Design of a New Movable Transfer Bridge at the Souris Ferry Terminal

Ieva Paegle, Ph.D., P.Eng.
Senior Bridge Engineer
Parsons Inc.
Halifax, NS
Ieva.Paegle@parsons.com

Jean-Michel Lamy, ing., P.Eng., M.A.Sc.
Principal Bridge Engineer
Parsons Inc.
Québec City, QC
Jean-Michel.Lamy@parsons.com

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Wiss, Janney, Elstner Associates Inc., Baird & Associates, and GEMTEC Consulting Engineers and Scientists.

Abstract
Parsons, as prime consultant and lead structural designer with subconsultants Wiss, Janney, Elstner Associates (WJE), Baird, and GEMTEC, was selected to provide engineering services to Public Services and Procurement Canada to design a new Movable Transfer Bridge (MTB) at the Souris Ferry Terminal in Prince Edward Island. The replacement of the existing MTB was required as the MV Madeleine ferry was replaced in 2020 with the interim MV Madeleine II. Required modifications to accommodate MV Madeleine II and other potential vessels and to achieve maximum allowable gradient changes necessitated the complete replacement of the MTB. The project included the design of the new bridge, a control building, all the mechanical and electrical equipment related, and civil works.

Design challenges faced by the team during the preliminary design phase included suitable configurations capable of achieving the required vertical movement, setting the elevation of the level deck in comparison to the terminal elevation, and protecting the bridge elements against climatic hazards. As the new MTB will be in service for at least 40 years, predicting the future sea level rise due to climate change played a considerable role in selecting total vertical movement that needed to be accommodated and the abutment elevation. The increased range of movement, together with requirements for low clearance and long overhang vehicles to be able to board the ship in most tidal conditions were the main inputs on selecting the length of the MTB. An effective structural concept was proposed and selected by the client to improve the bridge serviceability and durability: it consisted of

the minimization of the number of pivot bearings, their raising on pedestals to improve their protection, and the consideration of a non-redundant structural system consisting of only two (2) main girders and one (1) lifting beam.

This paper will detail the challenges encountered during the design process, including the development of a live load model and load combinations adapted to project specifics, a reliability analysis to improve structural safety of the non-redundant structure and limitations of Canadian codes and standards (CSA S826:01[1] and S6:19[2]) for this specialized bridge type. Other challenges, such as the detailed design of a small box section lifting beam, the request from the client to galvanize all the structural steel, and the design of a simplified orthotropic steel deck will also be investigated.

Introduction

The existing Movable Transfer Bridge (MTB) in Prince Edward Island, built in 1998, provides year-round service to Cap-aux-Meules, Quebec. Owned by Transport Canada and operated by Coopérative de Transport Maritime et Aérien (CTMA), the terminal features a MTB that is 17 meters long and 7.5 meters wide, with a steel girder and grating deck, lifted by double hydraulic cylinders.

The replacement of the existing MTB was required as the MV Madeleine ferry was replaced in 2020 with the interim MV Madeleine II. Required modifications to accommodate MV Madeleine II bow and stern ramps, and other potential vessel ramps and have a 40-year design life. The project included the design of the new bridge, a control building, all the mechanical and electrical equipment related, and civil works as shown in Figure 1.

The vessel determines the type of MTB required. For the Madeleine II, the final connection facilitating the embarkation and disembarkation of vehicles and passengers is a ramp attached to the ship. Referred to as the "ship's ramp" in this paper, this ramp will land on the seaward end of the MTB and be supported by it during operations.

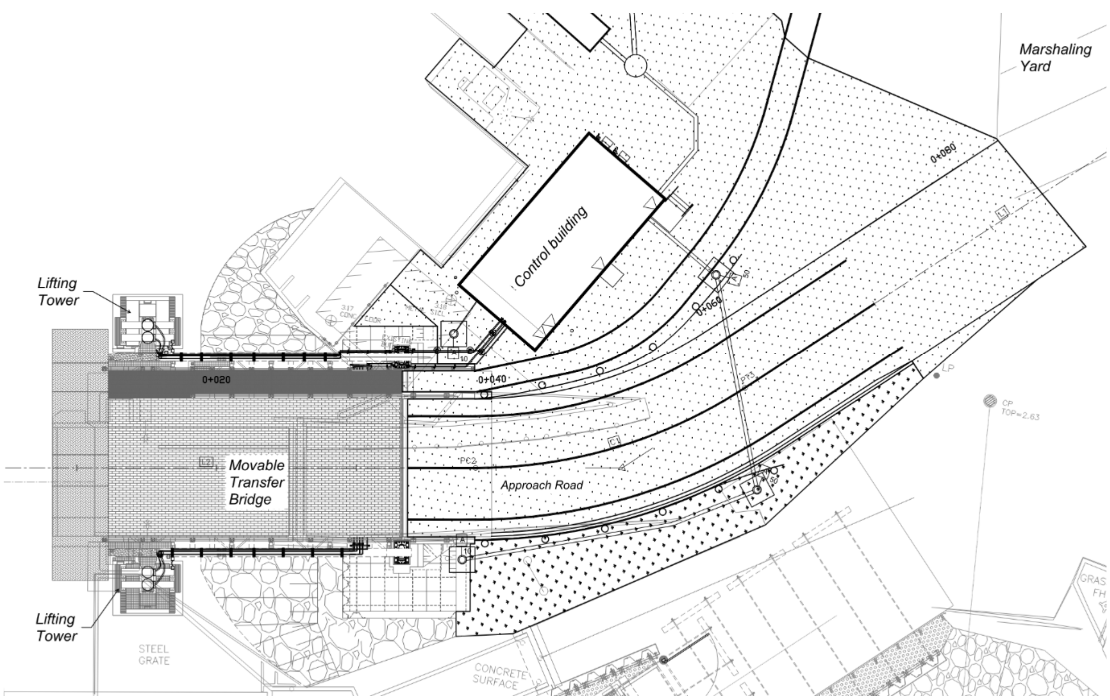


Figure 1: Site plan

Codes, Regulations and Standards

The design of the new MTB was carried out in accordance with CSA S826:01 (R2021), Ferry Boarding Facilities[1], and CSA S6:19, Canadian Highway Bridge Design Code (CHBDC)[2]. The ferry boarding facility code provides most of the requirements that are specific to such facilities. CSA S826:01[1] provides guidance on:

- the maximum slope transition requirements for vehicular access,
- the required protection for pedestrians using the MTB simultaneously with vehicles,
- additional dynamic impact loads on mechanical and structural components,
- special loads due to the ferry and bridge interface, etc.

Additionally, for the roadway design, vehicle parameters and geometry recommendations stated in the TAC Geometric Design Guide for Canadian Roads were applied. This guide provided essential criteria for roadway alignment, cross-section, and other geometric features to ensure safe and efficient movement of vehicles on the MTB.

Based on the criteria outlined in CSA S6:19[2], the following loads and load combinations were considered during the structural design of the MTB: dead loads, live loads, environmental loads such as wind and seismic forces, and dynamic loads from vehicular and pedestrian traffic.

In cases where Canadian standards CSA S826:01[1] and S6:19[2] did not provide enough guidance, recommendations from British Standard BS 6349-8:2007[3] were used. BS 6349-8 is a British standard that gives recommendations for the design of roll-on/roll-off (Ro-Ro) ramps, linkspans, and walkways used for the transfer of passengers and vehicles between shore and ship.

Finally, to enhance structural redundancy of the proposed concept, and as CSA S6:19 did not provide enough guidance, the design approach proposed in AASHTO LRFD Bridge Design Specifications, 9th Edition[4], was retained. To recalibrate the safety factors proposed in CSA S6:19, a reliability analysis was also conducted based on recommendations in CSA S408:11, Guidelines for the Development of Limit States Design Standards[5].

Functional Design Requirements

<u>Design Water Levels</u>

Limited water level data was available at the site, requiring data to be retrieved from nearby stations. The recommended design water levels at Souris were determined based on water level data from Pictou, NS and Charlottetown, PEI, with Pictou being the nearest station. However, interpretations of the extreme water levels based on this data vary between other sources, including report on Transportation Assets Risk Assessments (TARA) to Climate Change for Souris Ferry Terminal[6].

Using the recorded data, the determination of the high and low design water levels considers tidal effects and storm surges. There are two possible interpretations for these values.

- Interpretation 1 – A sum of the Large Tidal Range and Annual Surge event,
- Interpretation 2 – Annual Event – 1 year return period of a combined effect of large tidal range and storm surge.

