WALTERDALE BRIDGE REPLACEMENT

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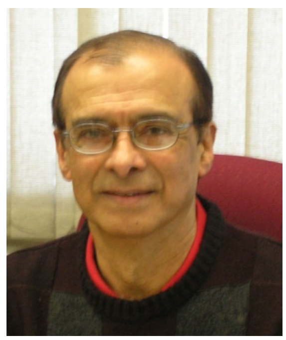

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BIOGRAPHIES

Dr. Jim Montgomery is a structural engineering principal at DIALOG in Edmonton, Alberta leading the design of a broad cross-section of significant bridge, building, and specialty engineering projects across Canada.

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Dr. Andrew Griezic is a Chief Project Manager at Buckland & Taylor Ltd. in Vancouver, BC where he has been the lead designer of several award winning bridge projects.

Shiraz Kanji is the City of Edmonton, Alberta bridge engineer who has been involved in the design and rehabilitation of the city's bridge inventory for over 25 years.

SUMMARY

Integrating with the urban realm and creating a landmark gateway to the city's downtown, the Walterdale bridge replacement will be a signature structure located in the heart of Edmonton, Alberta's North Saskatchewan River valley. The bridge will be a structural steel twin through-arch spanning 206 m, carrying the deck and a separate shared use path across the river.

WALTERDALE BRIDGE REPLACEMENT

Introduction

The new Walterdale bridge will be a signature structure located in the heart of Edmonton, Alberta's North Saskatchewan River valley, respecting the setting, and creating a landmark gateway to the City's downtown. Standing the test of time, the bridge will become a point of pride for the citizens of Edmonton and draw people to the river valley. The bridge will replace an existing three-span structural steel truss bridge that was constructed in 1912 to 1913 to carry two lanes of roadway traffic and a street railway across the river.

In the concept planning stage unique extradosed, arch and cable-stayed bridge alternatives were compared to a more conventional girder bridge alternative for the replacement. As the design progressed through detailed design, a structural steel through-arch bridge was selected as the preferred alternative, spanning 206 m from bank to bank with a deck length of 230 m between abutment centrelines.

The replacement bridge will carry three lanes of northbound traffic on an alignment to the east of the existing structure. It will have a wide sidewalk to the west of the roadway and a separate shared use path to the east.

The C$155 M project has included an extensive public consultation program. Construction of the bridge commenced in June 2013, with completion expected in 2015.

Preliminary Design

The request for proposal from the owner, the City of Edmonton, required that the bridge team design a “functional” signature structure for the bridge replacement, but asked the team to respect budget constraints that were set for the project. Figures 1, 2 and 3, respectively, show in increasing complexity and cost three alternatives for the bridge that were considered in preliminary design.

In these figures, the bridge spans from the south bank of the river in the lower left corner to the north bank in the upper right corner. The alternatives considered are as follows:

- **Alternative 1 -** A conventional twin arch bridge that has a sidewalk and a shared use path outside the planes of cables that support the deck. The width of the shared use path on the east side of the bridge varies to add interest and provide pedestrian lookouts. The cost estimate for this alternative is 10 % less than that for Alternative 2.

  This is the simplest to design, most economical to build and easiest to construct alternative for the bridge replacement. The signature feature is the use of arch ribs spanning a distance of more than two football fields between the riverbanks as part of the bridge superstructure. Many similar structures have been constructed throughout the world.

- **Alternative 2 -** A twin arch bridge with a sidewalk inside the plane of cables that support the deck on the west side and a separate curved shared use path in plan view on the east side.

  The complexity of design, cost and difficulty of construction of this alternative are greater than those for Alternative 1, but less than those for Alternative 3. Alternative 2 has two signature features: the use of arch ribs spanning between the riverbanks as part of the bridge superstructure; and a separate shared use path east of the main structure that acts as a magnet to draw pedestrians and cyclists across the river

- **Alternative 3 -** A single arch bridge with a curved roadway deck in plan view with a sidewalk on the east side balanced by a separate curved shared use path on the west side. The cost estimate for this alternative is 65 % more than that for Alternative 2.

Alternative 3 will be an iconic structure with three signature features: the use of a sculptural single arch rib spanning between the river banks as part of the bridge superstructure; a separate shared use path; and a novel structural system supporting the curved vehicular structure on the east side and the curved shared use path to the west.

This alternative will be much more difficult to design and construct, and expensive to build, than Alternatives 1 and 2. It is expected that the design and construction schedules will need to be extended for Alternative 3.

To achieve a balance between aesthetics, cost and constructability related issues, the design team recommended and the client accepted that contract documents be prepared for Alternative 2.

Figure 1 - Preliminary Design Alternative 1 - Twin Arch Ribs with Shared Use Path and Sidewalk Outside of Planes of Cables

Figure 2 - Preliminary Design Alternative 2 - Twin Arch Ribs with Separate Shared Use Path

Figure 3 - Preliminary Design Alternative 3 - Single Arch Rib with Separate Shared Use Path

Detailed Design

General

Figures 4 and 5 show architectural renderings of the proposed Walterdale bridge replacement. The general arrangement of the bridge is shown in Figure 6.

