

# ROTATED-ELLIPSE ARCH PEDESTRIAN BRIDGE FOR THE CALGARY WEST LIGHT RAIL TRANSIT EXTENSION PROJECT

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## ABSTRACT

As part of the Calgary West Light Rail Transit (LRT) project, the existing pedestrian overpass crossing Bow Trail SW, west of 24th Street SW, was replaced to provide a widened roadway and LRT right-of-way. An increase in vertical clearance was also necessary for the LRT power propulsion system catenary wires. The project-wide architectural concept of a rotated ellipse was incorporated into the bridge design through the ellipse shaped arches with the pipe components rotated by 10 degrees. The two pipe arches were also inclined inwards to further enhance the aesthetics. The bridge utilizes pipe arch as the main structural members, providing a main span length of over 50 m and a top-of-arch height of approximately 16m. The north abutment continues the elliptical theme by carrying the curve design through the exposed portion of the arch foundation wall. This paper presents the opportunities and challenges experienced throughout design, fabrication, erection and construction. The design had a focus on engineering solutions developed by the design-build team to minimize potential risks during construction.

## 1. INTRODUCTION

The new 24th Street Pedestrian overpass is part of the estimated \$1.4 billion Calgary West LRT expansion project. This showcase project opened for service in December 2012 and was a significant mobility improvement project, serving more than 100,000 residents in the West areas of the City of Calgary (<http://www.calgary.ca/>). The Project consisted of an 8.2 km extension to the LRT system between 11<sup>th</sup> Street SW to 73<sup>rd</sup> Street SW, 6 new LRT stations and major road and bike path improvements. MMM Group was a member of the SNC-Lavalin joint venture team awarded the contract to design, build and undertake procurement City of Calgary West Light Rapid Transit Extension Project.

The new pedestrian overpass replaces an old structure that was removed to facilitate the construction of the West LRT. The previous structure consisted of a steel slant-leg pedestrian overpass crossing Bow Trail SW, near the Shaganappi Point Golf Course. The new bridge spans the six lanes of Bow Trail, two LRT tracks at mid-span, and multi-use trails near each of the abutments.

The new bridge, shown in Figure 1, is much wider than the old structure with a clear width between handrails of 3 metres, providing a safe width for bi-directional pedestrian and cyclist traffic. The approach pathway has gradual inclines and curved ramps for pedestrians and cyclists. The new overpass also provides better access to the Bow River pathway system and bus stops on Bow Trail.



Figure 1: View of bridge deck from south abutment (left) and view of bridge from the north abutment (right).

## 2. DESIGN ELEMENTS

### 2.1. Design Criteria & Requirements

#### 2.1.1. Project Architectural Theme and Structure Configuration

The bridge's off-set ellipsis design portrays the project's architectural theme and mirrors the West LRT station canopies. This architectural theme was inspired by the Chinook arch which is a regular feature of Calgary's skyline. An elliptical or circular arch structure was not considered as the elliptical architectural theme was to be maintained. The main span length is approximately 50 metres from end-to-end of the half ellipse as shown in Figure 2 below. Another 12 metres of deck is supported by steel props on the south end of the bridge. A vertical clearance of 6 metres is provided for the LRT power propulsion system catenary wires near the mid-span and at least 5.5 metres above the Bow Trail roadways.