It was decided that the design would be completed based on Interpretation 1 for the design high water level and Interpretation 2 for the design low water level. Table 1 summarizes the current recommended design water levels at the Souris terminal. Additionally, the MTB is designed for the predicted sea level rise of 0.6m.

Table 1: Souris Design Water Levels

	Interpretation 1 High Water Levels (m, CD*)	**Interpretation 2** Low Water Levels (m, CD)
Tidal	+1.76	+0.07
Storm Surge	+0.75	N.A.
Design Value	**+2.51**	**+0.07**
Sea Level Raise (SLR)	+0.6	0

* CD - Chart Datum

Design Vehicles

The MTB was designed to be accessed by most vehicles that are present on Canadian highways, including passenger cars, busses, camper vehicles with large rear wheel overhang, skirted semi tractor trailers, and low boy tractor trailers. In the past, the operator (CTMA) noted they have had issues with boarding low boy trailers and long overhang campers; these vehicles were not able to clear slope transitions at high and low water levels. Therefore, the design included additional checks to make sure that these vehicles will be able to board and disembark the ferry.

Loading scenarios were checked for several vehicles, particularly those flagged by CTMA as having clearance issues when loading. Vertical clearance at slope transitions for multiple grade differentials was modelled in AutoTURN using data from the Transportation Association of Canada (TAC) Geometric Design Guide for Canadian Roads (2017)[7], National Cooperative Highway Research Program (NCHRP) Report 659 – Guide for the Geometric Design of Driveways[8] and the California Department of Transportation – Highway Design Manual 7th Edition (CAL Trans 2019)[9]. Figure 2 shows an example of the vertical clearance checks performed for the two vehicles. Locations along the drive path (shown in blue) where the path turns red are regions where a probable conflict between the vehicle and the drive surface is detected. The grade difference that the vehicles were able to pass was determined by making sure that no conflicts occur.

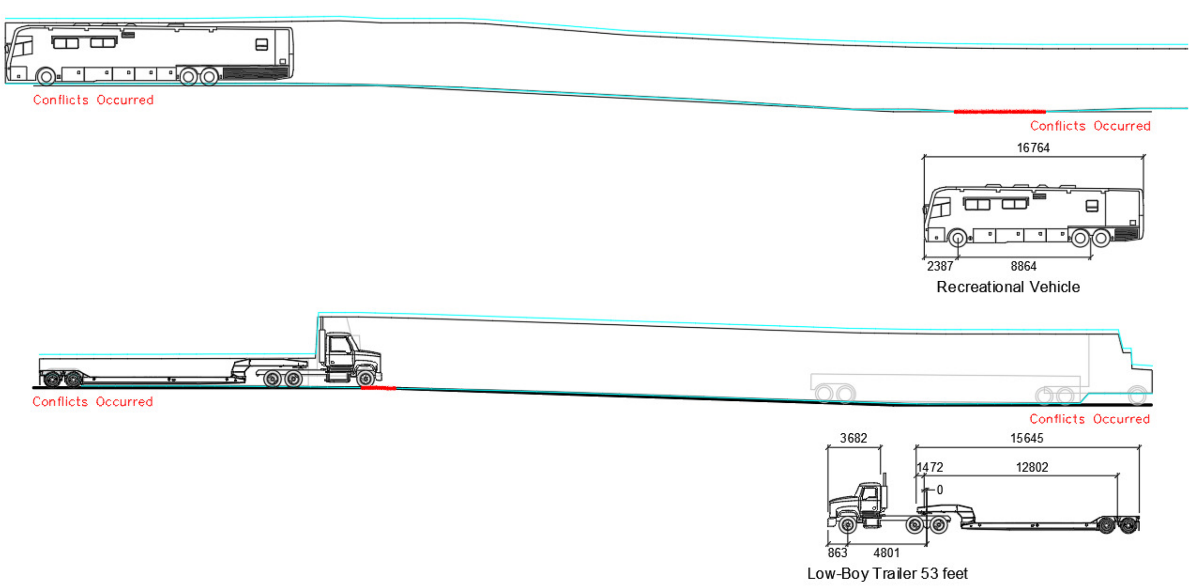


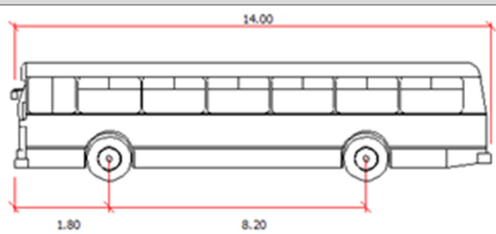
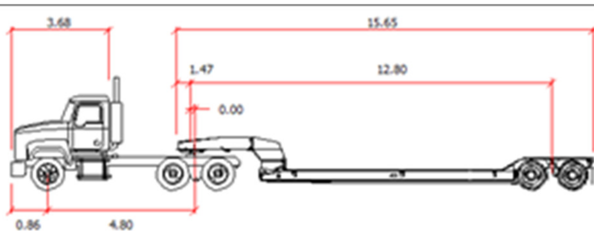
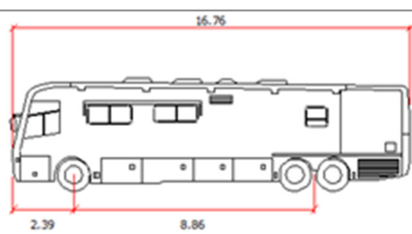
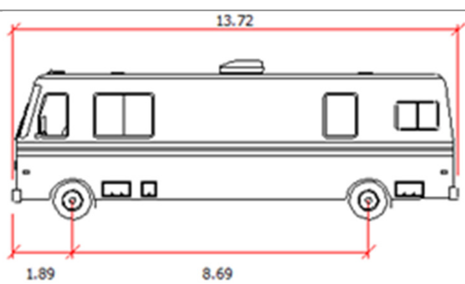
Figure 2: Examples of Vehicle Vertical Clearance Checks

The vehicles assessed, and the resulting maximum allowable grade differentials are summarized in Table 2, where grade differential is defined as the change in slope between successive planes on the structure.

In conformance with the recommended maximum grade differential in CSA S826:01[1] Part 1 Appendix A, the ramp and MTB do not exceed a grade differential of 6%. As a result, vehicle clearance allowances were not checked for grade differentials over 6%.

The new approach road was designed with a maximum grade differential of 2.5% that is functional with all the vehicles listed in Table 2. The most constraining vehicles for vertical clearance were the low boy trailer and a Class A recreational vehicle with a long back overhang. Still, both achieved a minimum vertical clearance of 30 mm.

Table 2: Vehicle Clearance Checks

Vehicle Type	Vehicle Schematic	Maximum Allowable Grade Differential	Comments
I-Bus (TAC 2017)		Over 6%	No anticipated issues with loading this type of vehicle.
Low Boy Trailer (NCHRP 659 2010)		3.9%	This vehicle is relatively rare but did dictate the approach ramp profile design.
Class A Camper – Long Back Overhang (NCHRP 659 2010)		3.8%	This vehicle has a long (5.5m) back overhang with 0.2m ground clearance.
MH-45 (CAL Trans 2019)		Over 6%	No anticipated issues with loading this type of vehicle.

MTB Length and Abutment Elevation

To determine the length of the MTB and the elevation of the top of deck at the abutment, various factors were considered, including:

- Low water level at operations, 0.07 m, CD,
- High water level at operations, 2.51 m, CD,
- Predicted sea level rise (SLR),
- Light ship draught,
- Heavy ship draught,
- Car deck elevation in the ship,
- Bow ramp length and movement limits,
- Stern ramp length and movement limits,
- Max grade differential for vehicle access,
- Site/marshaling yard elevation.

To keep the MTB as short as possible, the ideal top-of-deck elevation at the abutment would be at the midpoint of the MTB's operational range, allowing for equal movement up and down, for example, +/- 4.7%. However, due to the marshaling yard elevations and the potential impact on the site from a possibly longer approach road needed to reach that elevation, the top-of-deck elevation was slightly lowered compared to the ideal position.
After considering all the input parameters, it was decided that the top-of-deck elevation at the abutment would be set at +4.00 m, CD. The required length of the MTB was determined to be 25 m, with a normal operational range of +5.2% to -4.4%. Figure 3 provides an elevation view of the MTB, illustrating the maximum range of movement, which exceeds the operational range.

