

DESIGN AND CONSTRUCTION OF THE SIR AMBROSE SHEA VERTICAL LIFT BRIDGE
PLACENTIA, NEWFOUNDLAND AND LABRADOR.

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ABSTRACT

On September 23, 2016, the new Sir Ambrose Shea Vertical Lift Bridge located in the Province of Newfoundland and Labrador on the east coast of Canada opened to traffic. It was built as a replacement to an existing structure constructed in 1961 that had reached the end of its useful life. It is comprised of three spans, with a centre movable span (vertical lift span) flanked by two simple fixed composite plate girder spans. The towers for this lift bridge are comprised of a three-dimensional steel truss shaped representative of sails. Each tower component is connected by a three-dimensional exoskeleton truss housing the machinery operating the lift span.

In addition to being aesthetically pleasing with architecture reflecting the local culture and tourism potential of the region, the new bridge is designed to be durable, efficient and reliable. The new bridge was constructed adjacent to the existing bridge in order to minimize disruption to navigation and road traffic.

This paper discusses the bridge design and construction starting with the design aspects of the bridge including: movable bridge types considered; alternative lift span systems; foundation options; bridge architecture; mechanical components; durability; and constructability aspects of the design.

The bridge foundations, approach spans, and towers were constructed using temporary trestles and cranes and the lift span was assembled on a barge and lifted into position. The construction duration spanned over a period of three years and had to accommodate the harsh environmental conditions including high winds, tide, and fast currents.

INTRODUCTION

The Sir Ambrose Shea vertical lift bridge is located on the Avalon Peninsula, in the town of Placentia, approximately 100 km west by southwest of the capital city St. John's. Originally constructed in 1961, it remains the only movable bridge in the Province. Earlier, in the 1940s, a pontoon bridge had been built to cross the Placentia "Gut", a narrow waterway channel connecting the Atlantic Ocean to the inner harbour. Later, a ferry capable of carrying several vehicles and passengers was utilized in the 1950s. Both undertakings encountered rough tides and sea ice in the area, making the crossing untenable.

The bridge provides a vital link between the amalgamated communities of Placentia, Jerseyside, Dunville, and Freshwater and is part of Route 100, an important regional highway. The bridge is raised for commercial fishing boats approximately 2400 times annually, allowing them to enter and leave the Placentia Gut. Although the bridge remains in operation year round, the frequency of vessel passage is seasonal, driven by fishing activities.

The project's objective was to create a bridge that satisfied the functional requirements of the existing bridge including accommodating both vehicular and marine traffic, and minimize restrictions to navigation, which can negatively affect local commercial fishery activities. Furthermore, due to the bridge's high visibility in the historic community of Placentia and the importance of tourism to the local economy, the design required the incorporation of architectural features, to enhance the appearance of the bridge, consistent with the town's heritage, culture, and local environment. Figure 1 shows the new and existing bridges crossing the Placentia Gut.



Figure 1 – Placentia Lift Bridges crossing the Placentia Gut

This paper focuses on the design aspects of the bridge including: movable bridge types considered; alternative lift span systems; foundation options; bridge architecture; mechanical components; durability; and constructability aspects of the design. The bridge foundations, approach spans, and towers were constructed using temporary trestles and cranes and the lift span was assembled on a barge and lifted into position. The construction duration spanned over a period of three years and had to accommodate the harsh environmental conditions including high winds, tide, and fast currents.

DESIGN CRITERIA

The new bridge design and alignment needed to satisfy the functional navigational and roadway requirements while minimizing negative impact on the community of Placentia. Similar in functional design to the existing bridge, the new vertical lift bridge is comprised of three spans with a 33m lift span as the centre span, flanked by two 32m approach spans. The minimum required clear width of the navigation channel under the lift span is 25m with a minimum vertical clearance at the bridge above high water of 3.05m when lowered and 21.34m when raised. The design accommodates two vehicle lanes with a sidewalk on each side. It also carries power and communication utilities relocated from the existing bridge.

The horizontal alignment of the new bridge is parallel to the existing bridge alignment, but offset by 22 m to the east. An offset roadway alignment allowed for construction of the new bridge without affecting vehicular traffic while improving on the existing alignment as shown on Figure 1. The shortest detour to cross from one side to the other is about 35 minutes and requires driving on a gravel road.