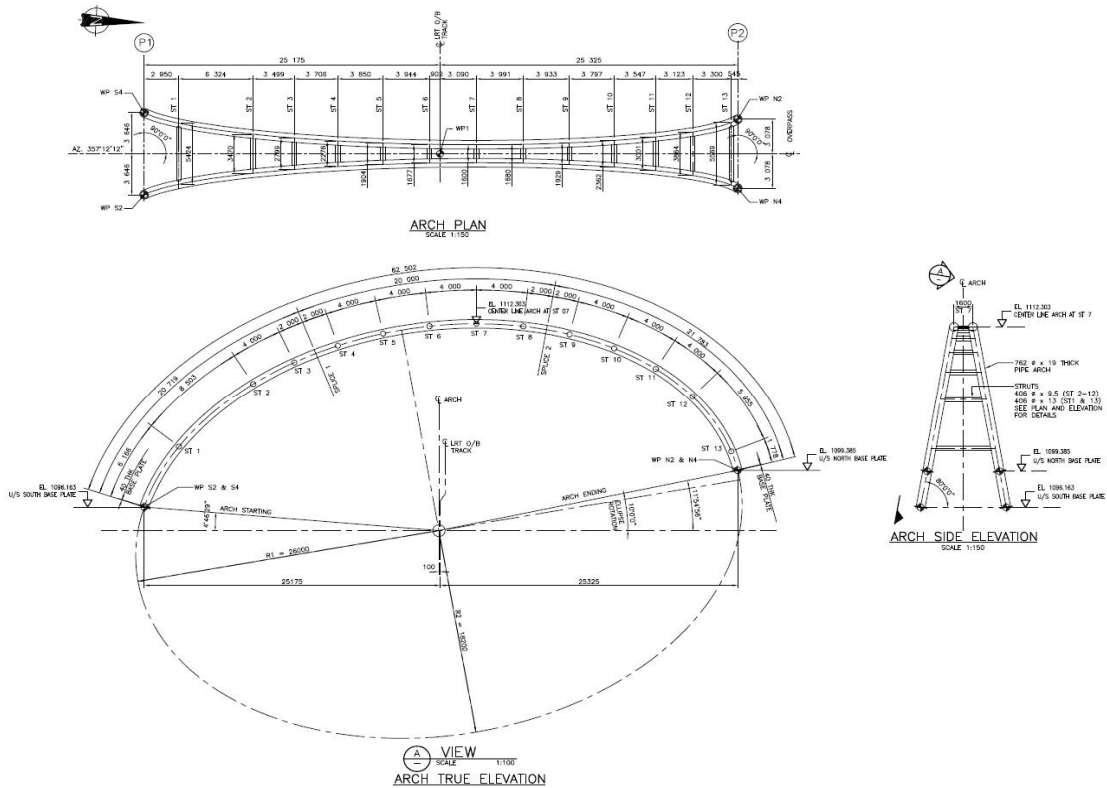


Figure 2: Geometry Layout of Arch

### 2.1.2. Design Loads & 3D Model

All elements of the pedestrian bridge were designed to meet the design requirements of CAN/CSA S6-06 and the City of Calgary's Design Guidelines for Bridges and Structures. Loads included pedestrian loads (4 kPa), vertical and horizontal wind loads, snow loading, ice accretion and seismicity. Also included was a live load maintenance vehicle load for snow clearing operations. The pipe arches were analyzed for seasonal thermal fluctuations from -30°C to +30°C temperatures which produced internal stresses caused by the contraction and expansion of the steel and concrete members.

The natural frequencies of the bridge were calculated to be 7.04 Hz, 2.12 Hz, and 3.03 Hz for the vertical, horizontal, and torsional mode shapes respectively. Typical critical frequencies for a pedestrian bridge are 1.65 to 2.35 Hz for vertical excitation and 0.85 to 1.20 Hz for horizontal excitation (Bachmann, 1995). The vertical natural frequency also exceeded the minimum 4 Hz acceptable for pedestrian bridge serviceability according to CAN/CSA S6-06, therefore no damping was required to prevent pedestrian walking cadences and seismic vibrations from damaging the structure. Figure 3 shows some of the analyzed vibration mode shapes.

The arch structure, supporting hangers and concrete deck were designed with the aid of 3D modeling software to determine stresses in the structure during construction and service, and to calculate the natural frequency. CAD dimensions of the arch were imported into the 3D software to ensure the correct geometry of the arch used during the analysis.