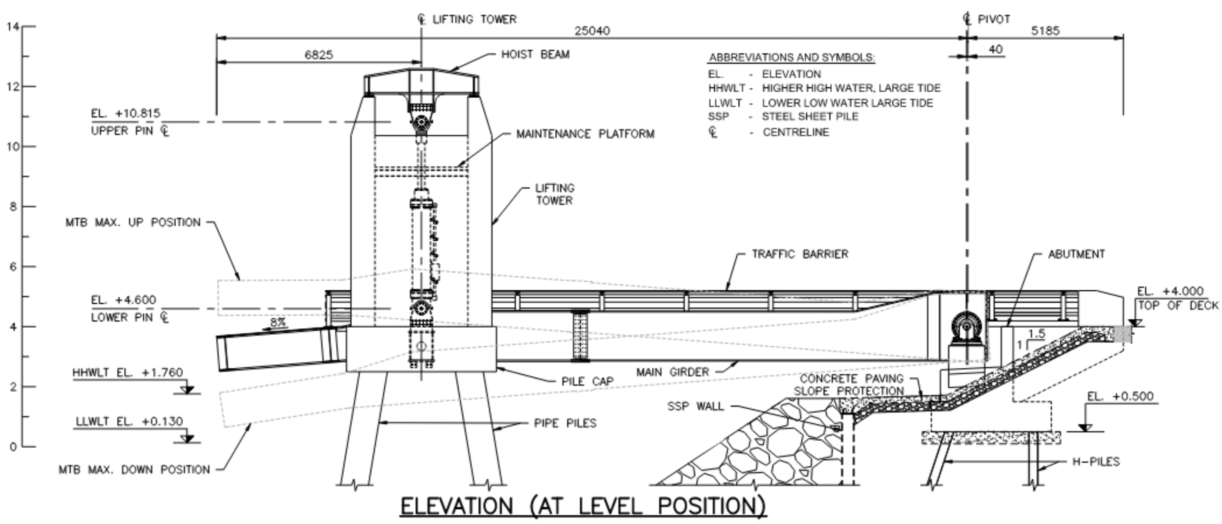


Figure 3: Elevation of MTB

Special Requirement – MTB Movement with Live Load

For the MTB with a maximum grade differential of +5.2/- 4.4% with the ship's ramp and/or approach road, most vehicles can maneuver this change in grade at all tide levels. This was considered the normal loading position. However, the low boy trailer and Class A recreational vehicle with a long back overhang cannot clear this grade differential; they were considered special cases. The loading of these vehicles will need to occur in two stages, as shown in Figure 4 with an adjustment of the MTB while the vehicle is on the MTB. In the first stage, the MTB must be positioned within the grade limitations specific to the special case vehicle, allowing the vehicle to drive onto the MTB. In the second stage, the MTB will be adjusted to a loading angle that aligns with the ship's ramp, enabling the vehicle to enter the ship.

Due to a two-stage loading and to provide slight additional movement, the operational range of the MTB was increased to +/-7.5% as shown in Figure 5.

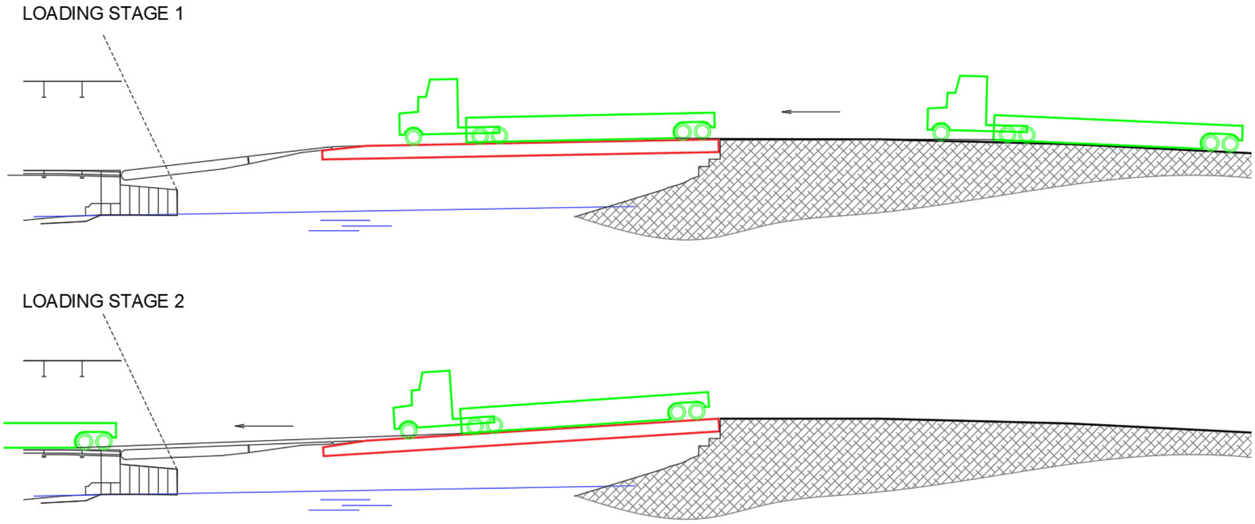


Figure 4: Special Case Loading Configuration

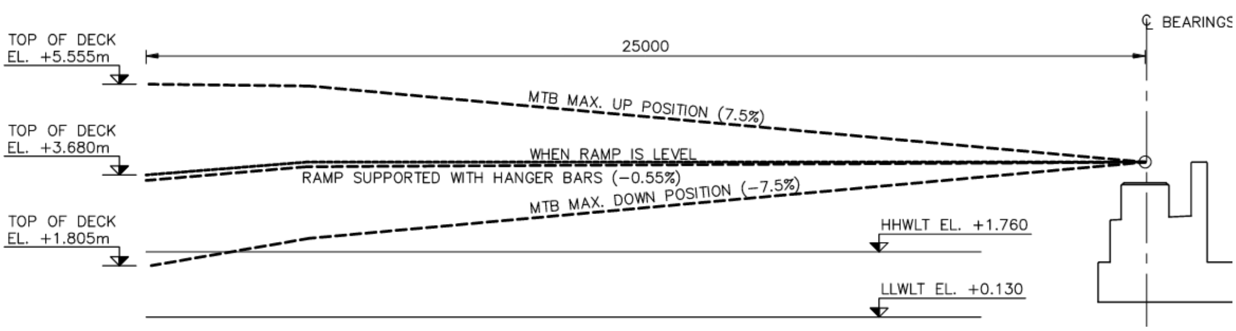


Figure 5: MTB operation range

Plan to Meet Functional Requirements

The new bridge ramp was required to be able to support both the bow and stern ramps of the MV Madeleine II. As per project requirements, the new MTB also needed to accommodate two 3.7 m lanes and a pedestrian walkway with a width of 1.5 m.

The CSA S826:01[1] set a requirement for at least a 1 m overlap between the bridge's seaward end and the ship's ramp landing beam. The landing beam is the element that transfers the loads from the ship's ramp to the MTB. For operational safety, the client required at least a 1 m buffer zone on either side of the ramp. To fulfill all these requirements, the width of the seaward end of the MTB was significantly increased compared to the main part of the MTB, see Figure 6. Additionally, the seaward end of the MTB was sloped to receive the ship's ramp and provide a smooth transition between the ship's ramp and the MTB.

As this ferry provides the main connection from mainland Canada to Magdalen Islands, QC and serves many trucks, trailers, and tractor trailers, the client expressed a need for the bridge to be wider than the minimum requirement of two 3.7 m wide lanes to ease the maneuverability of these large vehicles. Therefore, a decision was made to widen the main part of the bridge to nearly 10 m. According to CSA S6:19[2], this allowed for the maximum width of the bridge while considering not more than two lanes of traffic.