The bridge was designed in accordance with the Canadian Highway Bridge Design Code CAN/CSA S6-06, considering the requirements of Section 13 related to movable bridges and the various stages of operation. The design accommodated the harsh weather conditions and associated loading including: ice accretion of 66 mm; high wind loads with a reference wind pressure of 900 Pa and a horizontal wind load of 3.60 kPa; and ship collision forces associated with vessels with a dead weight tonnage of 200 tons. Figure 2 shows an elevation of the bridge.

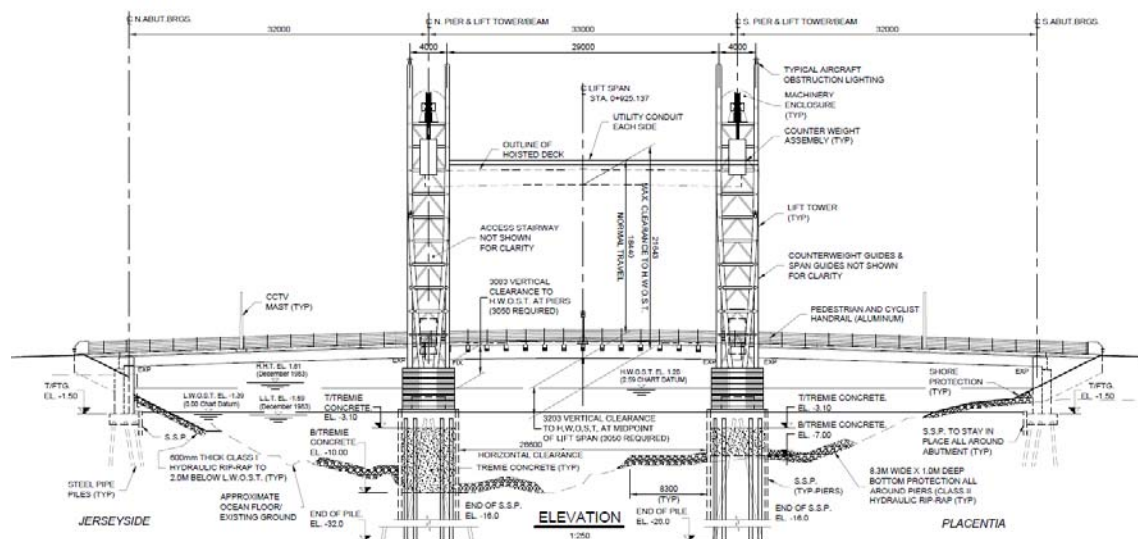


Figure 2 – Bridge elevation

ARCHITECTURE

The Newfoundland and Labrador Department of Transportation and Works, through the project terms of reference, recognized that given the high visibility of the new bridge in the cultural landscape, it should significantly contribute to the picturesque character of Placentia and add to the town's attractiveness as a destination for tourism and centre for economic development. A new vertical lift bridge, if designed to be a memorable and photogenic landmark, can position Placentia as one of Newfoundland's must-visit destinations and would contribute to the reversal of the town's economic decline through enhancing tourism, local confidence and investment. The location of the bridge serves as the dominant focal point in the picturesque landscape and can be seen from a series of viewpoints including: the primary visitor arrival entrance to town by land and sea; the waterfront recreational walking paths; the peak of Fort Royal at Castle Hill National Historic Site (Figure 3); and from the harbour.



Figure 3 – View of the Bridge from Castle Hill National Historic Site

The new bridge provided an opportunity for improvement to the architecture of the existing crossing. The architectural concept was developed with a vision of enhancing the crossing, complementing the surrounding features and architecture, and providing a light, visually pleasing structure with strong vertical lines to mimic the nautical imagery of the community (Figure 4). It is a very visible and intrusive object in the centre of the community (Figure 5), and the new bridge design has brought forward architectural forms and features that enhanced the crossing, while keeping with the desire for a practical, functional, and durable structure with conventional operating characteristics. Key architectural features on the bridge include:

- **Verticality:** the two towers on each side of the lift span are the dominant visual elements of the aesthetic composition, emphasizing verticality. They soar towards the sky and are shaped to represent boat masts and antennas.
- **Transparency and Silhouette:** the bridge towers composed of tubular members and the machine room transparent enclosure give a sense of transparency and provide an intriguing silhouette.

