International Journal of Bridge Engineering (IJBE), Vol. 12, No. 2, (2024), pp. 01-20

INNOVATIVE WIDENING STRATEGY FOR LONG SPAN STEEL GIRDER BRIDGES USING SINGLE GIRDER LINE ERECTION PROCEDURE

Satya Sapath Roy[1] and Pramalathan Arasaratnam[2]

[1] TY Lin International, PA, USA.
[2] TY Lin International, NY, USA.
e-mail: satyasapath@gmail.com, lathan.ratnam@gmail.com

ABSTRACT: This paper discusses an innovative approach in erecting single line girders over long spans. This procedure was successfully applied on the NSR bridges as a case study. The project involved upgrading existing twin bridges to accommodate increased traffic capacity, requiring the extension of the structures outward. Initially constructed in 2005, these twin structures—northbound (NB) and southbound (SB)—feature four spans (80 m – 100 m – 100 m – 80 m) and utilize 3.6 m deep welded steel plate girders. Each bridge was originally designed to accommodate two 3.7 m wide lanes of traffic, along with 2.5 m inside shoulders and 3.0 m outside shoulders. The SB bridge also supports a suspended pedestrian walkway. The widening project aimed to upgrade the roadway and bridges to a six-lane configuration, with three lanes in each direction, achieved by extending the structures outward. One of the significant logistical challenges was minimizing public disruption, given that the twin bridges serve over 80,000 vehicles per day (vpd) in this vital traffic corridor. Another key challenge was the erection of a single line of 3.6 m deep steel girders over long spans, necessitating careful detailing and erection methodology for girder stability. This study paper will provide a comprehensive overview of the design strategies, logistical solutions, and construction methodologies applied throughout the widening project.

KEYWORDS: Bridge widening, Single girder erection, Steel girder, Stability, 3D Scanning

1 INTRODUCTION

Over the last two decades, traffic volumes have surged considerably in urban areas across Canada, placing increased demand on roadways and bridges. To address this, governments have planned for future growth by incorporating provisions for potential widenings in the initial design of these infrastructures. This foresight aims to accommodate rising traffic volumes and maintain an acceptable level of service. However, when designing bridges with future widenings in mind, it is impossible to predict changes in design codes, technology, materials, and construction methods that may occur. This paper reviews a case study of a major river bridge, highlighting the challenges faced during the design and construction of its widening.

2 PROJECT BACKGROUND

The Southwest portion of AHD ring road was completed and opened in 2006. The section was designed for a 30-year design life, with a projected 40,000 vehicles per day (vpd) by 2020. This threshold was reached by 2009, much sooner than expected, partly due to faster-than-projected development in Southwest region. Residential and commercial development has grown significantly since 2004. The average daily volume is now between 75,000 and 80,000 vpd, and traffic congestion is experienced daily. At the current growth rate, it is projected that the ring road will reach 120,000 vpd by 2021. The ring road at the bridge crossing bottlenecks to four lanes from six lanes in preceding portions, further contributing to congestion. The overall widening project scope included the widening of the roadway and bridges to a six-lane cross section in three stages.

The expansion of the ring roadway included the expansion of two bridges along its route. Both bridges were constructed with future expansion in mind, though constructability issues must still be accounted for and mitigated. This paper specifically relates to the widening of the existing northbound (NB) and southbound (SB) bridges over the NSR crossing. It aims to provide detailed constraints and design parameters considered for the bridge widening project, covering all phases from design and tendering through to construction as per the local DOT requirements and Standard Specification for Bridge Construction (2017). The site plan for the bridge location is illustrated in Figure 1.

Figure 1. Project site plan

3 BRIDGE GEOMETRY, ARTICULATION AND ABUTMENT INTRICACIES

3.1 Description of bridge cross section

The existing NSR bridges had undergone a widening process to increase the clear roadway width from 12.9 m to 16.6 m. This expansion will allow for three lanes in each direction, resulting in a total of six lanes, each 3.7 m wide. Currently, both the Northbound (NB) and Southbound (SB) structures feature two 3.7 m wide lanes, a 2.5 m wide inner shoulder, and a 3.0 m wide outer shoulder. The ultimate design goal for the NSR bridges is to accommodate eight lanes, with each bridge consisting of four 3.7 m wide lanes and 3.0 m wide shoulders on both sides, in compliance with roadway design standard RAD-820.8-110. After the completion of the current widening project, the entire route has been added with one lane in each direction, creating a new lane configuration of three 3.7 m wide lanes, a 2.5 m wide inner shoulder, and a 3.0 m wide outer shoulder for each bridge. This updated configuration is illustrated in Figure 2.