The bridge deck and shared use path are suspended by cables from two thrust arch ribs that are fabricated from structural steel plate into box-shaped sections, supported on concrete thrust blocks and founded in clay shale bedrock on the banks of the river. The deck is constructed from a concrete slab supported by structural steel wide flange stringers, floor beams fabricated from plate and box-shaped edge girders. The shared use path that is curved in plan is a trapezoidal-shaped box girder fabricated from structural steel plate with a steeply slanted east web.

The bridge is designed using the provisions of the Canadian Highway Bridge Design Code (1) for the CL-800 design truck and lane loading, and the environmental conditions in Edmonton. In addition to pedestrian loadings, the shared use path is designed to carry an 80 kN maintenance vehicle.

A study of wind action on the bridge was undertaken by The Boundary Layer Wind Tunnel Laboratory (2).

Figure 4 - Walterdale Bridge Replacement Viewed from Top of Bank

Figure 5 - Walterdale Bridge Replacement Looking Towards Downtown

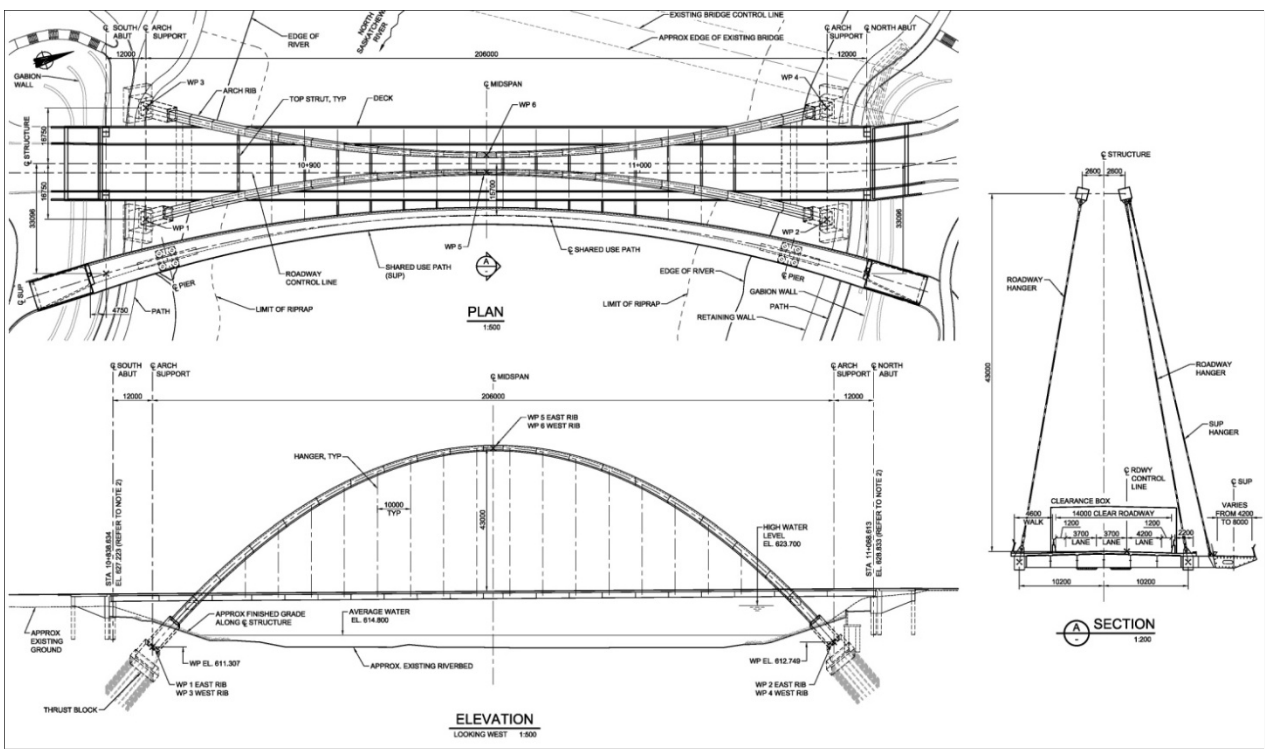

Figure 6 - General Arrangement Drawing

Analysis

The bridge superstructure was analyzed using CSiBridge (3) and CAMIL, an in-house computer program that was developed by Buckland & Taylor Ltd. for the design of cable supported structures. The computer programs considered the nonlinear geometric response of the structure to loads.

As part of the analysis of the bridge, the tensions in the hanger cables that transfer loads from the deck and shared use path to the arch ribs, and the axial forces in the arch ribs were tuned so that the member design actions are appropriate and the bridge has the desired geometry under dead load. The procedure is similar to tuning a harp or building a bicycle wheel.