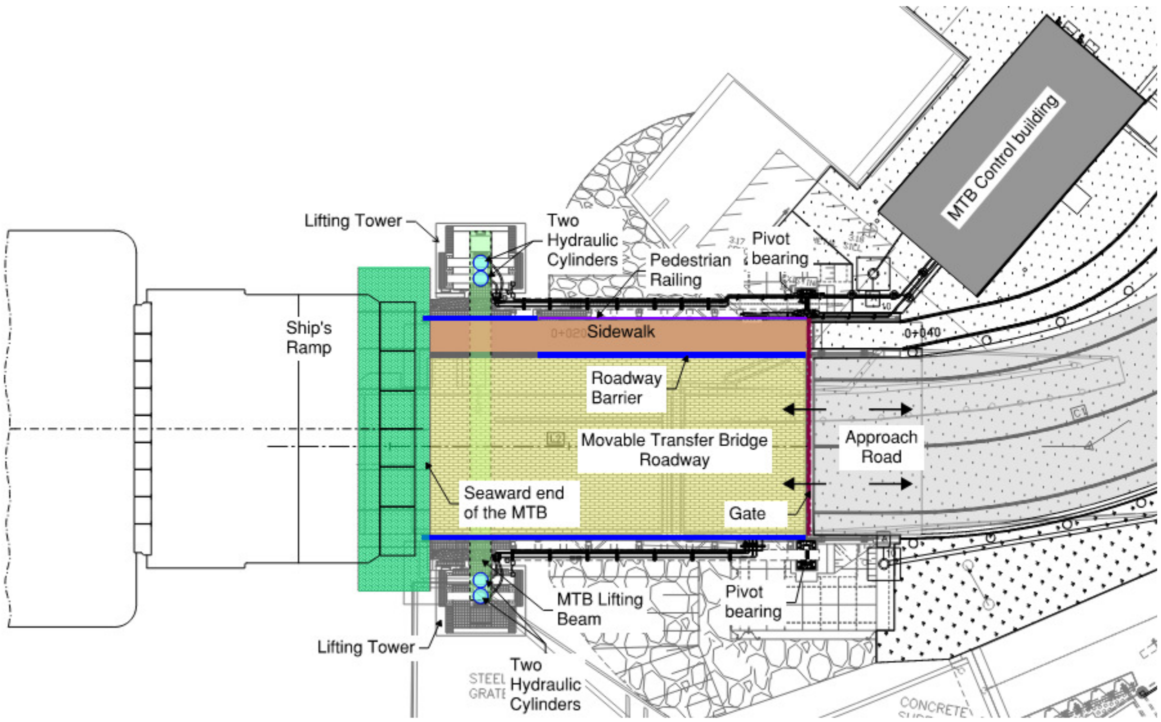


Figure 6: Functional plan of the MTB

Barrier System

The MTB was designed to accommodate both vehicles and pedestrians, with a protected walkway for pedestrians extending from the beginning of the MTB to the lifting tower. Beyond this point, pedestrians would transfer onto the roadway and traverse it until boarding the ferry. Since cyclists are required to walk their bicycles, a cyclist-height barrier was deemed unnecessary.

CSA 826:01 Part 1, Clause 5.8, mandates a minimum barrier height of 1.2 m for pedestrian protection; however, CSA S826:01[1] does not specify additional requirements for roadway barriers. Considering that CSA S826:01[1] was last updated before crash-tested barriers became mandatory for all highway bridges according to CSA S6, the requirements from CSA S6:19[2] were adapted for this project. Based on traffic data, vessel data, and an assumed ferry schedule, a barrier test level requirement of TL-2 was determined using Table 12.5 of CSA S6:19[2]. Additionally, for the comfort of truck drivers and maintenance personnel, the client requested all barriers to be 1.2 meters in height. Since no TL-2 crash-tested barriers are available at this height and connected to steel superstructure, it was decided to use a modified TL-4 barrier. Modifications to the TL-4 crash-tested barrier were made to increase its height as shown in Figure 7, and to avoid overdesign, the connections were designed using TL-2 barrier forces.

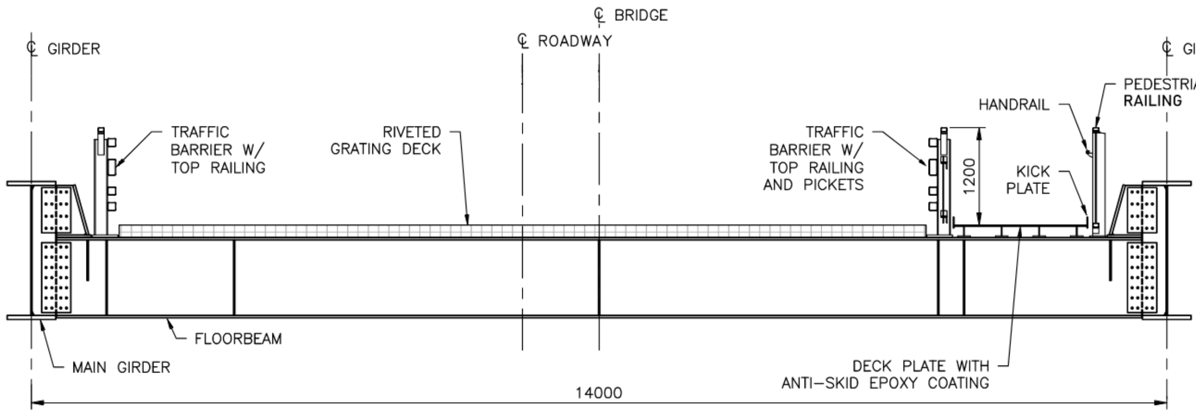


Figure 7: Functional cross-section of the MTB

Corrosion Protection of the Bridge

To minimize the need for maintenance repairs during the service life of the MTB, all structural steel was hot-dipped galvanized for corrosion protection. This requirement presented some challenges in the design, as the maximum size and weight of any individual structural element were constrained by the galvanizing shop's capacities, specifically the kettle dimensions and corresponding maximum crane capacities. Components larger than these capacities had to be constructed from individual hot-dip galvanized elements bolted connections. The maximum weight and size requirements for each individual element strongly influenced design decisions.

Lifting System

The CSA S826:01[1] differentiates transfer bridges into two categories: Condition I, which includes transfer bridges that are supported by a system distinct from the lifting system during operations, and Condition II, where the lifting system ensures the support of the movable transfer bridge during operation, including the support of the fully loaded MTB with live load. In the case of Condition II, a second physical connection must be provided to support all loads in case of a failure of the primary lifting system.

Since the Souris MTB lifting system needed to support all loads during operations, it was classified as a Condition II bridge. Additionally, the client and the operator preferred to have a hydraulic cylinder lifting system instead of a cable lifting system. Therefore, the primary lifting system for the movable transfer bridge consisted of a lifting beam connected to hydraulic cylinders supported by lifting towers. A second pair of hydraulic cylinders were designed and installed parallel to the primary cylinders to support all loads in case of a failure of the primary lifting system.

The design included considerations for mechanical and electrical systems to withstand the harsh winter environment. Where possible, components were located to provide protection from the weather or designed specifically for harsh environments to minimize the maintenance efforts required for winterization.

Girders and Bearings

In this non-traditional bridge design, the selection of girder options was considered in conjunction with the bearings. The bearings at the abutment had to accommodate the full rotational movement of the MTB. To facilitate rotation at the abutment, the bearings feature a full pin connection, allowing complete rotational freedom along the axis parallel to the abutment's length. These bearing pins could have been positioned beneath the girder's bottom flange (Figure 8a), within the girder web (Figure 8b), or at deck level (Figure 8c). Placing the bearing hinge below the deck level results in horizontal and vertical movement at the deck level due to rotation, necessitating the installation of a cover plate at the abutment to ensure smooth driving. Consultations with the operator revealed that these cover plates often require additional maintenance and may be damaged by low-clearance vehicles. Consequently, a solution minimizing vertical and horizontal gap changes at the abutment was preferred, as depicted in Figure 8c.

Various girder concepts were evaluated, including a traditional design with five girders and a concept with closely spaced girders to directly support an open steel grating deck. The advantages of these options include the ability to use smaller girders and a more redundant structural system. However, using more than two girders would render the bearing option shown in Figure 8c impossible, as the bearings would need to be placed under the roadway. Additionally, mechanical engineers recommended limiting the number of bearings to two to prevent potential misalignment and subsequent wear.

After evaluating all concepts, the chosen solution involves two girders placed outside the roadway, with bearings aligned with the top of the deck at the abutment.

