with Inclined Rib

The 80-metre-long main span features a single inclined rib steel tied arch. The arch comprises a trapezoidal steel box tie girder supported by a circular arch rib and 19 tapered "I" shaped hangers. The maximum height of the arch rib is 10m above the top of the tie girder. The rib is inclined 76 degrees to the horizontal to match the web slope of the box girder. One significant overall design parameter for the arch structure is the rise-to-span ratio. A relatively flat ratio of 1:7.6 was ultimately selected for aesthetic reasons. The tube section was chosen for its high overall stability against buckling, which gave designers the flexibility to use a relatively small rib size for better appearance.

Trapezoidal Box Tie-Girder

To reduce the demand on the size of arch rib, a relatively large closed steel trapezoidal box was used for the tie girder. The dimensions and depth were set to balance the structure behaviour under the asymmetric dead and live loads and to permit access for inspections and to install and service the Tuned Mass Dampers (TMDs).

Structural Analysis, Wind Analysis and Wind Tunnel Testing

The tied arch is generally considered to be a single load path (non-redundant) structure. Failure of the rib or tie girder could lead to total collapse. The added complexity of the single inclined arch heightened the need for thorough and detailed structural analysis. Several finite element models were developed using SAP2000 to investigate the bridge behaviour under all load conditions. To verify the redundancy of the hanger system, the analyses included a load case simulating complete failure of one hanger.

A key design consideration for long slender structures such as this is sensitivity to wind effects and pedestrian-induced vibrations. This, together with the unusual geometry of the arch span, led to the design team's decision to undertake a rigorous assessment of the bridge's dynamic behaviour. RWDI was retained to undertake wind/motion engineering studies and a pedestrian-induced vibration analysis.

After completing the initial design of the structure, static and dynamic analyses generated the required input into RWDI's work. Besides geometric properties, this included element masses, mode shapes and frequencies of the structural system for the construction condition and the final completed condition.

The wind tunnel test results showed that the structure was aerodynamically stable both during construction and in its final condition. Following wind tunnel testing, a 3D buffeting analysis was conducted to derive the full-scale wind loads and load factors for the structural design based on the turbulence properties at the bridge site.

Pedestrian-Induced Vibration and Tuned Mass Dampers

Human-induced vibration is a critical design consideration for lightweight and flexible pedestrian bridges. Pedestrian loading from walking, running, jumping or even vandal activities can cause high motions on footbridges. These motions can lead to uncomfortable or even dangerous vibration levels.

To examine the vertical vibration of the bridge, two analyses were conducted. First, a simplified analysis was performed to calculate the acceleration caused by one typical pedestrian weighing 700N. Second, a full dynamic analysis (time history method) was performed using the footfall impulse of a typical pedestrian for an "energetic" walk. The results showed that the structure would perform adequately with minimal pedestrian discomfort.

A study of the detailed human-induced vibration analysis for a group of pedestrians and a continuous pedestrian stream was then undertaken. The results indicated that vertical motions in the approach spans would exceed comfort acceleration criteria. The arch span had several modes approaching the generally accepted comfort criteria.

Revising the structural properties to change the bridge behaviour did not prove to be sufficient to address the vibration. Accordingly, a total of five tuned mass dampers (TMDs) were installed in the bridge: two in the arch span, one in the south approach span and two in the north approach spans. These are passive devices that incorporate a mass with dynamic properties based on the natural modes of vibration of the bridge. After installation, field testing was performed to examine the final frequencies of the structure to fine tune the TMDs.

Glass Fibre Reinforced Polymer (GRP) Reinforcing

Because of known problems associated with the corrosion of embedded reinforcement in concrete, particularly where de-icing salts are used, GFRP reinforcement was specified for the top layer of reinforcement in the deck slab to increase the durability and reduce future maintenance.

Environmental Impact

Permanent encroachment into an environmentally sensitive wetland between the creek and the QEW was minimized and special measures were taken to protect this feature and restore it upon completion of construction. Ecological restoration included rehabilitation of the environmentally sensitive wetland south of the QEW and plantings on the former Rennie and Brampton landfill sites adjacent to the trail and waterfront link.