The steps in tuning the bridge superstructure are as follows:

- Build a computer model of the bridge, assuming that the cables can be modelled as truss elements.
- Introduce initial tensile forces into the cables that are consistent with the dead loads that they will carry. The initial tensile forces can be introduced by subjecting the cables to initial tensile strains (or equivalently a reduced temperature or cable length).
- Introduce initial compressive forces into the arch ribs and other members that are in compression. The initial compressive forces can be introduced by subjecting the members to initial axial compressive strains.
- Analyze the bridge under dead loads to obtain member forces and displacements. In general, the member actions and geometry will not be as desired.
- Sequentially tune the cable and compression member forces until the design actions are appropriate under dead loads. In general, the calculated geometry will be close to but not exactly the desired geometry.
- Sequentially change the initial geometry of the bridge slightly and fine tune the cable and compression member forces to achieve the desired member actions and geometry under dead loads.
- Subject the bridge to other load cases. It may be necessary to fine tune the cable and compression member forces further to account for creep and shrinkage of the concrete deck.
- Finally, turn off gravity to determine the unstressed geometry of the arch ribs, girders and cables.

Thrust Blocks

The results of testing in the detailed design phase confirmed that the geotechnical conditions at the site are appropriate for a thrust arch bridge (4). In the view of the project team, the aesthetic appearance and technical performance of a thrust arch bridge is superior to that of a tied arch.

Figure 7 shows a partial elevation of one of the south thrust blocks supporting the arch ribs. The thrust blocks are founded on clay shale that in rock mechanics terminology is described as extremely weak to very weak (compressive strength of intact rock is less than 5 MPa). Although described as bedrock, the clay shale behaves as a heavily over consolidated soil.

A number of pressuremeter tests were performed in predrilled bore holes on the riverbanks to estimate the stiffness and strength of the clay shale bedrock. The Young's modulus for the bedrock generally varied between 360 MPa and 850 MPa, with localized horizons of softer rock having moduli between 133 MPa and 186 MPa. Undrained shear strengths estimated from the pressuremeter data, and unconfined and confined compression tests on core samples ranged between 920 kPa and 1700 kPa, with localized areas of lower strengths on the order of 400 kPa to 740 kPa.

In the detailed design phase, it appeared that the thrust blocks could be subjected to uplift under certain load cases. Using the theory developed for the analysis of reinforced concrete columns with biaxial bending (5), micropiles acting like reinforcing bars in tension and compression were sized to work with the thrust blocks to resist axial forces and moments.

However, finite element analyses of the thrust blocks undertaken using PLAXIS 2D and PLAXIS 3D software (6) indicate that the micropiles will generally be subjected to compressive forces for all load cases.

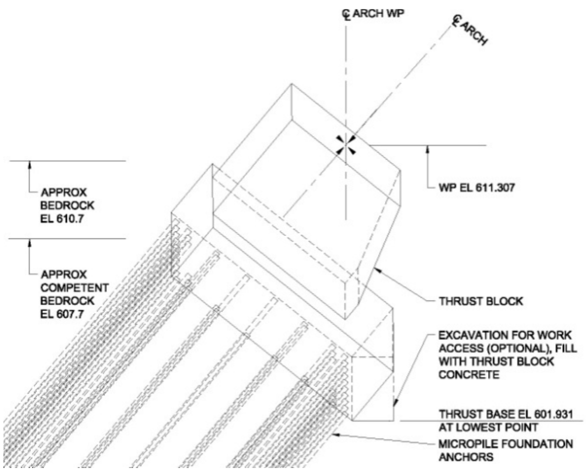

Figure 7 - Partial Thrust Block Elevation

Arch Ribs

The arch ribs are constructed from structural steel plate and have cross sectional dimensions that vary from approximately 2.5 m by 2.5 m at the base to 1.4 m by 1.4 m at the crown. Figure 8 shows a section through the east arch rib at a hanger location. The arch ribs are inclined at 13.5^{o} from vertical when the bridge is viewed in section (Figure 6). The plate thicknesses used for the arch ribs vary from 100 mm at the base to 75 mm at the crown, requiring substantial welded and bolted connections. There are architecturally shaped struts connecting the arch ribs together above the deck and structural steel beams between the arch ribs supporting the deck near each river bank. In addition to the connection details at the base of the ribs, each arch rib is spliced at 20 locations to facilitate shipping.

For the design of the arch rib members, global buckling was accounted for using the usual axial force biaxial bending interaction equation where moments are magnified to account for the increase due to P-Delta effects.

In sizing the arch ribs, an allowance was made for the out-of-plane bending stresses induced in the flanges owing to member curvature (7).

In addition to stresses from externally applied moments, the stresses in a compression member as it approaches failure are higher than those produced by the buckling load because of (8):

- "Buckling" moments.
- Moments induced by initial imperfections.
- Residual stresses.