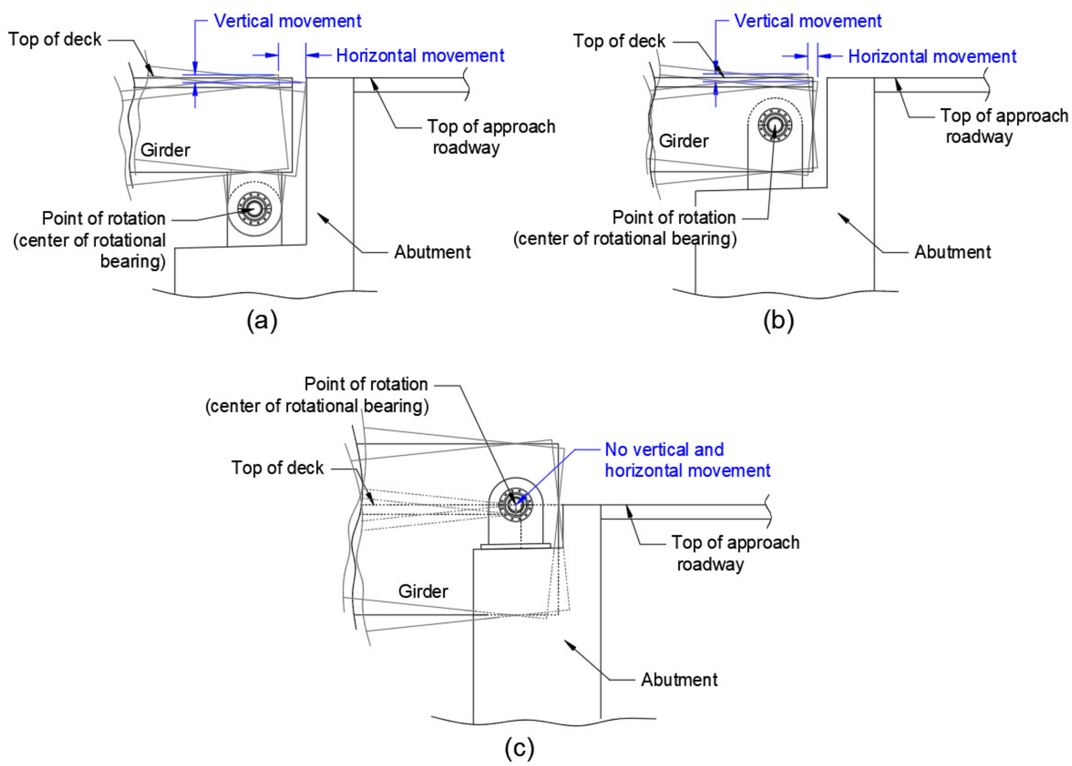


Figure 8: Rotational bearing option at abutment; (a) bearing under the girder, (b) bearing in girder web under the deck, (c) bearing at the deck level.

Loads and Load Combinations

As outlined in the Code, Regulations and Standards section, the loads and load combinations for the structural design were developed in accordance with CSA S826:01[1] and CSA S6:19[2]. This section elaborates on the specific load characteristics of this unique structure.

Permanent Loads

A key aspect of the permanent loads is the inclusion of the ship ramp's self weight in the design process. The ship's ramp, which lands on the MTB's seaward end, weighs 415 kN.

Live Loads

In addition to the CSA S6's CL-625 load model, which represents normal highway traffic on Canadian highways, special loads were devised to better reflect the local traffic on the MTB.

Firstly, the Souris Terminal uses special shunt trucks (Figure 9) to maneuver truck trailers between the terminal and the ferry. These trucks are relatively short to facilitate maneuvering. Discussions with the shunt truck manufacturer revealed that most of the trailer load is transferred to the rear axle, potentially resulting in non-standard axle loads compared to highway traffic allowance. Consequently, a "special load" model, as defined in CSA S6:19[2], was developed to account for these characteristics and is presented in Figure 10.

Secondly, it is common practice to load and unload trucks onto the ferry sequentially. This practice makes the CSA S6:19[2] lane load model potentially unconservative compared to two heavy trucks traveling consecutively. This issue was considered during the design of the existing MTB. The structural team developed two additional "special load" models: one representing two CL-625 trucks with a 4-meter separation, and another representing two shunt trucks with a 4-meter separation.

Thirdly, the dynamic load allowance (DLA) for the MTB followed CSA S826:01[1] design requirements. CSA S826:01[1] recommends higher DLAs for MTBs than those in CSA S6:19[2]. It requires a DLA that includes the CSA S6:19[2] allowance plus 0.10. Additionally, CSA S826:01[1] assumes a 0.10 DLA on dead loads. In practice, these design requirements effectively double the dynamic loads on the MTB compared to CSA S6:19[2] values.

Finally, regarding transverse live load distribution on the MTB, CSA S826:01[1] specifies a particular load distribution for ramps with only two main girders. In such cases, the load shall be distributed as shown in Figure 11.

Figure 9: Shunt truck in service at the Terminal, (Source: https://www.kalmarottawa.com/terminal-tractors/ottawa-t2-4x2-offroad)

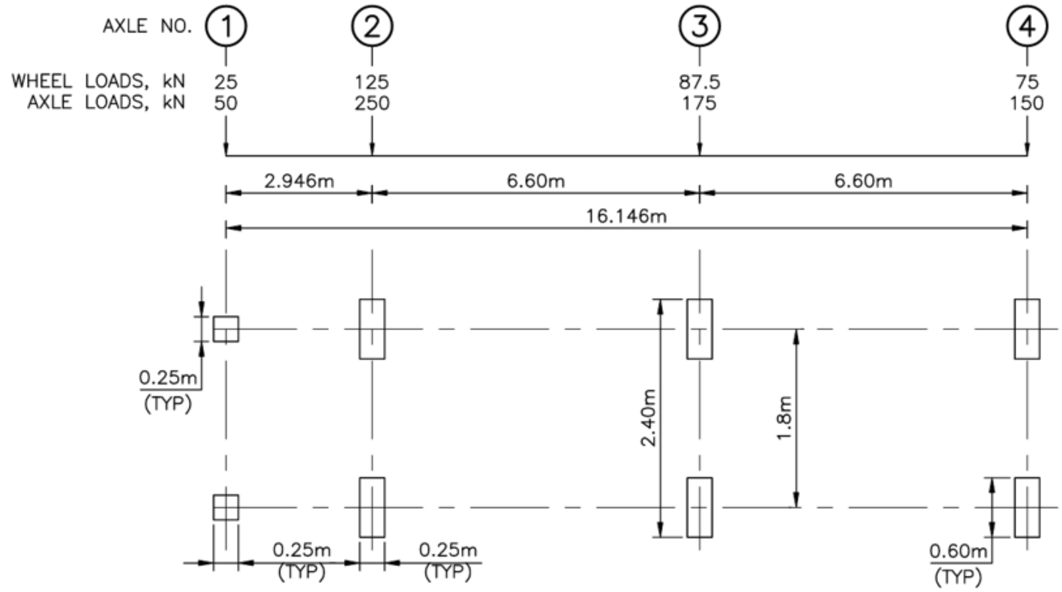


Figure 10: Proposed "Special Load" Model

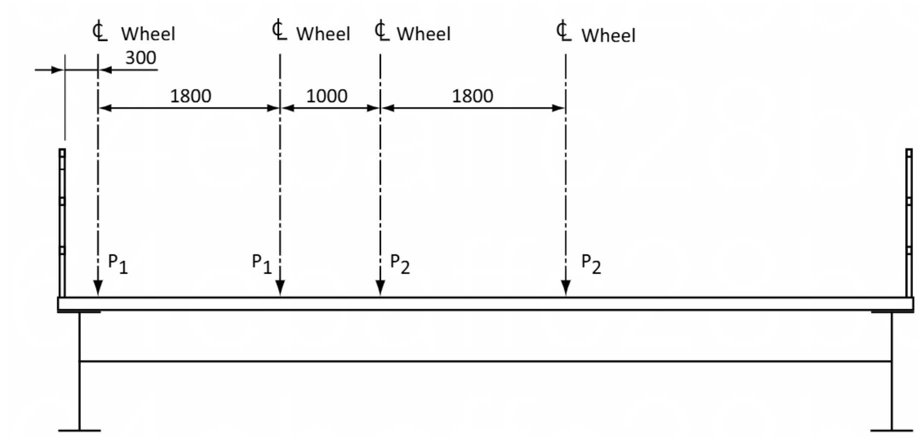


Figure 11: Transverse live load distribution (Source: CSA S826:01[1] Part 1, Figure 3)

Friction from Ship's Ramp

The ship's ramp can exert significant horizontal loads (transverse and longitudinal loads applied at the MTB deck level) due to vessel movement that are explained in Figure 12. This load is caused by friction between the ship's ramp and the MTB. CSA S826:01[1] requires consideration of this load in the structural design but does not specify a friction coefficient. After reviewing the literature, the design team adopted recommendations from BS 6349-8:2007[3], suggesting a friction coefficient of 0.30 for this application. The applicability of this load type for different load combinations was based on this standard, applying it for SLS and ULS combinations not concurrent with exceptional loads, such as ice impact or wave action.