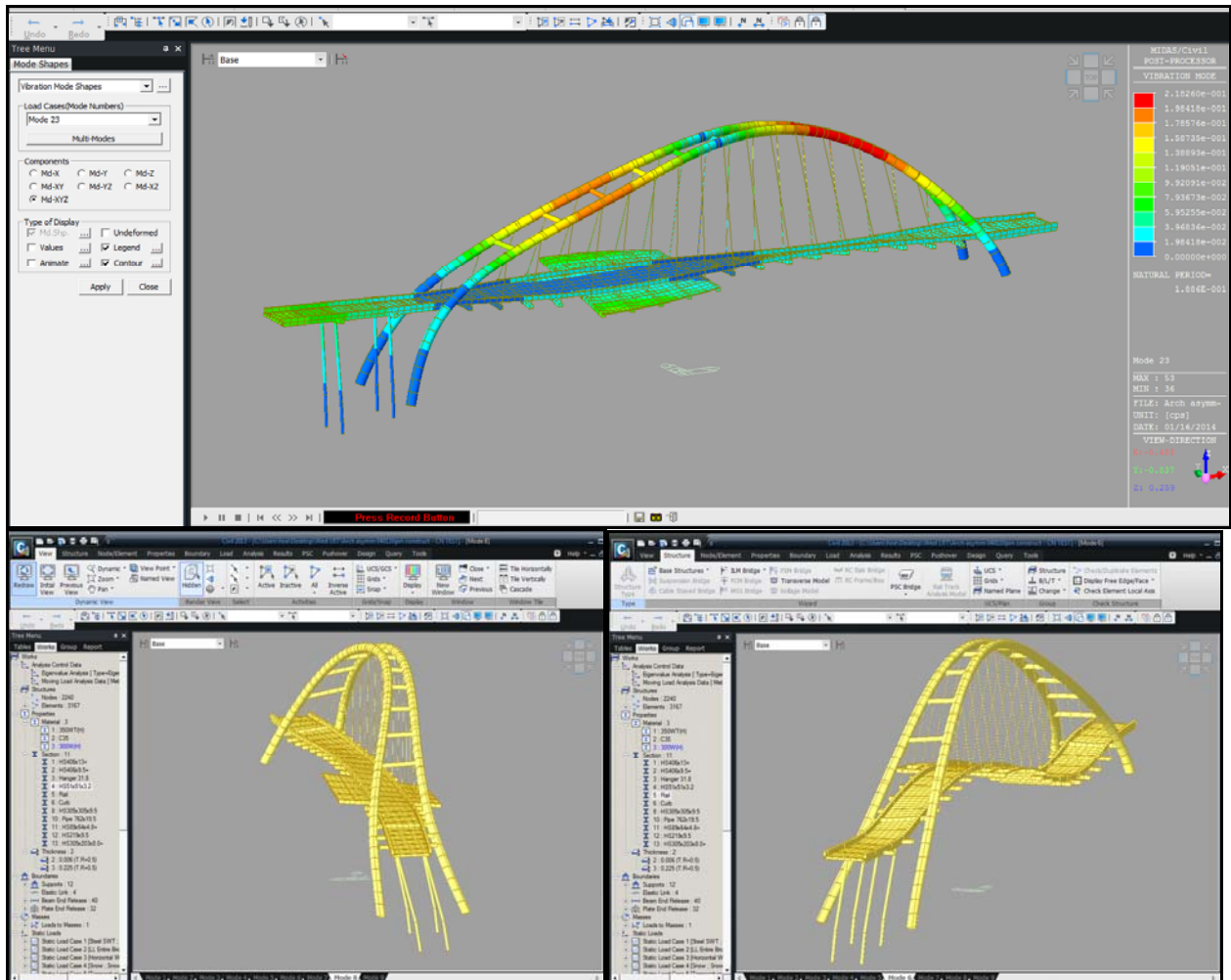


Figure 3: Modal Shapes Due to Structural Vibration

### 2.1.3. Durability

To satisfy the required design service life of 100 years, all structural steel, with exception of the arch and struts, were hot-dipped galvanized and followed by a three-coat paint system applied to all exterior surfaces only. The arch and struts included sacrificial corrosion allowance and were protected using the three-coat paint system applied to the exterior surfaced only. Areas that were damaged due to the field welding were repaired using approved procedures.