Social and Economic Benefits and Meeting and Exceeding Owner's/Client's Needs

The final design of the striking pedestrian bridge sends a strong message to drivers on the QEW, reinforcing the City of Hamilton's objective of stimulating the improved health of Ontario residents through recreational opportunities, habitat restoration and reduction of vehicular trips. It makes a valuable contribution to Hamilton's public realm, representing a true integration of structure, architecture and landscape coming together to provide a strong sense of place and civic pride.

"This bridge and environment restoration investment brings recreation, tourism and nature together in an innovative manner. This link is a welcome addition for citizens of our community and visitors to our community." - Ted McMeekin, MPP

"I am thrilled that the pedestrian bridge is open to the public and will connect ward four to our precious waterfront via our tremendous trail system for pedestrians and cyclists for generations to come," - Ward Four Councillor Sam Merulla.

"The completion of the East Hamilton Trail and Waterfront Link is an important addition to Hamilton's trail network. It offers opportunities to be active while taking in Hamilton's natural environment."- Sophia Aggelonitis, MPP

"The community has been waiting a long time for this. Hamilton has some wonderful trail systems and this was always the missing link." - Marco Oddi, Senior Project Manager for the Public Works Department.

"For us in the east end, we've always been looking for a better connection to the waterfront. It's a huge boost for our image. I think the bridge is symbolic that we're making significant upgrades in the east end and in the city." - Councillor Chad Collins.

Executive Summary

McCormick Rankin (MRC) was retained by the City of Hamilton to undertake the design and contract administration for a new signature pedestrian bridge to complete the final link of a continuous trail system that connects the Bruce Trail to the Lake Ontario Waterfront Trail. The multi-use pedestrian bridge is a new landmark for the City of Hamilton in a prominent location at the mouth of the Red Hill Valley Creek. At 220 metres long, it spans a restored, natural wetland and the 12-lane QEW. The new crossing enhances the connectivity of Hamilton's recreational trail system, providing pedestrians, cyclists and in-line skaters with safer, barrier-free access and direct connection from the valley to the Lake Ontario waterfront and linking hundreds of kilometres of trail in Southern Ontario.

The bridge makes a valuable contribution to Hamilton's public realm, representing a true integration of structure, architecture and landscape coming together to provide a strong sense of place and civic pride. The signature span with its "fireweed red" hue and dramatic night-time lighting is viewed by thousands of people daily.

- MRC's innovative design for this signature pedestrian bridge was developed after extensive wind tunnel testing. The site constraints and the unique appearance and configuration of the structure required solutions to a number of design and construction challenges:
- Minimizing environmental impacts on the creek and wetland;
- Minimizing impact to an existing landfill site and leachate collector system;
- Minimizing impacts to QEW traffic;
- Ensuring feasibility of superstructure erection;
- Ensuring the pedestrian and wind-induced vibrations are within comfortable ranges;
- The structure configuration and geometry added significant complexity to the analysis and design.