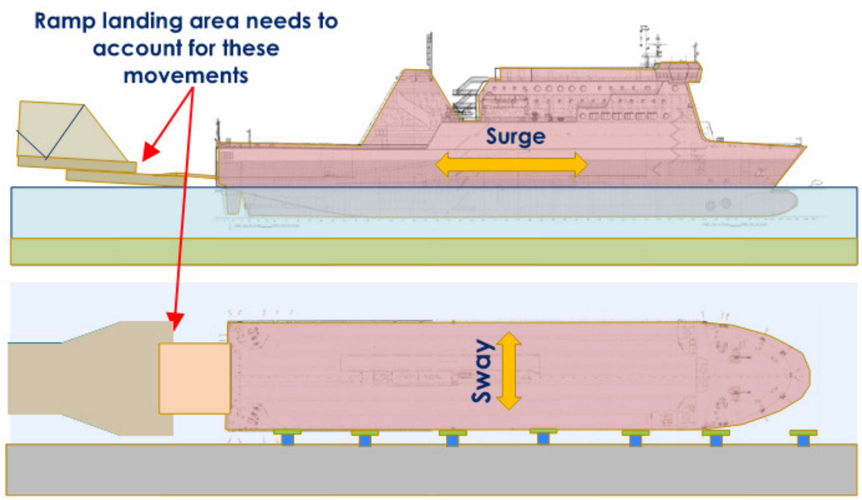


Figure 12: Vessel Motions – Translation (Source: PIANC, The Design of Terminals for Roro and Ropax Vessels, MarCom Working Group Report No 167-2023)

Wave Loads Applied to the MTB

During extreme storm events, wave action may push the MTB upward. To determine load intensity, our coastal engineering subconsultant, Baird, developed a refined time-history model to assess wave-structure interaction, the visual results of the model are presented in Figure 13. Two loading conditions were studied:

- Case 1: No ice accretion assumed in the open grating deck,
- Case 2: Ice accretion through the grating deck, assumed as a closed deck.

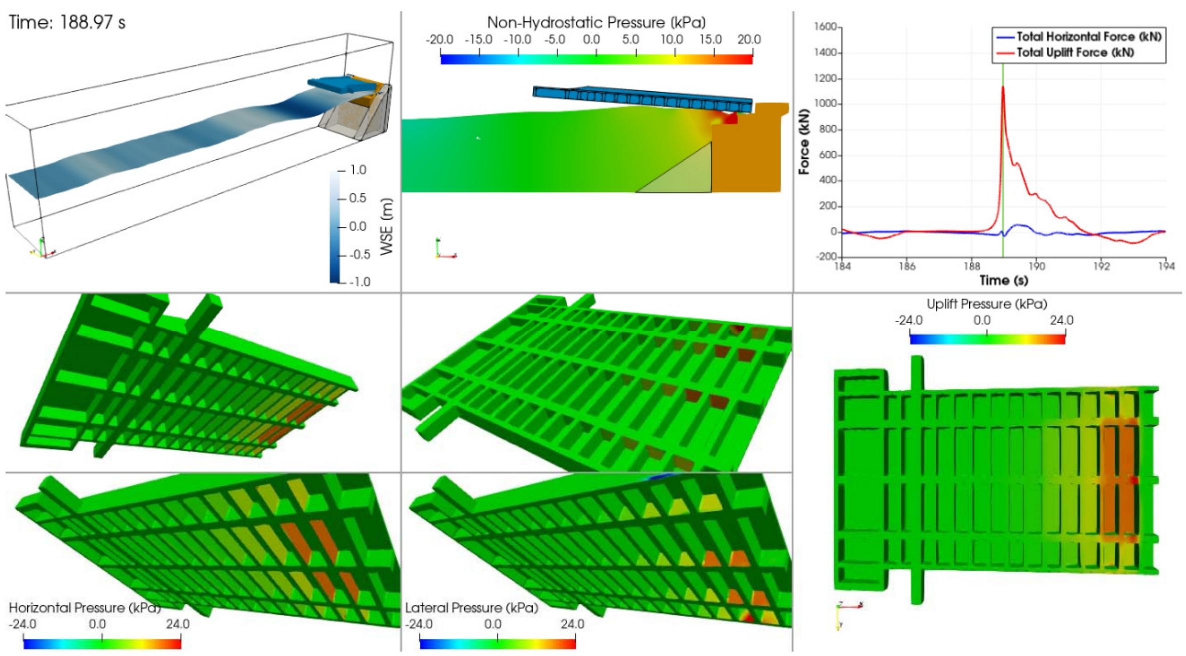


Figure 13: Time-history wave-structure interaction model

Initial results indicated extremely high loads under Case 2. Further discussions with the client confirmed the MTB would be raised during storm events. This design optimization, in collaboration with the bridge operator, significantly reduced demands, resulting in a more cost-effective solution.

Accidental Cylinder Failure

Consultations with our mechanical-electrical subconsultant, WJE, highlighted the need to consider an additional structural load case in the event of a sudden accidental loss of hydraulic pressure in one cylinder supporting the loaded MTB. Detailed studies defined the load condition, and the dynamic load allowance associated with the sudden load transfer from one cylinder to the adjacent one. This additional load case increased the MTB safety for users.

Load Combinations

Incorporating all previous loads and load conditions led to the development of site-specific load combinations. These combinations were initially based on CSA S6:19[2] design requirements, with additional loads integrated into the relevant load combinations. Load factors were derived based on other design codes and engineering judgement. Two exceptional load combinations were developed to account for wave action and accidental cylinder failure.

Analysis

To determine demands on MTB structural members, a 2D grillage model was created in Midas, as shown in Figure 14. The ship's ramp was modelled as an independent span supported on the MTB, conservatively assumed to land at the tip of the MTB seaward end. To address uncertainties in transverse load distribution, the ship's ramp was modelled with infinitely stiff elements.

Compression-only elements were used to model the connection between the ship's ramp and the MTB. Due to the non-linear nature of these connections, standard moving load analysis could not be applied concurrently with these supports. Additional design considerations were necessary to accurately analyze load effects from vehicular loads.

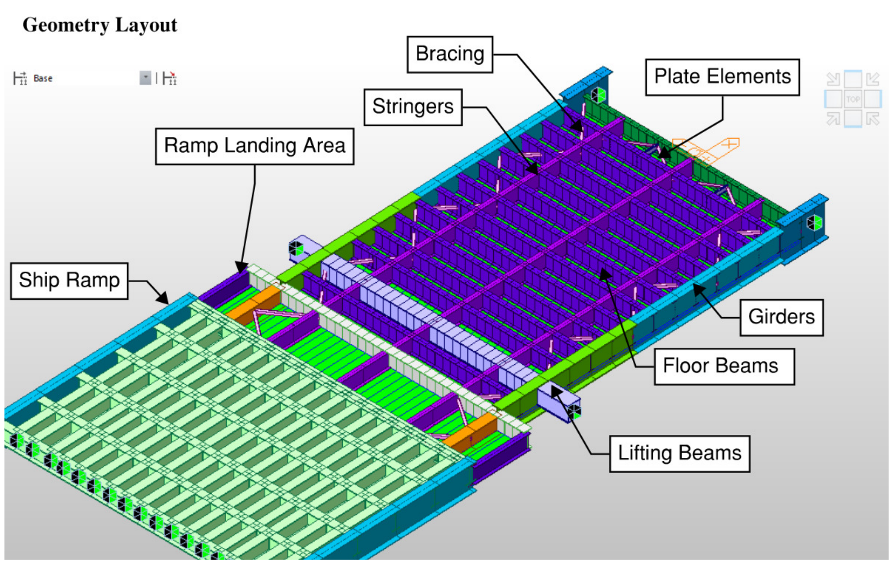


Figure 14: MTB Structural Model

Redundancy Analysis

Since the structural framing system features only one lifting beam and two main girders, the MTB is considered a single-load-path structure, meaning the failure of a single structural component or connection could lead to a collapse. CSA S6:19[2] provides limited design guidance for such a structure, categorizing structural steel members as Fracture Critical Members (FCM), which primarily impacts fabrication and inspection processes.

To address this issue and enhance structural redundancy, the design team adopted the approach from the AASHTO LRFD Bridge Design Specifications, 9th Edition[4]. This involved increasing safety by adjusting the design safety factors outlined in CSA S6:19[2] and designing critical members for infinite fatigue life. Although designing for infinite fatigue life is not officially part of the CSA S6:19[2] standard, it can be extrapolated. However, modifying the design safety factors to ensure adequate structural safety is more complex.