The bearings between the deck and arch struts were designed to facilitate replacement, if required over the service life of the structure.

The bridge deck and other cast-in-place concrete components within the splash zone were constructed using galvanized reinforcing steel and high-performance concrete.

## 2.2. Structure Design

### 2.2.1. Arch and Hangers

The steel arch is comprised of three sections splice welded together on site. The main steel pipe arches are tilted 10 degrees inward, towards each other, and are laterally connected with smaller transverse steel pipes as ties, as shown in Figure 4. The lateral ties are first bolted to the main arch at gusset plates on the pipes, and then the pipes are welded to ensure the correct fit after any initial deflection due to self-weight has occurred. The main pipes of the arch are API 5L X52 PSL2 steel pipes 762mm diameter x 19mm thickness with a minimum yield strength of 360 MPa. For lateral connectivity, the arches are connected using 406mm diameter cross-frame struts, including 13 struts located above the pedestrian clearance envelope and 2 struts located below the deck.

The steel hanger rods are Grade 316 stainless steel and 31.8mm in diameter. The rod size was chosen so the hangers would act as rigid bars rather than flexible wires and appear somewhat oversized to provide a sense of 'comfort' to the public. The hangers were designed to facilitate maintenance, as one pair of hanger rods can be removed at a time without the need for supplemental support.

The stainless steel hanger rods connect the arch to the suspended HSS steel floor beams supporting the concrete deck. The lateral floor beams are connected longitudinal with HSS beams to provide a rigid support frame for the deck. The steel framing rests on lateral struts between the main arch pipes with neoprene bearings in between.

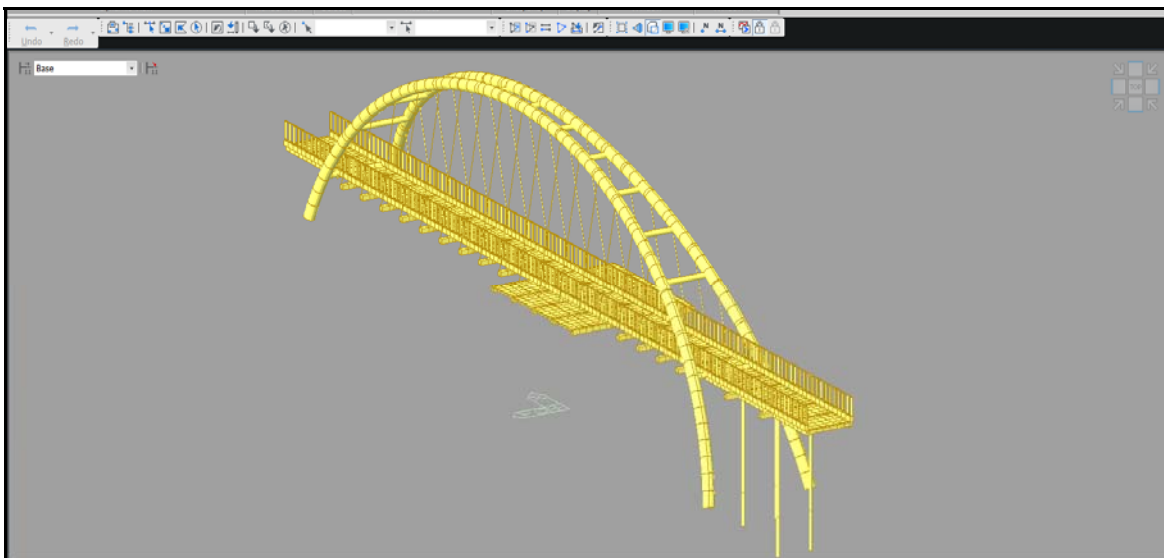


Figure 4: 3-D Model of Arch Bridge with MIDAS Civil

### 2.2.2. Permanent and Temporary Bearings

During the construction phase, the base plates at each end of the arches were supported by spherical bearings capable of rotating to allow the arch to settle into its natural final shape, as shown in Figure 5. After the arch was erected with the deck cross-ties, steel hangers, floor beams in place and the final concrete deck poured, the pipe end plates were bolted down and the temporary spherical bearings were grouted in place to convert the pinned connection to a permanently fixed connection. Bearings at the abutment accommodate expansion and contraction and are located at the bridge deck joints. There are sliding bearings where the deck is supported by the under-deck arch struts.