To account for these effects, the connections of the arch ribs to the thrust blocks and arch rib splices are designed to resist the total stresses, $\sigma_{x,total}$, determined from

$$[1] \quad \sigma_{x,total} = \frac{C_f}{A} + \frac{UM_{fx}}{S_x} + \frac{UM_{fy}}{S_y} + \sigma_{buckling}$$

$$[2] \quad \sigma_{buckling} = \frac{C_f}{C_r}(1-X)\phi_s F_y$$

$$[3] \quad X = (1-\lambda^{2n})^{-1/n}$$

$$[4] \quad \lambda = \sqrt{\frac{F_y}{F_{cr}}}$$

where C_f is the factored compressive force on a section, A is the cross-sectional area, U is the moment magnification factor accounting for the

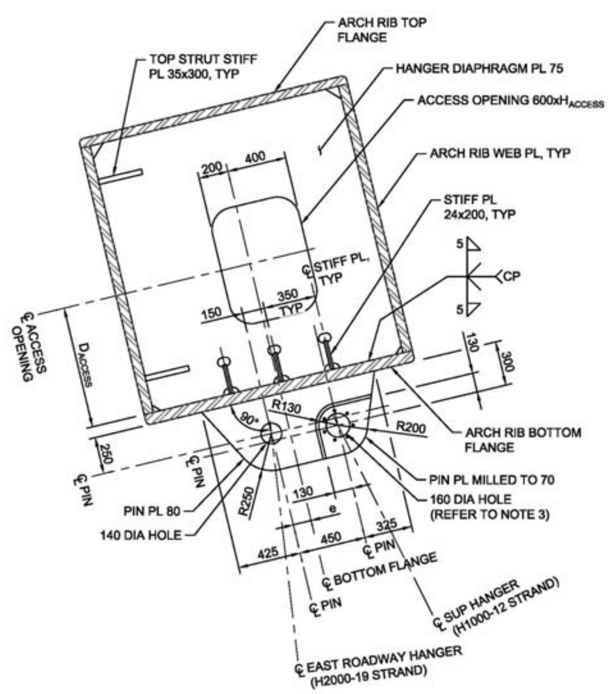

Figure 8 - Section Through East Arch Rib at Cable Hanger Location

increase in moment due to P-Delta effects (1), M_{fx} is the factored external moment about the x-axis, S_x is the section modulus about the x-axis, M_{fy} is the factored external moment about the y-axis, S_y is the section modulus about the y-axis, $\sigma_{buckling}$ is the stress due to "buckling" moments, initial imperfections and residual stress, C_r is the factored compressive resistance, ϕ_s is the resistance factor for steel, F_y is the yield stress of steel, n is a coefficient for axial buckling (1), and F_{cr} is the elastic critical stress determined from a buckling analysis.

Roadway Deck

A typical cross section through the bridge deck is shown in Figure 9.

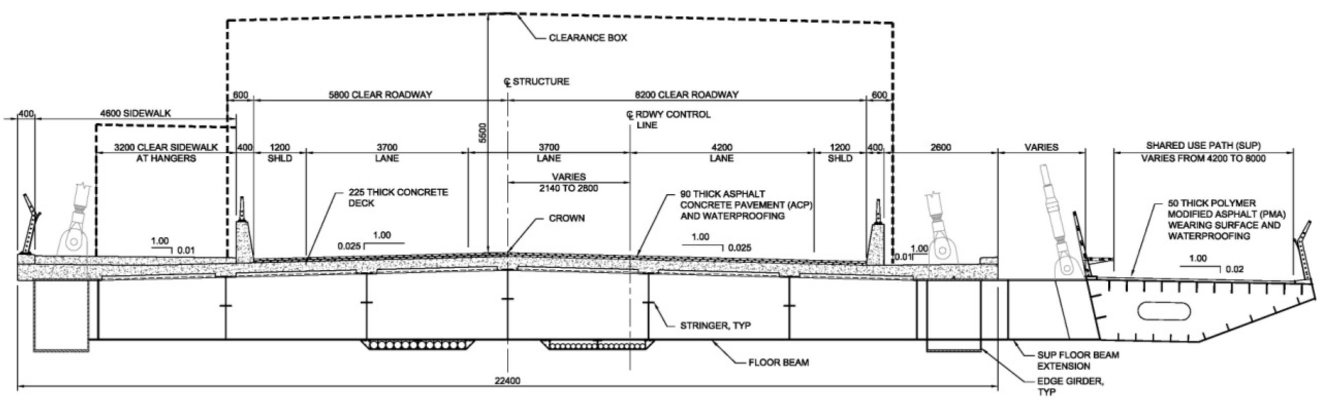

Figure 9 - Cross Section Through the Bridge Deck

The roadway deck, which has an asphalt wearing surface, is designed so that the west parapet can be moved over to accommodate a future fourth lane. Cantilevers from the floor beams overhanging the edge girder would then be added to accommodate the west sidewalk outside the plane of cables. The cable supported edge girders rest on bearings at the abutments and support beams between the arch ribs where the girders pass by the ribs.