- Colour: the main elements of the bridge superstructure were painted white in order to increase the bridge's visibility and to allow it to stand out in contrast with the dark surrounding hills and the often-grey seas and skies.
- A safe environment and inviting pedestrian experience with a wider sidewalk (1.8m) in comparison with narrow 1.2m walkway on the existing bridge.

Some of the architecture of the bridge was inspired by the Salford Quays Vertical Lift Bridge in Manchester, England. The bridge towers express their verticality like a cluster of ship masts; the towers are constructed of tubular steel members; and the bridge was coated white.



Figure 4 – Nautical imagery of Placentia



Figure 5 – Bridge standing out in the centre of the Placentia community

MOVABLE BRIDGE TYPE SELECTION

Swing, bascule, and vertical lift movable bridge options were considered. For this site, a vertical lift bridge similar to the existing bridge with a machinery platform supported at height was ideal, as it was evident that the best durability would be achieved by removing vulnerable elements of the bridge as far from grade level and water level as possible. A swing bridge option was not carried forward as a viable option as the pier for the swing span would be located in the middle of the channel thus reducing its effective width. A bascule bridge was considered unfavourable at this site as it requires a counterweight system for the moving parts to be slung below the stationary side spans which in turn requires a higher clearance above water and higher approaches. Also, the mechanical components of a bascule bridge would be located below the bridge deck and would therefore be vulnerable to de-icing chemicals and the salty ocean water, creating a long-term durability concern.

The reliability of the bridge's operations was a high priority during design. Simple and conventional operating systems bring the highest degree of reliability and minimize maintenance. These conventional systems, both mechanical and electrical, formed the basis of the bridge design. Standby generators were provided to ensure continued, reliable service in case of power outages. Furthermore, control system technology utilizing a Programmable Logic Controller (PLC) was used for system control and monitoring including the capability for remote monitoring and diagnostics. This proved useful during bridge commissioning given its remote location.

The mechanical and electrical systems from the lift bridge were integrated into the structure with minimal impact from a visual perspective while minimizing maintenance requirements and improving overall system efficiency. The mechanical design features two independent tower drive systems and rolling element main counterweight sheave bearings that minimize friction

and maintain a compact machinery system. Digitally controlled variable speed motor drives were used for the span drive system.

BRIDGE FOUNDATIONS

Subsurface conditions at the site are comprised of silty sand and poorly graded sand that gets looser with depth. No bedrock was noted in any of the boreholes, which were drilled up to 70 m deep.

The piers are approximately 26.7 m in length by 5.7 m in width. The size is dictated by the towers and the lifting mechanism. Design of the piers foundation had to rely on friction piles or a shallow foundation founded on a competent layer with limited bearing capacity. Two foundation options were tendered to give contractors flexibility to bid on the option they were more capable of building based on their experience, available equipment, and cost. These options included a shallow foundation system comprised of hollow reinforced concrete piers and a deep foundation option supported on friction pipe piles. For economic reasons, the Contractor elected to build the deep foundation option. The deep foundation option involved the installation of cofferdams; driving 136 – 324 mm diameter close ended pipe piles approximately 30m into the ocean floor; excavating sub-aqueously, the overburden within the cofferdam, down to competent bearing material and pouring tremie concrete; constructing the pile cap on top of tremie concrete and constructing the remainder of the pier in the dry. Pipe piles were selected as they provide a higher skin friction and end bearing in comparison to H-piles. The deep foundations option is shown in Figures 6 and 7.