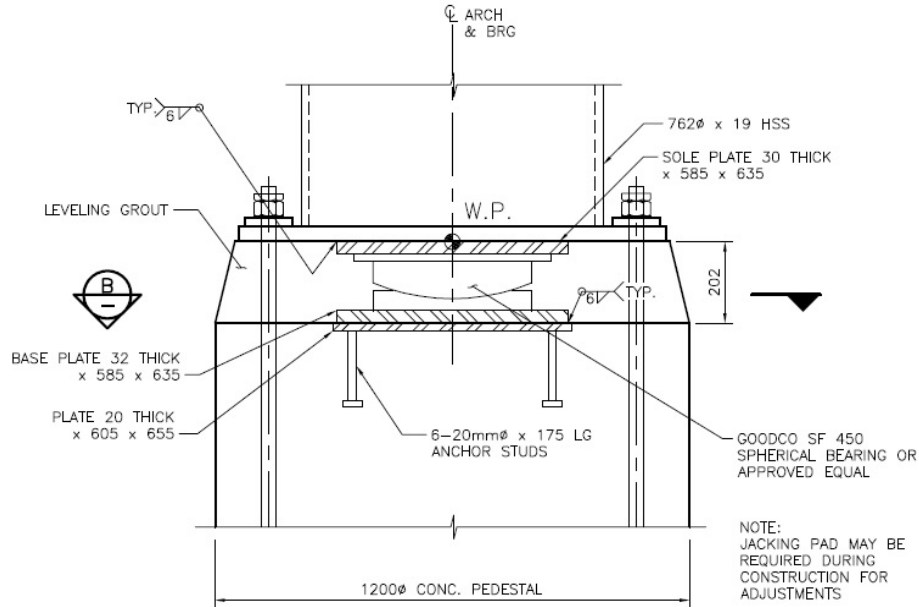


Figure 5: Temporary Spherical Bearing at Arch Ends

### 2.2.3. Deck and Floor Beams

The non-prestressed concrete deck was comprised of 100mm thick partial depth precast panels, acting as forms for the final steel reinforced 125mm thick cast-in-place concrete deck. All reinforcing for the deck was constructed with galvanized steel reinforcing. The precast panels were supported on steel floor beams or edge beams. Sole plates at each end of the precast panels are bolted onto the floor beams with slotted holes to allow for adjustment. The precast panels are fastened to the floor beams securely, the reinforcing steel is placed and concrete deck is poured. The concrete deck is made composite with the steel beams with anchor studs attached to the top of the HSS floor beams. The deck connection details are shown in Figure 6. The use of the precast panels reduced construction time by eliminating falsework and installation and removal of formwork.