Figure 10 shows a section through the east edge girder where a transverse floor beam frames in at the location of a cable hanger.

Shared Use Path

An important objective of the design of the bridge replacement is to provide a means for pedestrians and bicyclists using the trails in the valley to cross the river. The bridge has a separate shared use path on the east side, allowing people to cross without being immediately adjacent to the vehicular traffic on the roadway deck (Figure 6). With a clear width of 8 m at the river banks and 4.2 m near mid-span, the shared use path geometry will encourage people to cross the river.

Figure 11 shows an elevation of the shared use path with abutment supports at the river banks and delta piers adjacent to the water. Near mid-span the shared use path is supported by cable hangers from the east arch rib and in some locations cantilevers from the bridge deck floor beams overhanging the east edge girder (Figures 6 and 9).

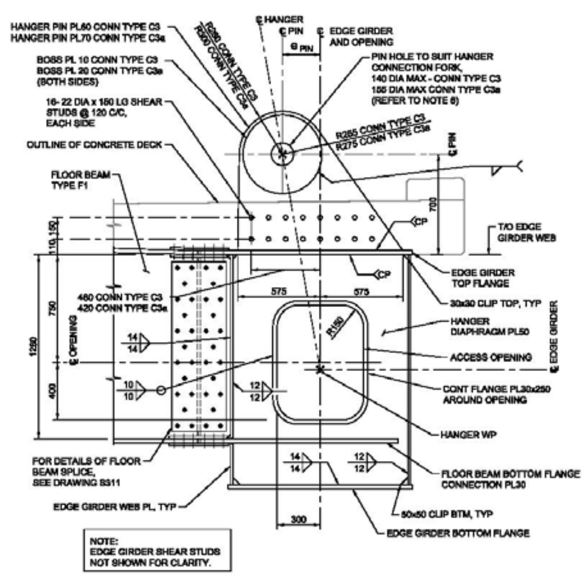

Figure 10 - Section Through East Edge Girder at Cable Hanger Location

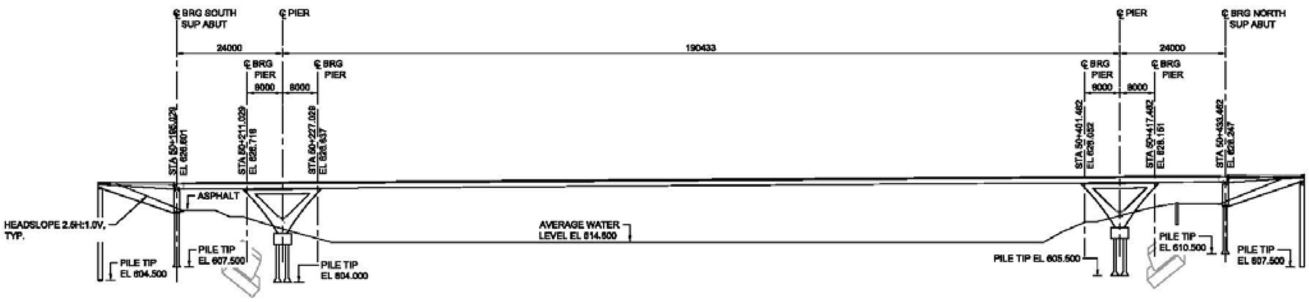

Figure 11 - Elevation of Shared Use Path

Figure 12 shows the structural steel box girder that supports the shared use path. The box girder is built up from relatively thin sections of steel plate that are stiffened longitudinally by plate stiffeners.

The shared use path has a polymer modified asphalt wearing surface with wood accents on the east side.

Figure 13 shows a typical cable hanger connection at the shared use path girder. The connection consists of a pin plate that is at the centre of a box shaped boss fabricated from steel plate.

Concrete ballast is placed inside the shared use path girder over the delta piers to counteract uplift forces at these locations. As trucks travel across the roadway deck, the arch ribs deform under load causing the shared use path girder which is in part supported by the ribs to deform. For example, when the north half of the bridge deck is loaded, the north half of each arch rib moves downward and the south half moves upward. This causes the south portion of the shared use path girder to displace upward.

Vibration of the shared use path under pedestrian traffic is an important design consideration. Using the Guidelines for the Design of Footbridges (9), the design team confirmed that pedestrian vibrations will not be excessive as a single jogger, a small group of people or a large group of people cross the river on the shared use path.

Cables

Figure 14 shows cable hangers from the east arch rib that supports the roadway deck and the separate shared use path. The hangers are parallel strand stay cables with the strand bundled inside a high density co-extruded polyethylene pipe. The cables are fixed at the upper fork anchorage, but are adjustable at the lower fork anchorages.