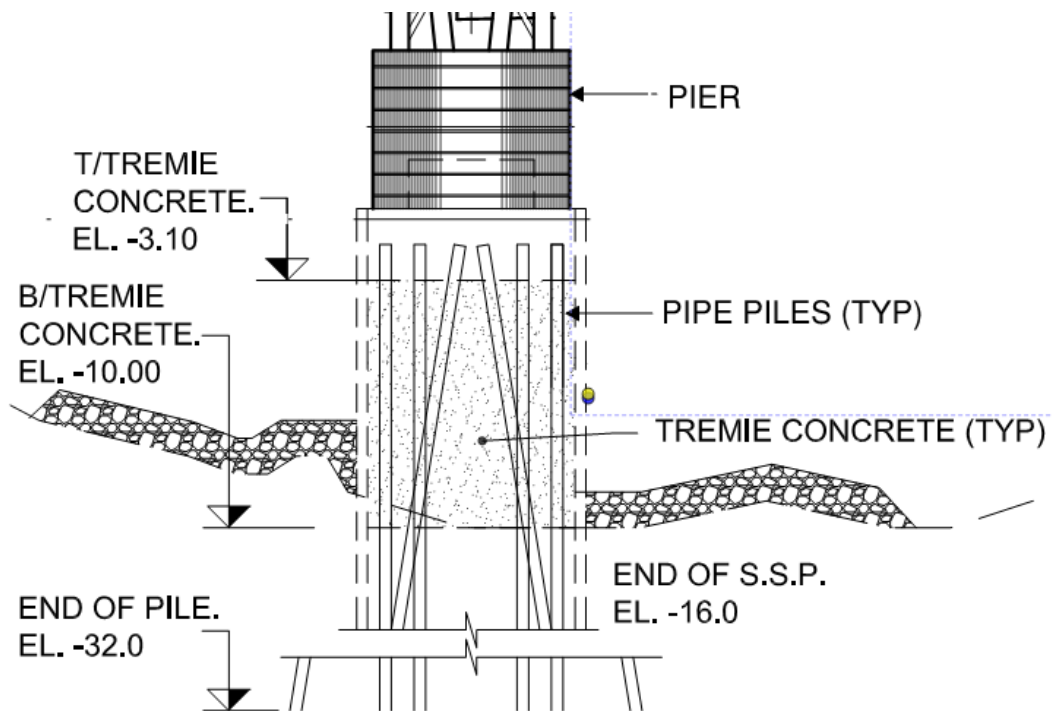


Figure 6 – Pier deep foundation option



Figure 7 – Pipe piles at pier foundation

The shallow foundation option would have required installation of cofferdams and excavating sub-aqueously to competent bearing material, placing a tremie plug; and constructing the concrete foundations in the dry within the cofferdam. This would have required providing significant bracing for the cofferdams and excavating about 6.5 m below the ocean floor for the north pier and 16 m for the south pier.

The abutment foundations are supported on 30-324mm diameter friction pipe piles driven about 16.5 m into the soils at the north abutment and 20 m at the south abutment.

The abutment and pier piles are closed ended and filled with concrete for added stiffness. At the piers, several pipe piles had to be driven open ended to account for the stiffening of the soil within the cofferdam from the pile driving operations. Access for the piers construction was facilitated by the construction of a temporary work bridge from shore.

SUPERSTRUCTURE

Approach Spans

Two designs were provided for the approach spans, allowing the Contractor flexibility to select the best option that suited its means and methods, and which provided the best value to the Owner. Options considered are shown below and include side-by-side pre-stressed concrete box girders (Figure 8) and a steel plate girder option with a cast-in-place deck (Figure 9). For both options, waterproofing and an asphalt wearing surface were used to protect the concrete deck. The steel girder option was selected by the Contractor for economic reasons.