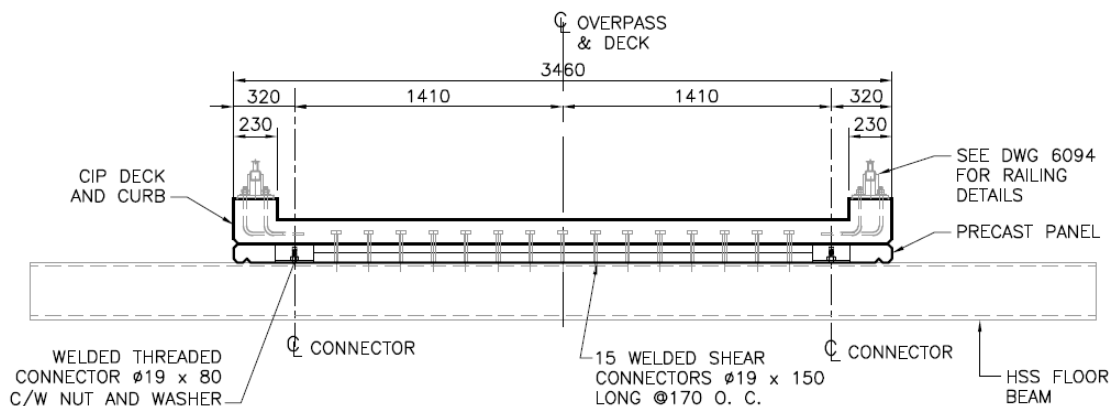


Figure 6: Deck and Floor Beam Connection Detail



#### 2.2.4. Foundations, Substructure and Retaining Walls

The arch foundations and abutments at the bridge ends are founded on steel H-piles up to 15 metres in length. The piles were either vertical or battered up to 4:1 inclination. The reinforced concrete abutments include wingwalls and MSE walls to retain embankment soil. The south span from the arch strut to the south abutment is supported by two vertical steel HSS props. These props were also supported by a concrete pile cap on steel H-piles.

The south abutment foundation is located away from the arch foundation near the deck elevation which helped create an open space below the south spans to improve path user safety and comfort. Rather than use extensive concrete faced retaining walls, a natural look was produced by selecting large scale, roughly rectangular, block stone suitably designed for the steep slope up to the south abutment (Figure 7 – left).

The north arch foundation (Figure 7 – right) is situated approximately 4 metres above the adjacent trail. This exposed face was vertically curved to continue the shape of the arch ellipse. The approaching wingwalls are two-stage MSE walls. The first stage consisted of a wire faced MSE wall that could tolerate settlements which were significant when compared to the pile-supported arch foundation. Following the settlement period, the wire face was covered with a final cast-in-place concrete facing which was also curved to match the shape of the arch ellipse.



Figure 7: View of the south abutment, utilizing a rock-stack wall for improved slope appearance (left) and the north arch foundation and adjacent 2-stage MSE wall facing (right).

#### 2.2.5. Electrical Protection and Grounding

As the LRT system passing beneath the bridge is powered by an overhead catenary system, steel fabrications such as this bridge, are require to be grounded to provide protection to the public. The bridge has electrical connectivity through all the elements – specifically from the arch to the reinforcing steel in the concrete foundations to the steel H-piles driven into the ground. The pedestrian bridge also has wider deck floor beams and Lexan (clear fibreglass) directly over the LRT tracks. This provides increased protection between bridge users and the LRT catenary wires that carry the electrical current.

### 3. CONSTRUCTION

#### 3.1. General Construction Procedure

The following is a general outline of the arch construction and erection procedure followed by the contractor.

1. Shop drawings were submitted, reviewed and approved for fabrication.
2. Arch sections were cut to length and bent to suit then fabrication welding of assemblies. Other steel elements were also fabricated including HSS props, deck framing and railings.
3. Bearings were fabricated.
4. Hangers were ordered and fabricated.

5. Steel elements were dry-fit together to ensure compatibility.
6. Arch and all steel elements were painted or galvanized.
7. H-piles were driven for foundations.
8. Substructure concrete elements were cast and wire faced MSE walls were installed.
9. Temporary bearings were installed at arch ends
10. Individual arch pieces were transported by truck to site and unloaded. The arch was completely fabricated on falsework adjacent to the site. The hangers and deck floor beams were hung from the arch while in its temporary location.
11. During a single night closure, the roadway was closed to traffic, the erection crane was rigged to the assembled bridge and it lifted the entire structure and placed it on its temporary bearings.
12. Following the arch erection, the remaining steel components were installed including the props and deck floor beams. The permanent bearings were installed.
13. The precast deck panels were installed, followed by reinforcing steel and the cast-in-place concrete deck and curb.
14. The railing was installed
15. The curved cast-in-place facing was cast in front of the wire faced MSE wall and lastly,
16. The approaches were completed.