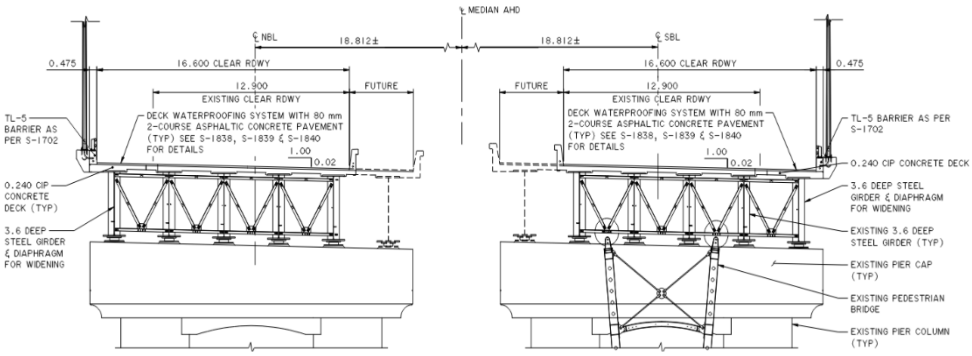
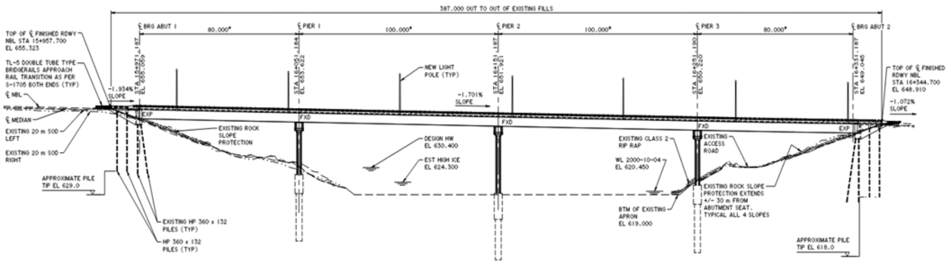


Figure 2. Cross section after the current stage of widening

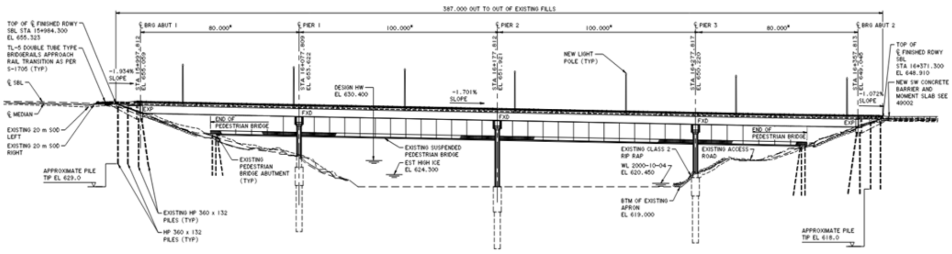
3.2 Description of bridge articulation for NBL and SBL

The existing NSR Bridges, both the northbound (NBL) and southbound (SBL), are 387 m long (out-to-out) 4 span composite steel girder structures with a span arrangement of 80 m– 100 m – 100 m – 80 m. The girders have a uniform depth of 3600 mm throughout the spans. Flange thickness varies from 30 mm to 70 mm, and flange width ranges from 500 mm to 1485 mm. Notably, the SBL bridge includes a suspended pedestrian bridge beneath it. The superstructure is continuous over Piers 1, 2, and 3, featuring fixed bearings at all pier locations and expansion bearings at the abutments. The girders support a 240 mm thick cast-in-place concrete deck slab and a deck waterproofing system topped with an 80 mm two-course asphaltic concrete pavement. Figure 3 illustrates the general arrangement of the SBL bridge structure. Figure 3 shows the general arrangement of the NBL and SBL bridge structures.