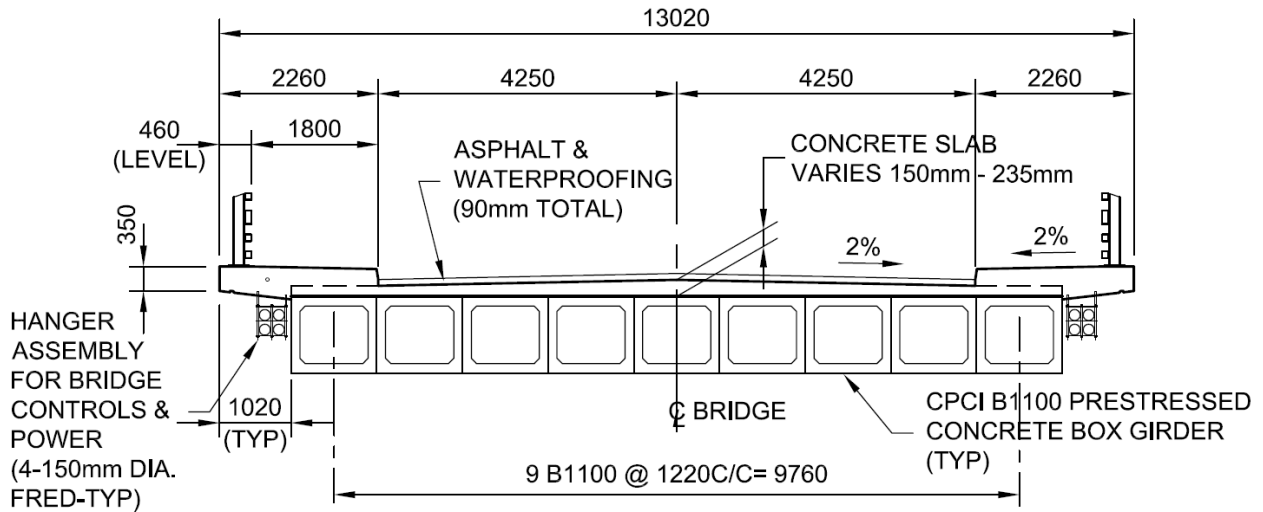


Figure 8 - Side by side precast girders approach span option

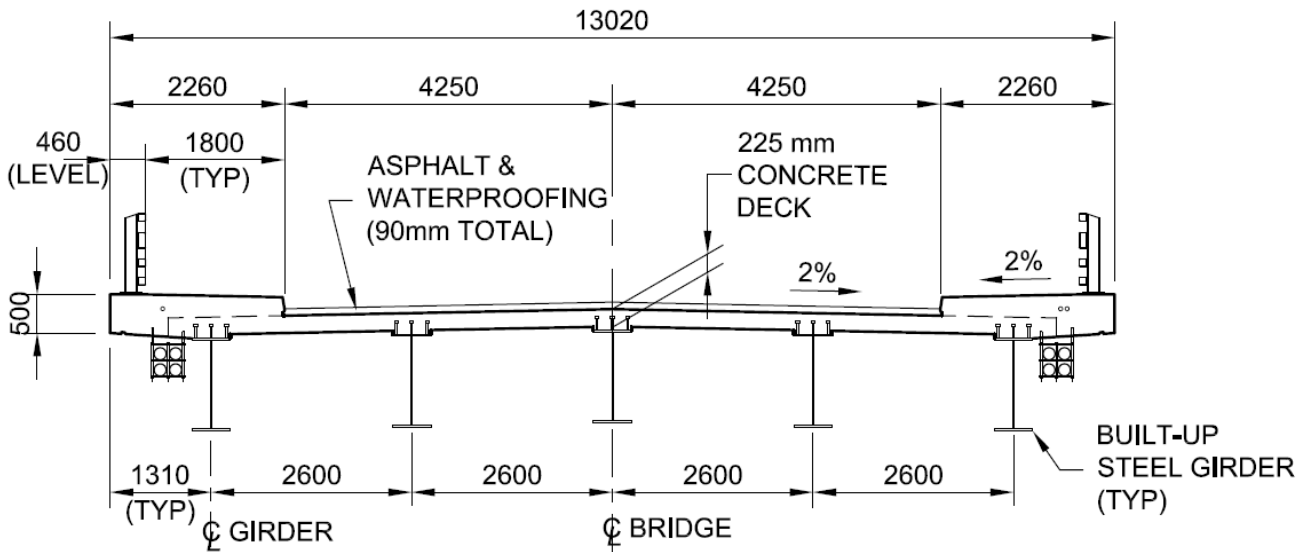


Figure 9 – Steel plate girders approach span option

The approach span girders were erected using a crawler crane from the trestle with the pair of exterior girders assembled complete with end and intermediate diaphragms.

Lift Span

An orthotropic steel deck as shown in Figure 10 was recommended for the lift span. However, for economical reasons a riveted open deck grating system shown in Figure 11 was selected by the owner.