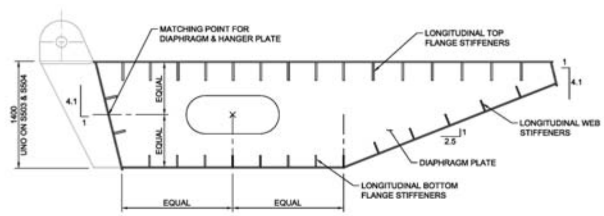

Figure 12 - Section Through Shared Use Path Girder at Cable Hanger

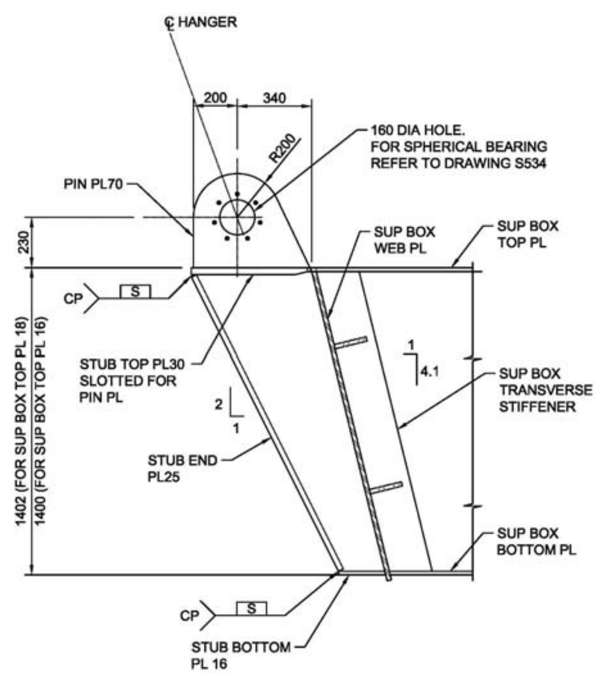

Figure 13 - Cable Hanger Connection at Shared Use Path

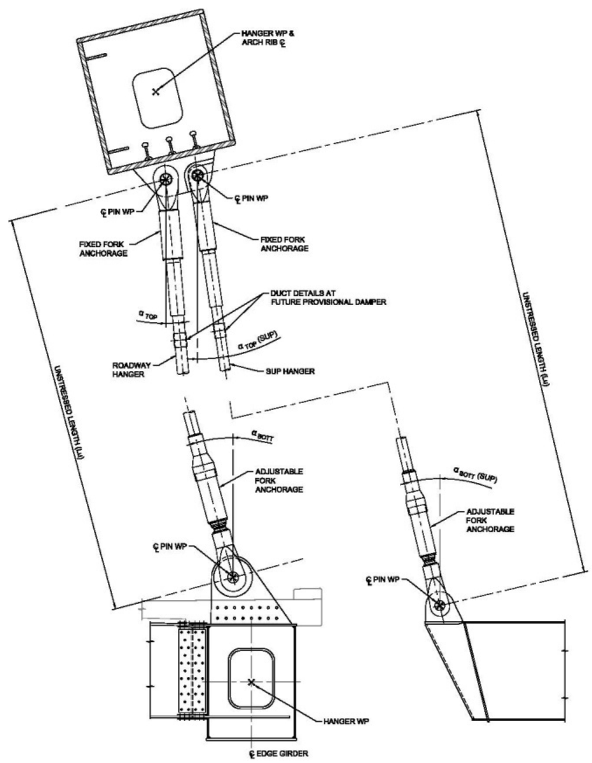

Figure 14 - Cable Hangers

The pin plates that connect the cable hangers to the arch ribs, edge girders and shared use path girder subject these members to primary through-thickness tensile stress. In the immediate areas of cable hanger connections, the arch rib bottom flange, edge girder top flange and shared use path web are fabricated with z-steel tested in accordance with ASTM A770 (10) to confirm that the material has an adequate resistance to lamellar tearing.

The cable hangers supporting the shared use path are relatively long and have small cross-sectional areas when compared to the members typically used for bridges. Spherical bearing are used at the ends of these cables to reduce the potential for fatigue to occur as a result of cable vibrations.

The Boundary Layer Wind Tunnel Laboratory (2) identified the potential for dry cable galloping for many of the cable hangers that support the shared use path and a few of the cables that carry the east edge girder of the bridge deck. This is a relative new phenomenon in wind engineering that is difficult to observe in wind tunnel tests and has not been observed on bridges with larger, heavily loaded cables.

Provisions are built into the shared use path cable hangers to allow for the installation of devices to increase damping if required to reduce the potential for dry cable galloping. The bridge will be monitored over time and if the performance needs to be altered damping devices will be installed.

The bridge is designed to allow for the replacement of any one cable hanger supporting the roadway deck, with one lane of traffic closed adjacent to the cable under exchange. When a cable supporting the shared use path is removed and replaced, the pathway is closed to pedestrian traffic.