Reliability Analysis

To establish the appropriate safety factors, the design team conducted a reliability analysis based on CSA S408:11[5], Guidelines for the development of limit states design standards, Annex B. This analysis helped to determine the resistance safety factor to be used in the design process. Firstly, CSA S408:11 was instrumental in defining the relevant reliability index β, for a non-redundant structure. This standard, along with CSA S6:19[2], indicated the need to increase the reliability index by 0.50 compared to the one assumed for normal bridges, not classified as single-load-path structures. Thus, the reliability index is set at 3.75 annually, but for this non-redundant MTB, a value of 4.25 was chosen. Secondly, a reliability analysis using an approximate method showed the necessity to reduce the resistance safety factors ϕ, by 5% to enhance structural safety with the proposed reliability index. This reduction was incorporated into the final design of all FCMs.

Final Design

Abutment Design

The proposed abutment features a standard concrete wall supported by a pile cap, utilizing standard driven H-piles. To enhance scour protection, a steel sheet pile was added in front of the abutment, complemented by an armour stone revetment on the slope facing the ocean. Additionally, concrete slope paving will be installed around the abutment.

Lifting Tower Design

The lifting towers comprise a U-shaped concrete structure, a pile cap, and four battered drilled piles. Hoist beams are positioned above the tower to support the cylinders. The primary function of the lifting tower is to support the lifting cylinders, which support and adjust the MTB at the desired inclination. Various challenges were encountered during the design process as detailed below:

Location

For different reasons, the new lifting towers need to be situated approximately where the existing ones are located. Since the towers rest on pipe piles, it was crucial to find a new pile configuration to avoid conflicts with the existing piles. The final tower location was chosen to minimize this risk while not excessively increasing the cantilever portion of the MTB.

Loads

In addition to the tower's self weight and gravity loads from the MTB, significant lateral loads are also applied to the towers, including:

- All the lateral loads originating from the MTB. The lifting towers function as a transverse buttress, supporting the loads transmitted via the lifting beam, with the primary transverse load being the friction from the ship's ramp.

- Various ice load conditions assumed on the towers. Our subconsultant, Baird, analyzed different loading scenarios, including horizontal and vertical ice loads on a single pile, a pile cluster, and the pile cap.

Piles

Battered drilled pipe piles are frequently used in marine projects and were selected as the most suitable technical solution for this application. The analysis revealed that unbalanced loading conditions could occur on the piles due to ice impacts on the pile cap. This situation led to significant axial tension in some piles and high axial compression in others. To mitigate the effects of this imbalance and avoid conflicts with existing piles in the bedrock, the piles are inclined at a 1:6 ratio. Additionally, to handle the considerable transverse loads and enhance the lateral stiffness of the tower, pile heads were assumed with a fixed head condition. This necessitated the development of a pile head, incorporating a combination of pile embedment in the pile cap, the insertion of shear studs on the steel pipe, and additional reinforcement.

Pile Cap and Tower

The pile cap and the tower are designed in a U-shape to accommodate the lifting cylinder. Given that the proposed tower is 10 m tall, stairs and platforms have been included to facilitate inspection and maintenance. The cylinders are supported by hoist beams positioned above the tower. To enhance constructability and manage construction tolerances, the hoist beam anchors will be placed in grout cans, which will be filled with grout after the final installation. This approach offers the contractor flexibility to ensure the cylinders are installed vertically.

Superstructure Design

Main Framing Plan

Figure 15 presents the structural framing consisting of two main girders (in red), one lifting beam (in blue) and various floorbeam types (in yellow, orange and green). The floorbeams support various deck types and transmit the loads to the main girders. The lifting beam also acts as a floorbeam between the two main girders.

Main Girders

The main girders feature a complex geometry, as shown in Figure 16. During the preliminary design, it was determined that the optimal depth for the main girders would be 1.6 m, which was applied to most of their length. At the pivot bearing location, the girders are 2.2 m deep to accommodate the large bearing housing. The seaward end of the girders required a reduced depth because the deck rests directly on them. This end is also inclined at an 8% slope to optimize the roadway profile, as the ship’s ramp includes an inclined apron resting on the deck at this point. Additionally, since the lifting beam is integral to the main girders, special attention was needed for the splice between these elements.

Lifting Beam

During the design process, it was determined that the torsional demands were significantly high when the ramp was inclined. This finding supported the decision to use a closed box-section for the lifting beam. To optimize the ramp depth and improve water protection, the lifting beam was integrated with the rest of the structural framing, as illustrated in Figure 17. This decision limited the lifting beam depth to 1 m, making the closed section inaccessible for internal inspection by bridge inspectors. To address concerns related to constructability and inspection, access holes were incorporated along the beam. This will allow bridge inspectors to examine the interior of the lifting beam using a camera.