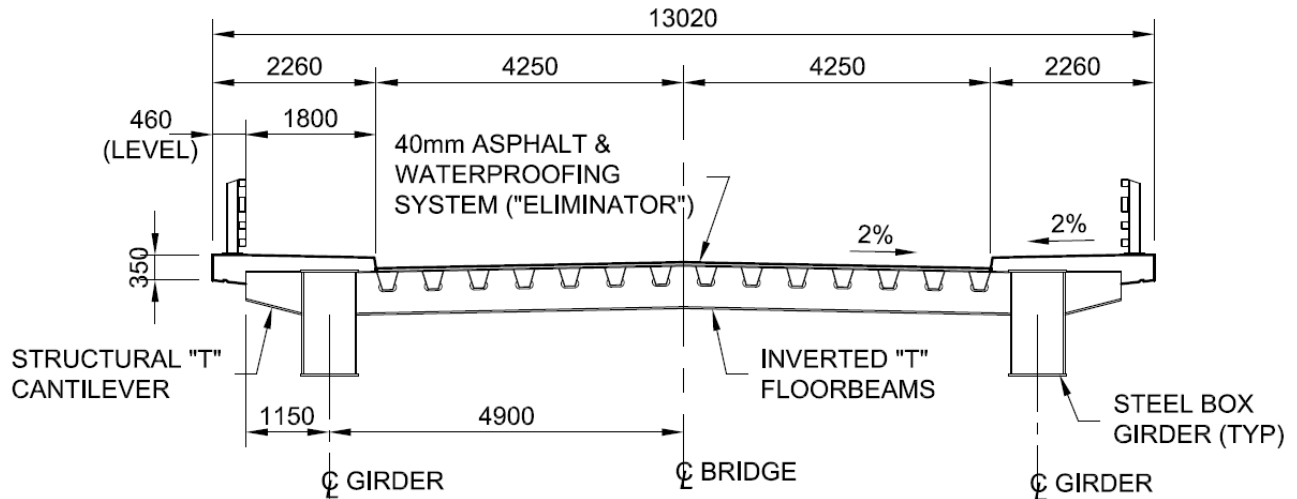


Figure 10 - Lift span cross-section - orthotropic steel deck option

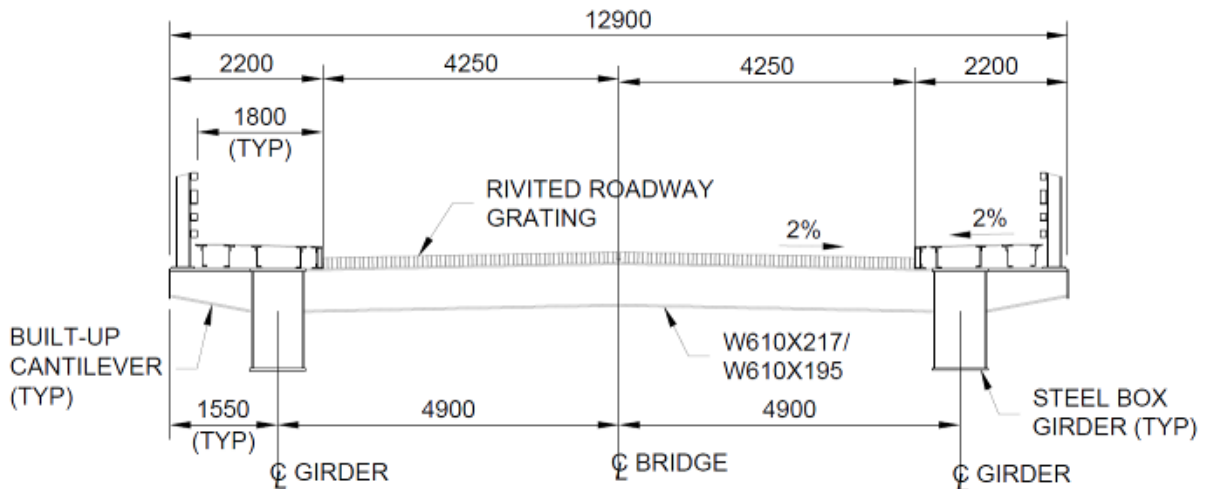


Figure 11 - Lift span cross-section - open deck grating option

The framing system is shown in Figure 12 and is comprised of two main longitudinal box girders with transverse floor beams in between supporting the deck. Two box beams (lift beams) support the longitudinal box girders at the ends of the lift span and are used to lift the span during operation with the use of 32 - 38mm diameter wire ropes. The ropes are supported on 3.0m sheaves and are connected to counterweights within the tower. A total of four counterweights, each weighing about 50 tonnes, are required to balance the lift span. The lift span was designed to travel vertically 18.44 m.



Figure 12 - Lift span framing system

Towers

The towers consist of a three-dimensional truss, shaped to mimic nautical lines as shown in Figure 13. Components of each tower are connected by a three-dimensional exoskeleton truss which houses the enclosure for the machinery. The tower structural members are comprised of closed circular hollow structural sections (HSS) 508 mm in diameter for the main tower legs and varying from 168 to 273 mm in diameter for the diagonal members. The tower design had to accommodate the counterweights, the counterweight and span guides as well as the access stairs.

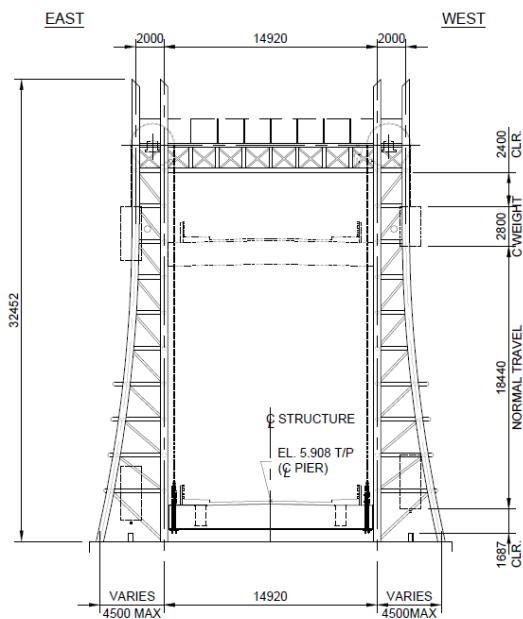


Figure 13 - Steel tubular towers