The bridge is designed to withstand the loss of any one cable without the occurrence of structural instability in accordance with Post-Tensioning Institute recommendations (11). The Ultimate Limit States load combination considering the loss of a cable is

$$[5] \quad 1.1DC + 1.35DW + 0.75(LL + IM) + 1.1CLDF$$

where *DC* is the dead load of the structure and fixtures, *DW* is the dead load of the wearing surface, *LL* is the live load, *IM* is the live load impact allowance [taken as the Dynamic Load Allowance (1)], and *CLDF* is the cable loss dynamic force taken as 2.0 times the static force in the cable applied at the top and bottom anchorages. The resistance factor for cables is taken as 0.9.

Expansion and Contraction

The bridge is allowed to expand and contract symmetrically about the centre line of the structure. Elastomeric bearings at the abutments supporting the roadway deck and the bearings resting on beams between the arch ribs at the locations where the deck edge girders pass by the arch ribs restrain the longitudinal movement of the bridge deck. Special restraints are installed at the abutments to prevent excessive longitudinal movement of the edge girders.

The cantilevers that extend from the roadway deck floor beams to support the shared use path vertically for gravity loads also restrain the longitudinal movement of the pathway.

Corrosion Protection

Prior to coating, the hanger plates attached to the edge girders and the arch ribs to 6 m above the deck are hot-dip galvanized or zinc metalized. The coating system specified for the structural steel components consists of a two component epoxy organic zinc rich primer intended to provide cathodic protection, an epoxy stripe coat, a two component epoxy mastic mid-coat, and a two component aliphatic urethane gloss enamel topcoat. The intent is for the coating system to protect the bridge structure against corrosion for an expected life of 25 years.

To extend its life, the concrete roadway deck is reinforced with stainless steel and protected by a hot applied rubberized asphalt membrane below the asphalt wearing surface.

Snow and Ice

Northern Microclimate (12) was engaged to ascertain whether snow and ice can accumulate on the cables, arch ribs or struts between the arch ribs and result in snow or ice “bombs” falling off the bridge superstructure, putting motorists and pedestrians at risk. Northern Microclimate concludes that the icing of the cables will not be an issue given the climate conditions at the bridge site, but there is the risk of the falling or sliding of a windblown piece of ice or snow from the arch ribs or struts at least once a year.

A winter operations protocol will be developed to maintain a safe environment both during and after winter storm events. If falling or sliding snow becomes an issue after the bridge is open to traffic, mitigation devices will be installed on the arch ribs and struts.

Urban Realm and Aesthetic Considerations

The Walterdale bridge replacement is an important structure that is located in a prominent location in the North Saskatchewan River valley. The objective is for the bridge to announce Edmonton’s downtown to people crossing the bridge from the south and help draw people to the river valley for recreational purposes. The design architects and landscape architects on the project worked closely with the bridge engineers to develop an aesthetically pleasing design and integrate the structure into the urban realm.

The parabolic shape of the arch ribs in elevation, the height of the arch ribs above the deck, the inclination of the arch ribs in section and the shape of the separate shared use path in plan view (Figures 4, 5 and 6) are all selected to enhance the appearance of the bridge. To improve their appearance, the arch ribs and shared use path steel sections are curved not faceted between splices.

The north abutment of the bridge is close to the historic Fort Edmonton site and an aboriginal burial ground. There are plans to repurpose abandoned utility buildings on the north bank for the good of citizens of Edmonton and people visiting the city. Figure 15 shows how the bridge ties into the urban realm at the north abutment.

There are a number of trails along the river valley that are widely used by pedestrians and bicyclists. Figure 16 illustrates the passage of the trail on the north bank under the bridge deck at the abutment.

Specially designed for the project, the handrails and guardrails on the roadway deck and the separate shared use path are fabricated from stainless steel. Figure 17 shows the design for the east hand rail on the shared use path.

A bench positioned along the middle 50 percent of the length of the shared use path on the west side will allow people to sit and enjoy views to the river valley. The solid back of the bench will help to shield people using the share use path from the prevailing west wind and traffic noise from vehicles on the bridge.

In addition to street lighting for the roadway with attractive poles and fixtures, kinetic lighting is installed along the arch ribs. The kinetic lighting can be programmed for the different seasons and to suit the requirements of special events. In addition, aesthetically pleasing, functional lighting is installed in the railings along the separate shared use path.