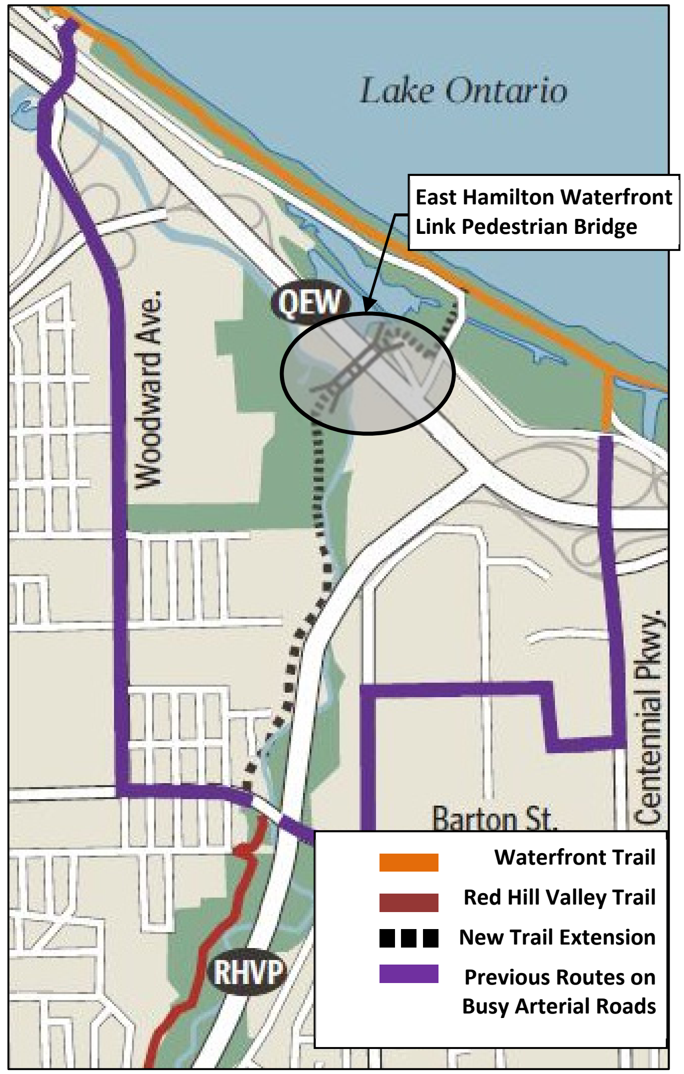

Figure 1: Site Plan

Figure 2: View of Completed Bridge at Night

Project Objectives, Solutions and Achievements

Project Objectives

The $240M Red Hill Valley Parkway opened to traffic in the Fall of 2007 and connects the Queen Elizabeth Way (QEW) expressway with the City of Hamilton's south-eastern development area on Hamilton Mountain. The Parkway project, which constitutes the City's largest ever infrastructure project, winds through the environmentally sensitive Red Hill Valley and includes a trail system that connects to the Bruce Trail.

The final connection of the Red Hill Valley Trail to the well-developed Lake Ontario trail system required a multi-use pedestrian bridge located between the Red Hill Valley Parkway and Burlington Street and spanning the Red Hill Creek and the 12-lane QEW. Figure 1 shows the bridge which links two major trail systems – the Red Hill Valley Trail, which links to the Bruce Trail, and the Waterfront Trail, which links to the Lake Ontario trail system.

Because of the high visibility of the structure from the QEW near the eastern entrance to Hamilton, the City specified that the pedestrian bridge be a "signature span" structure with high aesthetic appeal.

Solutions and Achievements

The existing site conditions for the new bridge had a number of constraints that influenced the design. These include:

- The Red Hill Creek;
- An environmentally sensitive wetland between the creek and the QEW. Permanent encroachment into this area had to be minimized and special measures were specified in the contract to protect this feature and restore it upon completion of construction;
- The QEW highway – the structure had to span 12 lanes of this heavily travelled freeway. In addition, there were severe constraints on lane closures during construction; and,
- The alignment of the bridge had to thread between two overhead signs on the QEW;
- The south abutment is located on a former landfill site – the piles for this abutment had to be galvanized for long-term protection. In addition, an existing leachate collector pipe for the landfill is located at the toe of slope of the south bank. This pipe prevents leachate generated by the landfill from migrating to the creek. Avoiding damage to this pipe was a critical constraint to the project.

To overcome these site constraints, a 200-metre-long, four-span structure arrangement was developed with a unique "Z" shaped alignment. The alignment suited the site constraints and afforded views of the main arch span by pedestrians and cyclists from the approach spans. The bridge was designed with two distinct structural systems. The main span over the creek and wetland is an 80m span steel tied arch with a single inclined rib. The approach spans are steel single box girders: the north approach has two continuous spans over the QEW with span lengths of 50m and 35m; the south approach is a simply supported span of 35m. The structure layout and details are shown in Figures 3, 4 and 5 (Appended).

A number of architectural and "user-friendly" enhancements were incorporated into the design including:

- Diamond-shaped platforms are provided at the ends of the arch span to provide rest areas and observation points;
- The Z-shaped alignment provides views of the main arch span by pedestrians and cyclists from the approach spans;
- As the symbol of the City's steel heritage, a "fireweed red" coating was applied to all structural steel. This is the same coating used on the Golden Gate Bridge in San Francisco;
- Unique inclined and faceted piers are located at the ends of the arch span. The inclined profile was set to match the profile at the ends of the arch;
- Custom designed aluminum railings; and,
- Dramatic accent lighting to enhance night-time views.