Both bridges follow a 3.5 km horizontal radius. Despite this curvature, the girders were detailed as straight, inscribed chords of the horizontal curve, with each splice location aligned on the curve. The maximum angular change at the splices (Splice 1 and Splice 12) is 0°32’25”. The small eccentricity (300 mm) of the girders at mid-spans due to the horizontal curve necessitated additional measures to ensure stability of the first erected girder until adjacent girders were braced to it. Girder splices were extensive, requiring bolts ranging from 428 to 568 bolts per splice. The two end spans have intermediate diaphragms spaced at 8.0 m while inner spans have diaphragms spaced at 7.7 m. All spans include lateral bracing between the two internal girders. This detailed description captures the complex engineering and design considerations of the NSR bridges, ensuring structural stability and accommodating unique design constraints.



A. NBL



B. SBL

Figure 3. General arrangement of bridge

3.3 Abutment intricacies of existing structure

The substructure of the NSR bridges consist of cast-in-place (CIP) abutments founded on steel piles (HP360X132) and CIP piers founded on concrete piles. The top 8 to 10 m of the concrete piles are a 4.6 m diameter concrete caisson supported on 3.0 m diameter drilled cast-in-place piles. Pier 2 is situated within the normal water level of the NS River (NSR), while Piers 1 and 3 are located on the riverbanks above normal water. The abutments are conventional and include bearings allowing for rotation and longitudinal movement. The roof slabs span over two grade beams supported by steel piles (HP360X132), with a flexible Wabo compression sealer of 25 mm between the roof slabs at Grade Beam A as can be seen in Figure 4. Additionally, the bridges are equipped with 3.80 m and 3.65 m long approach slabs on the north and south sides, respectively.

The abutments are composed of an abutment seat linked to two grade beams by a wingwall and roof slabs. As part of original design of the bridge, the geotechnical design had predicted a maximum 250 mm long-term movement for the north head slope, either transversely, longitudinally (towards the river), or a combination of both (Nima et al, 2005). To accommodate this movement, the original design includes:

a) An unusual two-span roof slab arrangement for the abutments, with the inner roof slab on the north abutment designed as a floating slab supported by sliding bearings between the backwall, wingwalls, grade beam, and roof slab is shown in Figure 4.
b) The strengthening of the abutment girder diaphragm of the center bay and attachment to the restrainers on each abutment are shown in Figure 5.
c) A system reliant on bridge inspections and survey monitoring to detect abutment movement.
d) An adjustment process involving jacking the girders incrementally (15 mm at a time) to correct alignment and shifting shims to maintain alignment, along with adjusting the floating roof slab connected to the deck through a finger joint (see Figure 5).

These measures ensure the structural integrity and flexibility of the abutments to accommodate potential movements over time.

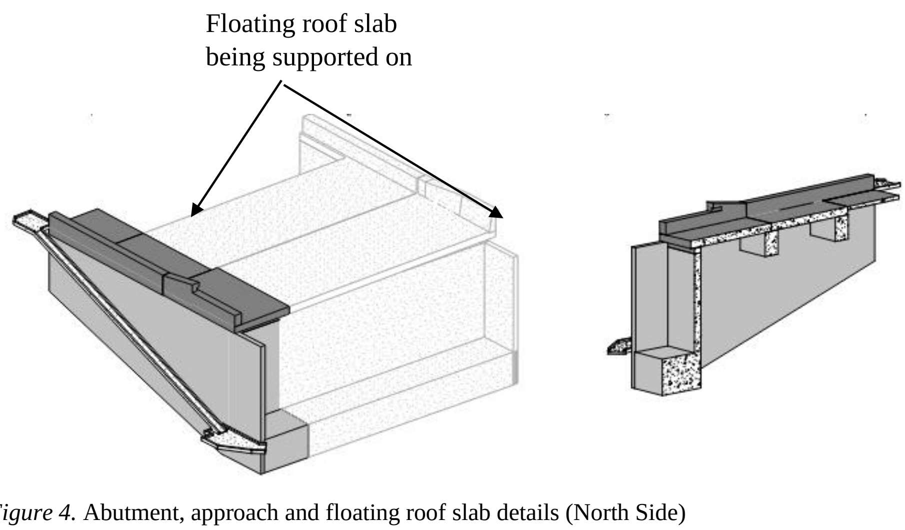


Figure 4. Abutment, approach and floating roof slab details (North Side)

The transverse movement of the overall girder assembly at the abutment locations can be controlled/restrained by a lateral restrainer with multiple shims (15 mm plate shims).