### 3.2. Steel Fabrication

Steel fabrication was completed by a Calgary company. The elements were fabricated in the shop in accordance with the design drawings. The fabricators requested particular splice locations which were reviewed by the design engineer. Due to the unusual shape of the arch, significant focused effort was necessary in fabricating and bending the various elements (Figure 8). Conventional steel material, (API 5L X52 PSL2) and welding fabrication quality testing was conducted on each of the elements to confirm quality.



Figure 8: View of fabrication of the arch sections in the shop.

### 3.3. Arch Erection

Erection engineering was completed by the contractor's fabricator, who was also responsible for site assembly and erection planning. They undertook analysis to guarantee the erection process would not overstress any elements. The crane supplier confirmed the lift parameters such as maximum swing radius and lift capacity as needed for the erection planning.

The various temporary stages of erection that occurred just off-line from the bridge's final location were checked and where necessary, additional support and stabilization was provided (Figure 9).

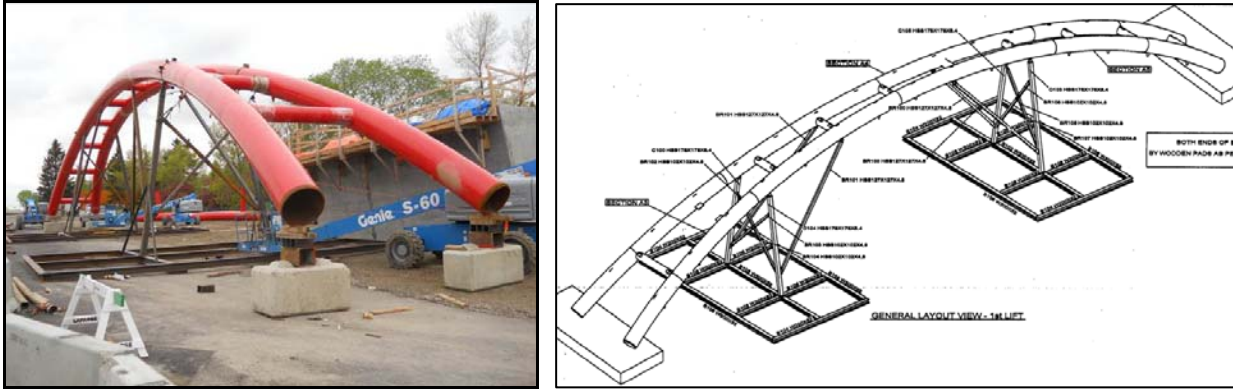


Figure 9: View of bridge arch during assembly, off-line from the final location, with temporary supports.

In order to minimize traffic disruptions, the erection scheme was developed considering a single-night road closure. Erection occurred after the bridge arch, hangers and deck floor beams were fully assembled. A crane with capacity to lift and place the entire bridge was stationed and rigged in the appropriate location. The bridge was then rigged with fabric slings at pre-determined locations (Figure 10). The bridge was erected onto its temporary bearings in a single lift. An assist crane was on site to facilitate the arch erection. When the flexible arch structure was picked up from near mid-span, its own weight caused the arch to deflect and the end moved toward each other by over 1 metre. When placing the ends of the arch on the bearings, the assist crane and construction tools such as come-alongs were used to pull the arch ends back to the original design location.