Technical Excellence, Innovation and Level of Complexity

The following areas of technical excellence and innovation on this challenging project are highlighted:

Tied Steel Arch with Inclined Rib

Selected from a number of options, this bridge concept includes a tied steel arch main span with an inclined single tube rib. The length of the arch span is 76m between the supporting bearings, and the steel tie girder extends 2m beyond the bearings at both ends to provide connections with the side spans and supports for the lookout areas. The arch comprises a trapezoidal steel box tie girder, circular arch rib and tapered "I" shaped hangers. The maximum height of the arch rib is 10m above the top of the tie girder. The girder is connected to the arch by 19 hangers spaced at 3.8m on centre. Refer to Figures 3 and Figure 4 (appended) for the structure layout and configuration.

Figure 6: View of Tied Steel Arch Span

Arch Rib

The arch rib is a 760mm diameter steel pipe with 28.5mm thick walls. Due to the size of pipe required, it could not be fabricated using typical structural steel in accordance with CSA G40-21. API-5L Grade X52 steel was chosen to provide similar strength. The rib is inclined 76 degrees to the horizontal to match the web slope of the box girder. One significant overall design parameter for the arch structure is the rise-to-span ratio. A relatively flat ratio of 1:7.6 was ultimately selected for aesthetic reasons. The arch rib carries significant compressive forces and relatively small bending moments from biaxial bending. The tube section was chosen for its high overall stability against buckling, which gave designers the flexibility to use a relatively small rib size for better appearance. The arch rib was designed as a plane circular segment with a constant 70.6m radius resulting in a rib diameter-to-span ratio of 1:100. To prevent lamellar tearing at the connection of the hanger to the rib, internal stiffener rings were added.

Figure 7: View of Inclined Arch Rib

Trapezoidal Box Tie-Girder

To reduce the demand on the size of arch rib, a relatively large closed steel trapezoidal box was used for the tie girder. The dimensions were set to balance the structure behaviour under the asymmetric dead loads and live loads. The top flange width is 4.5m between the centerlines of the webs, and the bottom flange width is 3.875m. The web slope is 4:1 and has a constant depth of 1.25m. This minimum depth was selected to allow future internal inspections. Matching the depth of the approach span girders provides some visual continuity through the entire bridge. Two access hatches are located at the ends of the tie girder for the future inspection of the interior of the box girder, which provide the access to the approach spans. Four additional access hatches are spaced along the length of the span. The additional openings were provided to improve ease of worker rescue in an emergency situation during a future inspection in this confined space, and provide improved access to install and service the Tuned Mass Dampers (TMDs).

Figure 8: Fabrication of Trapezoidal Steel Box Girder

Hangers

In a typical arch bridge with vertical hangers, the hangers are required to carry only tensile forces. However, due to the inclination of the arch, the hangers are required to resist bending moments and tensile forces. As such, high strength strands or wire ropes, which are often used for tied arches, could not be used. Instead, built-up structural steel sections were chosen for the hangers to provide the rigid connection between the arch rib and the tie girder. The hangers are comprised of welded wide flange I-sections and are tapered in both directions for structural requirements and improved aesthetics.

Figure 9: Tapered Hangers

Connections

To transfer the torsional moments and the compressive forces from the arch rib into the steel box, complex analyses and careful attention to detailing were required. Fabricated cradles were detailed for the connection between the rib and the hangers. Because of the varying geometry of the rib and hanger at each connection, each cradle is unique and comprises a cut-to-fit web and sloping flanges that are welded to the tube and bolted to the hanger. A finite element analysis was completed for the connection using SAP2000, Finite Element Method (FEM) software, to verify the stresses in the joint. High strength ASTM A325 22mm diameter bolts were used to connect the arch hangers with the rib cradles. Short stub sections of hangers were welded to the box girder to enable field-bolted connections to the hanger.