Figure 15 - Urban Realm on North Bank

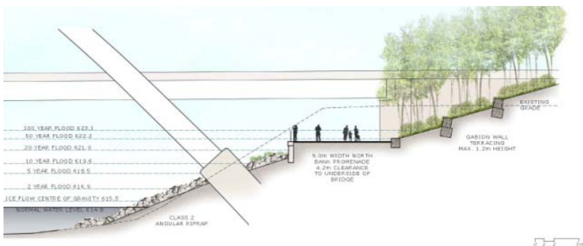

Figure 16 - Shared Use Path Passing Under the Bridge on the North Bank

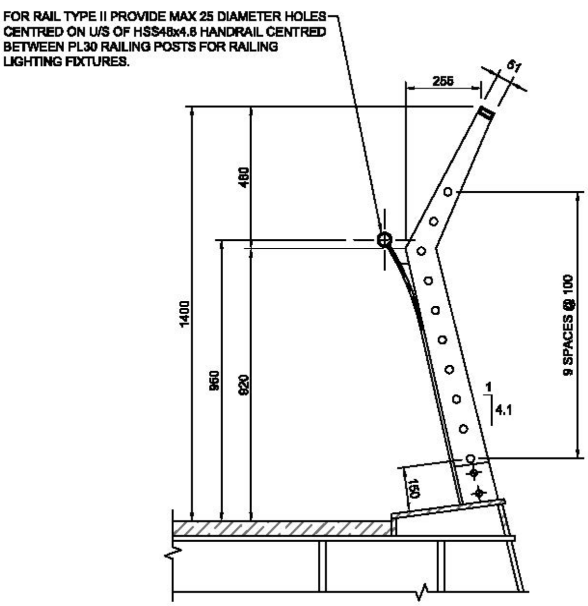

Figure 17 - Shared Use Path Handrail

Construction Methodology

General

An extensive process was undertaken by the design team and City of Edmonton representatives to prequalify structural steel fabricators and general contractors for the Walterdale bridge replacement. Several Canadian and a few international steel fabricators and general contractors were prequalified to bid on the project. The contract for construction of the bridge and approach roadways has been awarded to the Acciona Pacer Joint Venture for an amount of C$126 M. The structural steel for the bridge is being fabricated in Korea by Daewoo International Corporation.

Figure 18 is an air photograph viewing the construction site from above the south bank of the river towards downtown Edmonton. The existing Walterdale bridge, which will be demolished after the new bridge is open to traffic, is located to the west of the new alignment.

Figure 18 - Early View of Construction Site (photograph courtesy of Ron Simonsmeier of Alberco Construction Ltd.)

Foundation Excavation

Four excavations approximately 18 m deep with plan dimensions of 15.5 m by 14.2 m are required at the locations of thrust blocks on the river banks. The excavations will be braced by steel sheet piling with walers built up from structural steel sections.

Figure 19 shows the start of the excavations for the thrust blocks on the north bank. Sheet piling for the excavation for the north-east thrust block is projecting above the ground surface. The west edge of the excavation for the north-west thrust block is very close to the north abutment of the existing Walterdale bridge.

Steel Erection

The Acciona Pacer Joint Venture is in the process of developing an erection procedure for the bridge. It is likely that a few sections of the arch ribs will be erected on the south and north banks of the river. The remaining arch sections and struts will be assembled as a unit on the south bank, floated into position on barges and then lifted up for connection to the previously erected arch rib sections by means of cranes.

The structural steel members for the roadway deck and shared use path will be assembled in sections on the south bank and floated into position on barges for erection.

Details of the steel erection will be reported on in a subsequent publication.

Figure 19 - Thrust Block Excavations on North Bank

Summary

The existing Walterdale bridge will be replaced with a steel twin through-arch structure. The new bridge has a separate shared use path for pedestrians and bicyclists on the east side of the roadway deck that is supported at mid-span by cables from the east arch rib and cantilever extensions of the floor beams.

The bridge is located in a central and important part of Edmonton. Great care was taken to develop an aesthetically pleasing design for the bridge that integrates with the urban realm.

Key aspects of the design include:

- Analyzing and proportioning the twin arch ribs with complicated geometry to support the roadway deck and the eccentric load from the shared use path.
- Transferring design actions from the arch ribs into the clay shale bedrock through thrust blocks accounting for the interaction of the concrete bases and micropiles.
- In addition to externally applied moments, accounting for "buckling" moments, moments induced by initial imperfections and residual stresses when proportioning the connections of the arch ribs to the thrust blocks and arch rib splices.
- Allowing for the interaction of the shared use path with the arch ribs and edge girders as trucks cross the river on the roadway deck.
- Working with an integrated team of bridge engineers, civil engineers, architects and landscape architects to develop an innovative design for the bridge that will be a point of pride for the citizens of Edmonton and stand the test of time.

Construction of the bridge replacement will be completed in 2015 for a project cost of C$155 M.

Acknowledgement

The input into design and support of Byron Nicholson, Allan Bartman, Mike Bindas and Ryan Teplitsky of The City of Edmonton are acknowledged and greatly appreciated. ISL Engineering and Land Services, DIALOG, Buckland & Taylor Ltd., and Al-Terra Engineering Ltd. are the primary consulting firms that are providing engineering design and contract administration services on the project.

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