The counterweights for the lift span were housed inside the towers and are comprised of built-up steel boxes filled with steel plates. The machine rooms are accessible using stairs located within the towers. An aerial view of one of the towers showing the machine rooms is shown in Figure 14.



Figure 14 – Aerial tower view

KEY DESIGN FEATURES

The complexity of designing the Sir Ambrose Shea vertical lift bridge arose from the requirements to design an aesthetically pleasing structure celebrating the community's local heritage and yet provide a safe, reliable, and robust structure in a relatively harsh environment.

Key design features include:

Steel Design: Design of the tower's tubular connections is not covered in traditional literature or codes, and required extensive finite element models to confirm the capacity of these connections. This was complicated by the fact that numerous loading conditions had to be considered for a movable bridge in both the open and closed position. Figure 15 shows a section of the structural model used to analyze the tower tubular connections. Furthermore, bending the tower legs and braces to the required radii is unconventional and required detailed specifications and testing to ensure the steel tubular member properties were not adversely affected by the bending process.

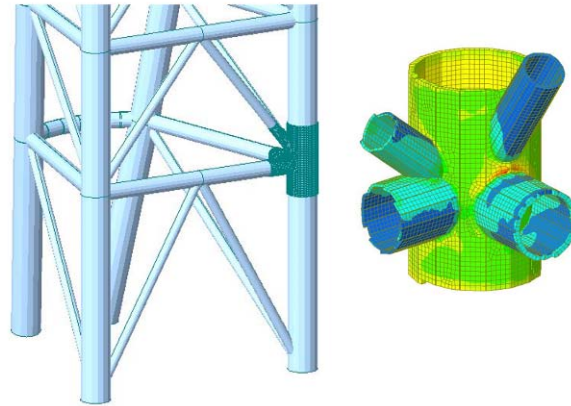


Figure 15 - Tower finite element model

Durability: Based on observations of the existing bridge’s performance, it was evident that the new bridge is located in a very harsh environmental condition. As such, special care was taken to select members, details, and systems that would be long lasting and enhance the durability of the structure. Such details included:

- sealed tubular structural sections;
- enclosures for mechanical machinery and components;
- positioning of mechanical and electrical components in machine rooms 25 m above the water level, minimizing salt spray and salty ocean water exposure;
- the use of galvanized rebar within the concrete elements;
- minimizing expansion joints by using semi-integral abutment details at the approach spans; and
- all structural steel components are metalized and received a two-coat paint system on top for extended corrosion protection in comparison with similar structures.

Utilities:

Existing power and communication lines on the old bridge were transferred to the new bridge using conduits hanging at the side of the approach spans, and up through the tower and into utility pipes specially designed between the towers.

The design paid attention to aesthetics both globally and in detail. The design integrated the mechanical, electrical, and HVAC systems into the structure with minimal impact from a visual perspective while minimizing maintenance requirements and improving overall system efficiency.

CONSTRUCTION CHALLENGES

Design had to consider transportation, erection, and long-term durability. This was achieved by designing the tower members with sealed and welded tubular pipe members. Flange bolted connections were designed to allow the Contractor to fabricate the towers in manageable segments to be transported and handled on site without the need for field welding. This option allowed the Contractor to fabricate each of the towers in ten segments, assemble them on site, and erect them using a crane from a temporary work trestle. Bolted connections minimized the erection duration of the towers significantly, to a few days in comparison to field welding which

would have required substantially more time and a significant window of good weather, which is hard to achieve at this project site (Figure 16).



Figure 16 - Tower bolted connections

Similarly, the lift span was designed with optional splices, which allowed the contractor to assemble the lift span on a barge from shore and move it into position (Figure 17). The centre span was a major challenge because it involved shutting down the shipping lane for several days to allow the erection of a 100-ton span using strand jacks to lift it into position.



Figure 17 - Moving lift span into position

A key challenge that is common to all movable bridges is the tight construction tolerances for the movable components and small deflection requirements for the structural members supporting the mechanical equipment. This required extensive multi-disciplinary coordination during all stages of design and construction.

High winds, changing tides, and fast current are the norm at the bridge site. The bridge is exposed to high winds due to its location in the open surrounded by hills. Although this was accounted for in the design to ensure that the structure is stable during all stages of construction, it added complexity to the construction and limited crane operations on site. Furthermore, the tide at the bridge site changes direction three times a day and the current can be up to 8 knots. This was encountered during the geotechnical investigation program at the pier locations during preliminary design and was a design consideration for the pier foundations.

CONCLUSIONS

Construction of the new bridge commenced in March 2013 and the bridge was opened to traffic on September 23, 2016 (Figure 18). Impacts to navigation were limited to a few days during the construction of the lift span and during commissioning of the new bridge. This is attributed to the design and detailing of the structure which allowed the construction of the substructure, the approach spans, and lift span towers without encroaching on the navigation channel.

The new bridge provides an aesthetically pleasing iconic structure with architecture sympathetic to the local culture and the region's tourism potential while being durable and reliable at the same time. It exceeds the imposed design requirements and provides a sustainable design with net positive effect from the natural, social, economic, and environmental perspective. The new landmark bridge should serve as a focal point in the community attracting visitors and new businesses to the area.

On-going collaboration and coordination during design and construction was extensive for the various multi-disciplinary interface components including: structural, electrical, mechanical, architectural, HVAC and geotechnical disciplines.

The bridge cost approximately \$47.7 million, which includes construction, engineering, demolition and removal of the existing bridge.



Figure 18 - Sir Ambrose Shea Vertical Bridge on opening day September 23, 2016

ACKNOWLEDGEMENT

The owner of the bridge is the Newfoundland and Labrador Department of Transportation and Works. Parsons is the Bridge Engineer; Barry Padolsky Associates Inc. is the Architect; Stafford Bandlow Engineering Inc. designed the electrical control and mechanical systems; GPY Associates carried out the HVAC design and Golder Associates provided geotechnical engineering services.

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