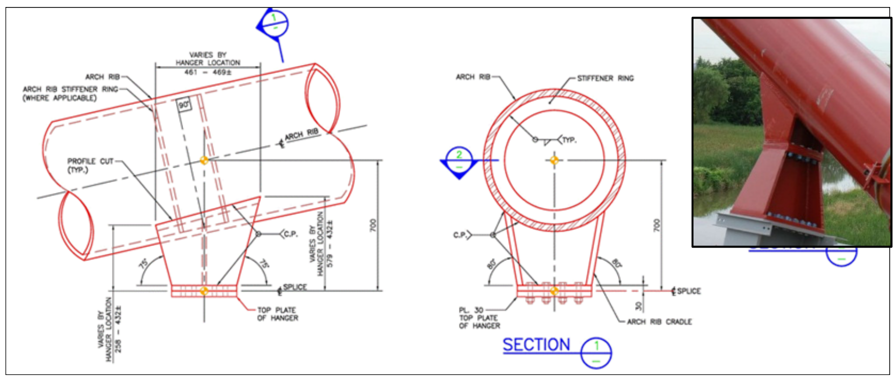

Figure 10: Custom-Fabricated Connection Cradles

Structural Analysis, Wind Analysis and Wind Tunnel Testing

The tied arch is generally considered to be a single load path (non-redundant) structure. Failure of the rib or tie girder could lead to total collapse. The added complexity of the single inclined arch heightened the need for thorough and detailed structural analysis. Several 2-dimensional and 3-dimensional beam-element and plate-element finite element models were developed using SAP2000 to investigate the bridge behaviour under all load conditions. To verify the redundancy of the hanger system, the analyses included a load case simulating complete failure of one hanger.

A key design consideration for long slender structures such as this is sensitivity to wind effects and pedestrian-induced vibrations. This, together with the unusual geometry of the arch span, led to the design team's decision to undertake a rigorous assessment of the bridge's dynamic behaviour. To that end, RWDI was retained to undertake wind/motion engineering studies and a pedestrian-induced vibration analysis. This was completed for the main arch span and the approach spans.

After completing the initial design of the structure, static and dynamic analyses generated the required input into RWDI's work. Besides geometric properties, this included element masses, mode shapes and frequencies of the structural system for the construction condition and the final completed condition. A photograph of wind tunnel testing in RWDI's laboratory is shown in the Figure 11

The wind tunnel test results showed that the structure was aerodynamically stable both during construction and in its final condition. Following wind tunnel testing, a 3D buffeting analysis was conducted to derive the full-scale wind loads and load factors for the structural design based on the turbulence properties at the bridge site.

Figure 11: Wind Tunnel Testing

Pedestrian-Induced Vibration and Tuned Mass Dampers

It is known that pedestrian loading from walking, running, jumping or even vandal activities can cause high motions on footbridges. These motions can lead to uncomfortable or even dangerous vibration levels. One of the most well-known occurrences of this was the Millennium Bridge in London, UK. Therefore, human-induced vibration is a critical design consideration for lightweight and flexible pedestrian bridges.

To examine the vertical vibration of the bridge, two analyses were conducted. First, a simplified analysis was performed to calculate the acceleration caused by one typical pedestrian weighing 700N. Second, a full dynamic analysis (time history method) was performed using the footfall impulse of a typical pedestrian for an "energetic" walk. The results showed that the structure would perform adequately with minimal pedestrian discomfort.

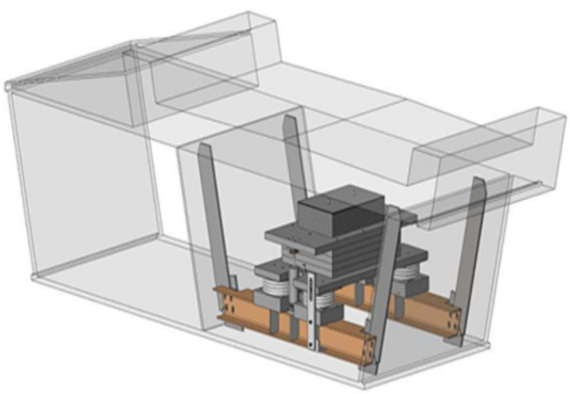

Fig.12: Tuned Mass Damper for Arch Span

A study of the detailed human-induced vibration analysis for a group of pedestrians and a continuous pedestrian stream was then undertaken. The results indicated that vertical motions in the approach spans would exceed comfort acceleration criteria. The arch span had several modes approaching the generally accepted comfort criteria.