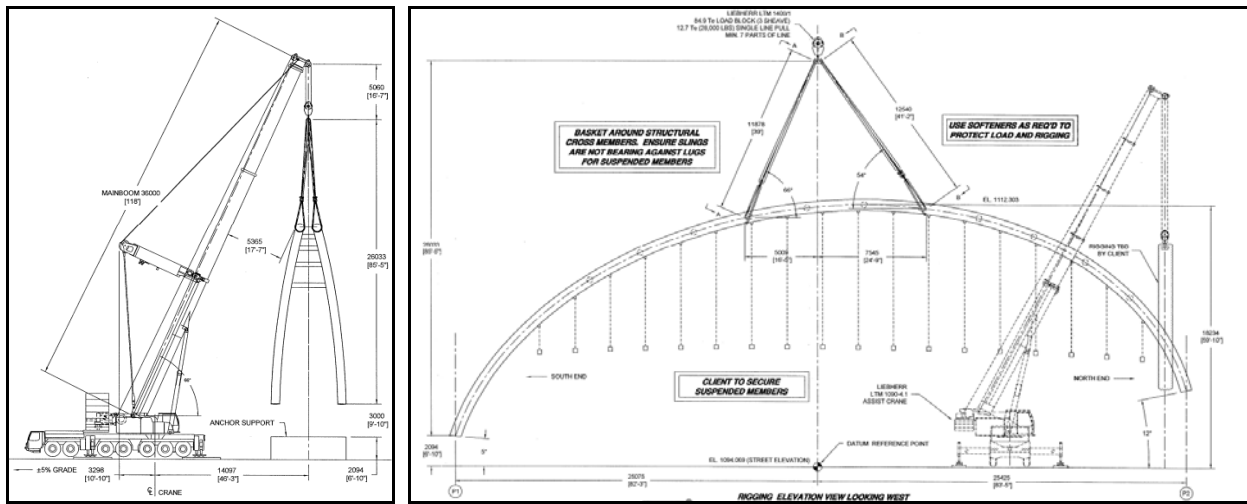


Figure 10: Excerpt of the erection plans, showing section view of the crane and bridge (left) and elevation view of bridge with sling locations and assist-crane.

### 3.4. Deck Placement

To evaluate arch deflections during the deck construction, a staged construction analysis was completed for the placement sequence of the precast-deck panels and also for the direction in which the cast-in-place concrete topping was poured. The precast deck panels functioned both as a structural element in the deck and also as a stay-in place form for the deck topping and the curbs. The sequence of the placement of the deck panels was specifically arranged to manage the arch deflections.





Figure 11: View of bridge, following arch erection, prior to erection of precast deck panels and placement of cast-in-place concrete topping.

### 3.5. Bearing Fixity

As previously mentioned in Section 2.2.2., the arch bearings were designed to accommodate rotation; specifically to allow the pipe arch to rotate slightly during the accumulation of dead loads throughout construction. This prevented the build-up of large moments which would have been induced by the dead load from the deck and railings on fixed a fixed connection. Further, use of the rotational bearing allowed for increased tolerance during erection.

Following complete installation of the deck and railings, the temporary bearings were locked down with anchor rods and then fully grouted to provide a fixed connection (Figure 12)



Figure 12: View of temporary bearings just after arch erection (left) and following grouting to achieve fixity (right).

### 3.6. Wall Facing

Upon completion of the MSE wall settlement duration of approximately six months, a concrete facing was added. This facing continues the ellipse themed curve throughout its length (Figure 13).



Figure 13: View of North arch foundation and curved retaining walls.

#### 4. CONCLUSIONS

Design build projects can achieve a high level of aesthetics by specifying a viable reference concept that the contractor can accomplish economically. Furthermore, construction risks can be minimized when the design team has clear communication with the contractor and their erection engineers. Clear communication allows incorporation of elements that will be used to improve the construction duration or ease of fabrication and ultimately lead to the success of the project.

The ways that the design team help achieve success on this project include:

1. Early engagement of the erection engineering team to understand the plan and make adjustments as necessary. Ultimately this evolved to a one-night erection of a fully assembled arch complete with hangers & deck floor-beams, including the use of temporary bearings at arch base to improve erection tolerances.
2. Use of 2-stage MSE walls for the north arch foundation approach, allowing construction to occur during the settlement period.
3. Use of precast deck panels to eliminate deck forming over live traffic, reducing construction time.
4. Use of rock stack wall at the south abutment to improve aesthetics. Further these rocks were reclaimed from another area of the project.

#### 5. ACKNOWLEDGEMENTS

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