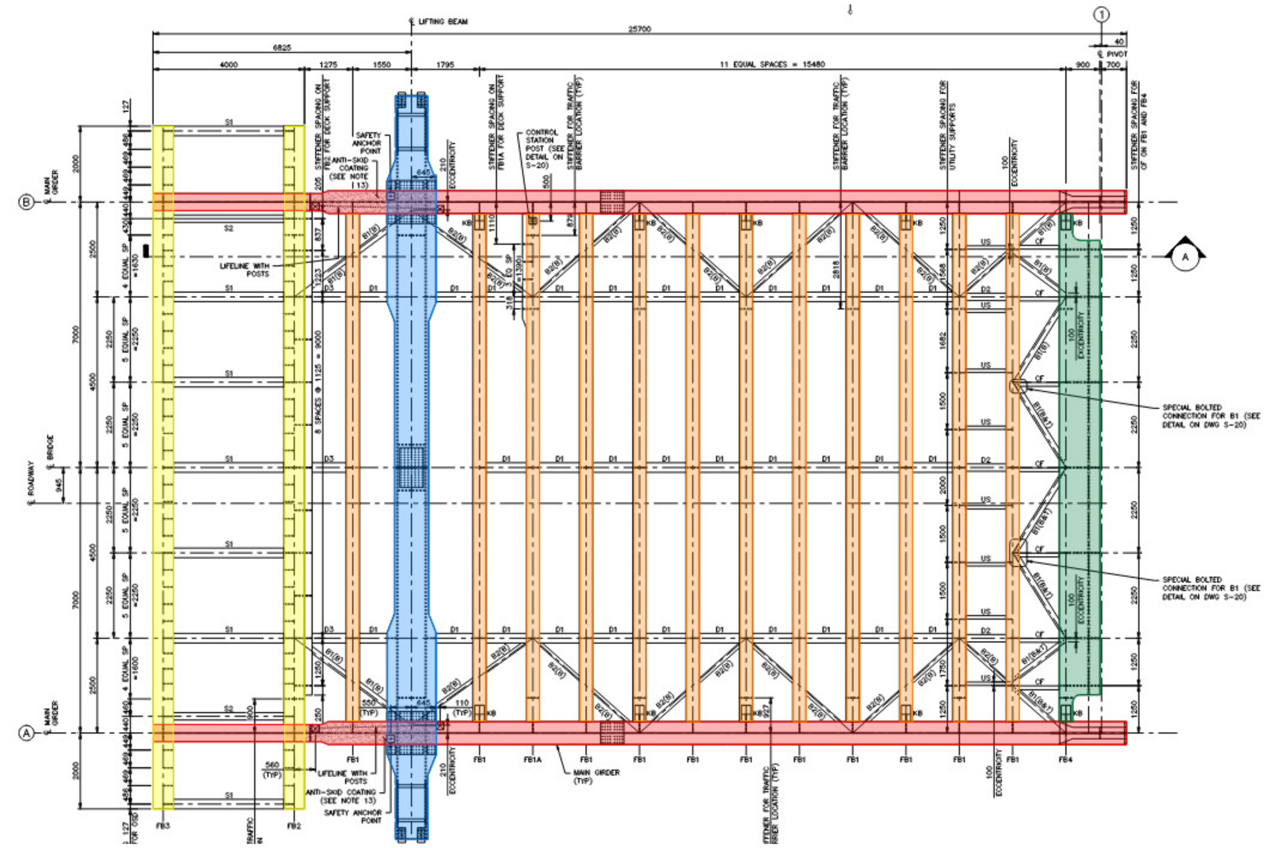


Figure 15: MTB Structural Framing Plan

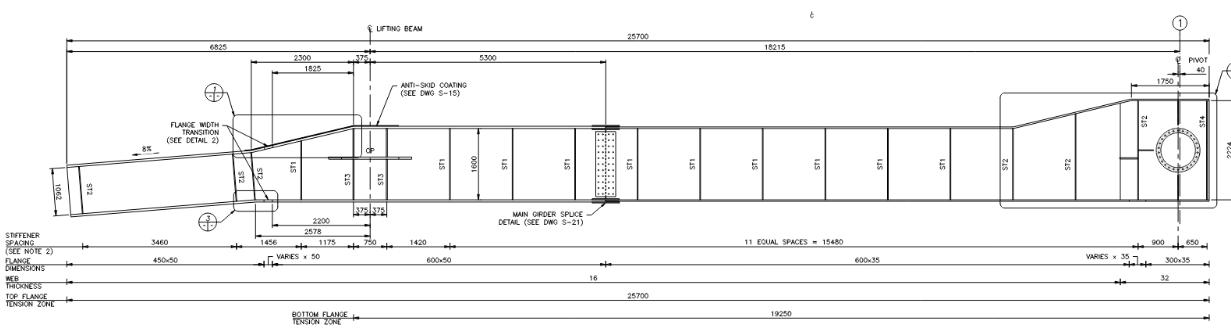


Figure 16: Main Girder Elevation

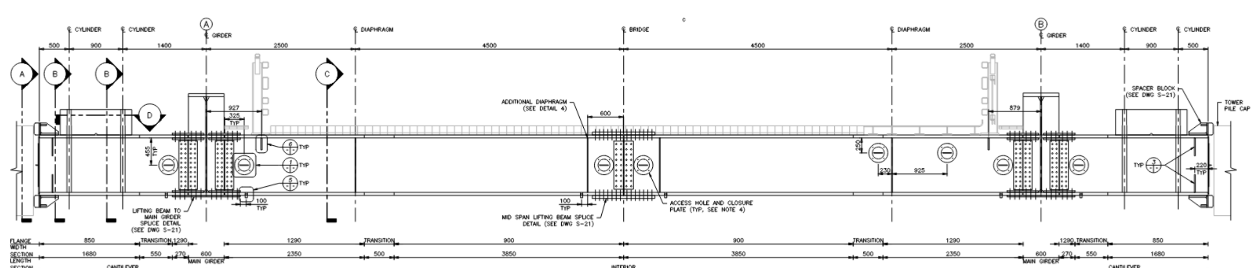


Figure 17: Lifting Beam Elevation

Decks

To accommodate the needs, three different decks were designed for the MTB, as shown in Figure 18. The primary deck, applicable for most of the roadway portion, is a riveted open grating deck (in red). To improve rider comfort, the deck is serrated. At the seaward end, a checkered plate was the preferred solution as this portion is where the ship's ramp lands (in green). This deck was designed as an orthotropic steel deck and required attention to ensure fatigue resistance. The walkway also contained a specific deck type (in blue) incorporating continuous surface for accessibility and an anti-skid coating.

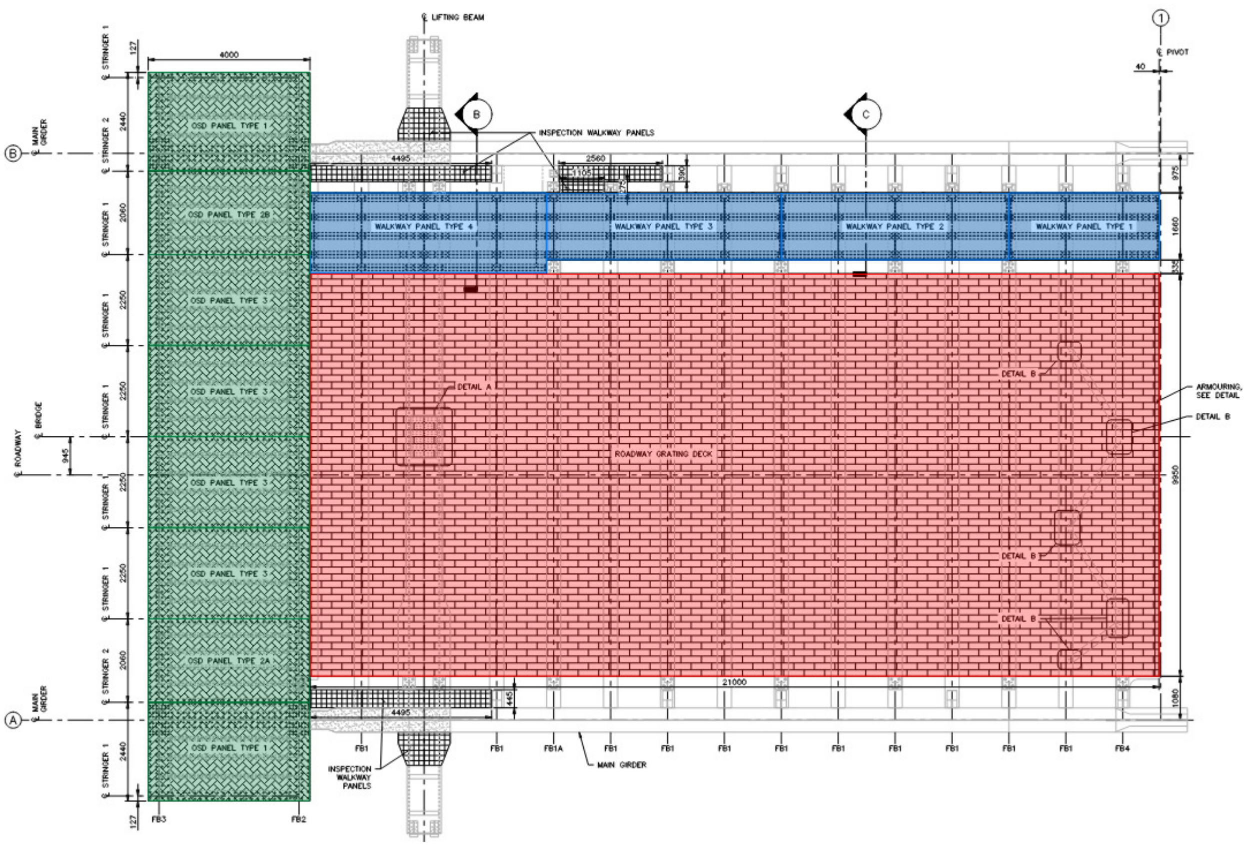


Figure 18: Deck Framing Plan

Summary

A new MTB was designed for the Souris ferry terminal in PEI. The MTB featured two lanes for traffic and a sidewalk to accommodate pedestrian access. The end of the bridge was widened and sloped to effectively receive the ship's ramp, ensuring seamless transitions during operations. A four-cylinder lifting system was incorporated to provide operational redundancy, enhancing reliability. Additionally, two pivot bearings were elevated to facilitate easier access for maintenance, increase durability, and eliminate the need for a cover plate at the deck joint between the MTB and the approach road.

The design of a MTB for ferry terminals requires careful consideration due to its specialized function and operational demands. These bridges must accommodate the dynamic movements associated with ferry operations, including the transfer of passengers and vehicles between the shore and the vessel. To ensure safety, reliability, and efficiency, specific standards are available to guide the design process.

The Canadian Standards Association's CSA S826:01[2] standard is specifically tailored to ferry boarding facilities and provides essential guidance on various design aspects. In addition, the Canadian Highway Bridge Design Code CSA S6:19[2] is applicable to the design of MTBs. While CSA S6:19[2] covers many relevant aspects, it does not encompass all the specialized parameters required for MTBs in ferry terminals. This necessitates the integration of additional standards to fill the gaps.
In situations where Canadian codes do not provide sufficient detail, the British Standard BS 6349-8:2007[3] was utilized as a supplementary resource. BS 6349-8:2007[3] is a well-regarded standard that offers recommendations for the design of roll-on/roll-off (Ro-Ro) ramps, linkspans, and walkways. These components are critical for the seamless transfer of passengers and vehicles between the shore and the ship.

By combining the insights from CSA S826:01[2], CSA S6:19[2], and BS 6349-8:2007[3], Parsons and our partners designed an MTB that meets the rigorous demands of ferry terminal operations while ensuring compliance with international best practices. This integrated approach ensures that MTB is not only functional but also safe and reliable, contributing to the overall efficiency of ferry services.

References

[1] Canadian Standards Association. CSA S826-01 (R2021) Ferry Boarding Facilities. Toronto, ON (2021)
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[3] British Standards Institution. BS 6349-8:2007: The Standard for Maritime Structures - Code of Practice for the Design of Ro-Ro Ramps, Linkspans and Walkways (2007)
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