Revising the structural properties to change the bridge behaviour did not prove to be sufficient to address the vibration. Accordingly, a total of five tuned mass dampers (TMDs) were installed in the bridge: two in the arch span, one in the south approach span and two in the north approach spans. These are passive devices that incorporate a mass with dynamic properties based on the natural modes of vibration of the bridge The TMD image for the arch span is shown in Figure 12. After installation, field testing was performed to examine the final frequencies of the structure to fine tune the TMDs.

Glass Fibre Reinforced Polymer (GRP) Reinforcing

Because of known problems associated with the corrosion of embedded reinforcement in concrete, particularly where de-icing salts are used, GFRP reinforcement was specified for the top layer of reinforcement in the deck slab to increase the durability and reduce future maintenance.

Environmental and Social Benefits

The multi-use pedestrian bridge is a new landmark for the City of Hamilton in a prominent location at the mouth of the Red Hill Valley Creek. From its clay-red hue to its slanted steel arch, the new pedestrian bridge spanning the QEW and Red Hill Creek was designed to reflect the city and capture its unique character. At 220 metres in length, it spans a **restored, natural wetland** and the QEW. The bridge is the last link of a continuous trail system that **connects the Bruce Trail to the Lake Ontario Waterfront Trail** through the Red Hill Valley Trail. The new crossing enhances the connectivity of Hamilton's recreational trail system, providing pedestrians, cyclists and in-line skaters safer, barrier-free access and direct connection from the valley to the Lake Ontario waterfront linking hundreds of kilometres of trail in Southern Ontario. It also provides a convenient point for users to pause and enjoy the views of the wetland at the foot of the creek and towards the lake.

The bridge sends a strong message to drivers on the QEW, reinforcing the City of Hamilton's objective of stimulating the improved health of Ontario residents through recreational opportunities, habitat restoration and reduction of vehicular trips. It makes a **valuable contribution to Hamilton's public realm**, representing a **true integration of structure, architecture and landscape** coming together to provide a strong sense of place and civic pride. The **signature span with its "fireweed red" hue and dramatic night-time lighting** is viewed by thousands of people daily.

THE HAMILTON SPECTATOR

High: 9
Low: 0
Mostly cloudy with showers. And it only gets colder this week.
Details: Go 2

TUESDAY, NOVEMBER 16, 2010 ✦ THESPEC.COM ✦ THE VOICE OF OUR COMMUNITIES SINCE 1846

East end gets its missing link to lake

Pedestrian bridge expected to open in weeks

BY TERI PECOSKIE

From its clay-red hue to its slanted steel arch, the new pedestrian bridge spanning the QEW and Red Hill Creek was designed to reflect the city and capture its unique character.

And in just a few weeks, Hamiltonians will be able to see the city's new landmark firsthand, as construction on the project wraps up.

Unlike other areas of the city, such as the west harbour, Cootes Paradise and Dundas, the heavily industrial east end has long been alienated from green space, separated from the Lake Ontario waterfront by old landfills and a tangle of high-speed roadways.

But with the construction of the bridge, residents will soon have easy access to an expansive system of trails and parklands, without having to risk life and limb on busy city streets to get there.

Continued on A4

JOHN RENNISON, THE HAMILTON SPECTATOR

The 200-metre-long bridge was the key part of a $14-million waterfront project, funded by a municipal infrastructure grant.

By the numbers

76: The tilt, in degrees, of the bridge's signature arch.
12: The number of lanes of traffic the bridge will traverse on the QEW.
200: The length, in metres, of the bridge's deck.
14,000,000: The budget, in dollars, for the East Hamilton Recreational Trail and Waterfront Link.
7,600,000: The cost, in dollars, for the bridge alone.
1996: The year in which the idea for a pedestrian pathway across the QEW was initially raised.
2008: The year in which construction formally started on the project.

"This bridge and environment restoration investment brings recreation, tourism and nature together in an innovative manner. This link is a welcome addition for citizens of our community and visitors to our community."
- Ted McMeekin, MPP

"I am thrilled that the pedestrian bridge is open to the public and will connect ward four to our precious waterfront via our tremendous trail system for pedestrians and cyclists for generations to come,"
- Ward Four Councillor Sam Merulla.

"The completion of the East Hamilton Trail and Waterfront Link is an important addition to Hamilton's trail network. It offers opportunities to be active while taking in Hamilton's natural environment."
- Sophia Aggelonitis, MPP

"The community has been waiting a long time for this. Hamilton has some wonderful trail systems and this was always the missing link."
- Marco Oddi, senior project manager for the public works department.

"For us in the east end, we've always been looking for a better connection to the waterfront. It's a huge boost for our image. I think the bridge is symbolic that we're making significant upgrades in the east end and in the city."
- Councillor Chad Collins

Owner and Stakeholder Satisfaction

The project has been widely received as a monumental success by the public, the press and the City of Hamilton.

The project was completed in May 1, 2011, on budget with a total cost of $10.2 million. The overwhelming success of the project is articulated in the following quotes of the press and prominent local and area politicians:

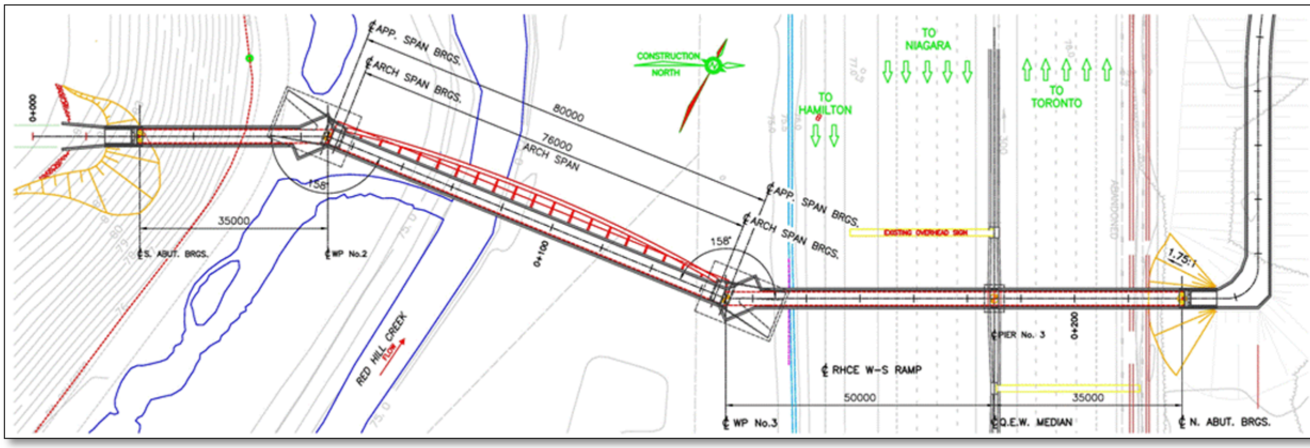

Figure 3: Plan of Bridge

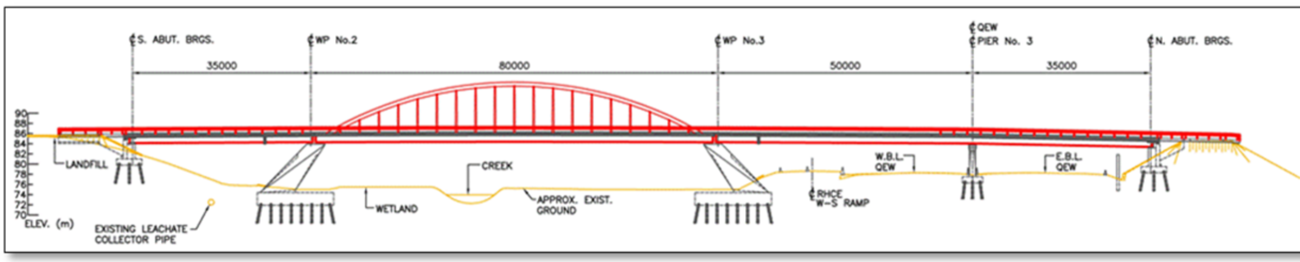

Figure 4: Elevation of Bridge

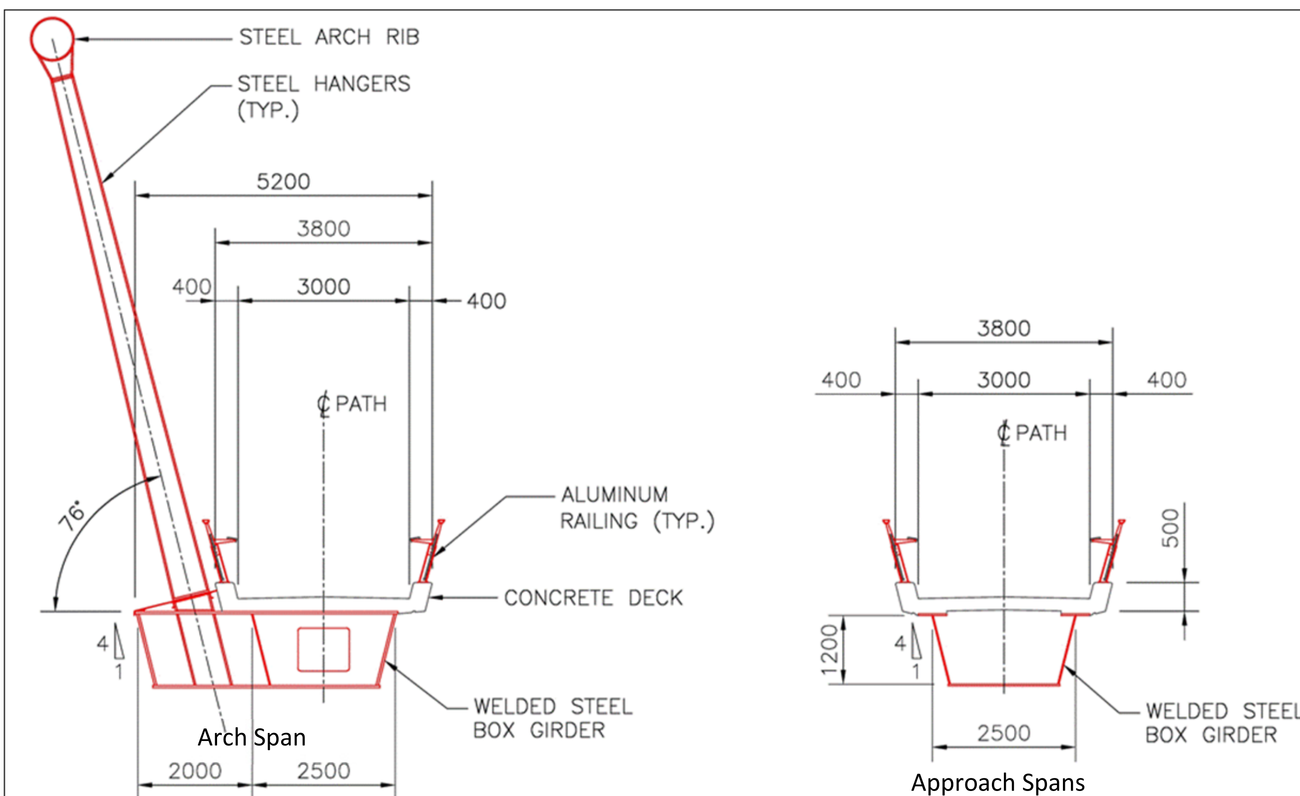

Figure 5: Cross-sections of Arch

Main Span Steel Erection
Photo Credit: McCormick Rankin Corporation

Erection during Night-Time QEW Closure
Photo Credit: McCormick Rankin Corporation

Photo Credit: Francis Fougere Photographic

Photo Credit: Francis Fougere Photographic

Photo Credit: Philip Castleton Photography

Photo Credit: Francis Fougere Photographic

Photo Credit: Philip Castleton Photography

Photo Credit: McCormick Rankin Corporation