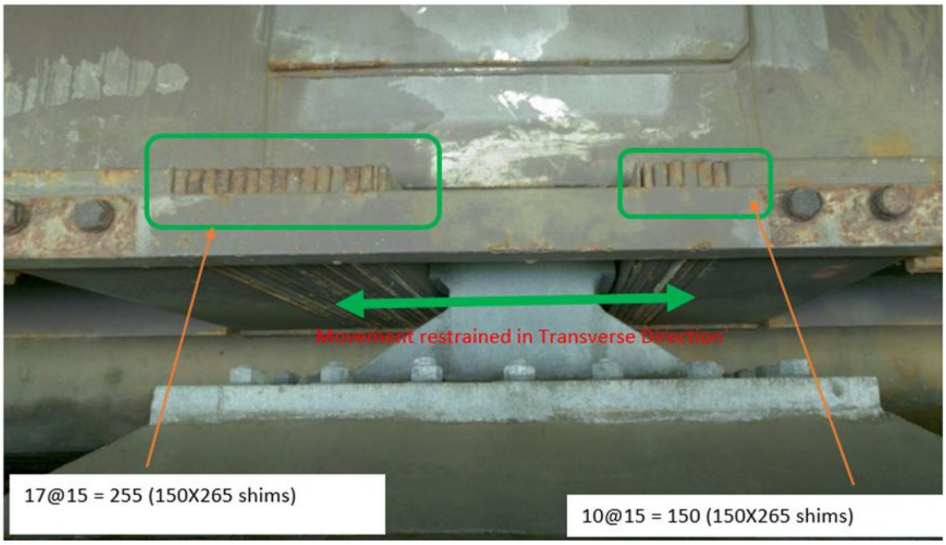


Figure 5. Restrainer assembly

4 DETAILS OF BRIDGE WIDENING

4.1 Existing roadway cross-section

- **Vertical Alignment:** The bridge widening project has been designed to align perfectly with the existing bridge geometry. This alignment includes maintaining the same skew angle, as well as horizontal and vertical alignments. The mainline roadway crossing the bridges has a vertical grade ranging from 1.13% to 1.92%, descending from north to south as seen in Figure 3. Additionally, through the curved section over the bridges, the roadway features a 2% superelevation, sloping downward from the east barrier to the west barrier.

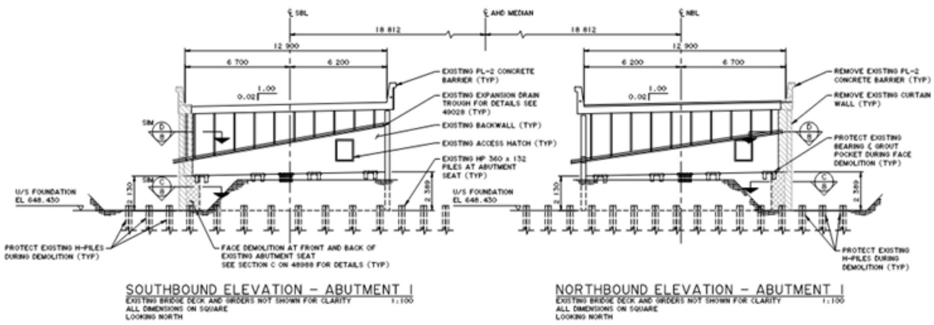


Figure 6. Horizontal alignment details

- **Horizontal Alignment**: The existing horizontal alignment of the roadway over both the northbound (NB) and southbound (SB) bridges follows a curved path with a radius of 3.5 km. The alignment of both bridges is parallel to the control line radius of 3500 m. Within this curved section, the roadway incorporates a 2% super elevation, sloping downward from the east barrier towards the west barrier as shown in Figure 6.

The existing bridge head slopes and roadway width were initially designed and constructed to accommodate the ultimate roadway alignment. These pre-existing allowances and slopes have been field-verified to ensure their accuracy. A Civil 3D analysis was conducted to assess and confirm that there is sufficient space for the new lanes, minimizing the need for significant earthwork, as illustrated in Figure 7. As noted earlier, the project involved the widening of the existing bridges to the outside for a six-lane configuration with each bridge supporting three lanes, each 3.7 m wide. Additionally, the design included a 3.0 m wide outside shoulder and a 2.5 m wide inside shoulder. This configuration results in a total clear bridge width of 16.6 m, ensuring adequate space for traffic flow and safety.

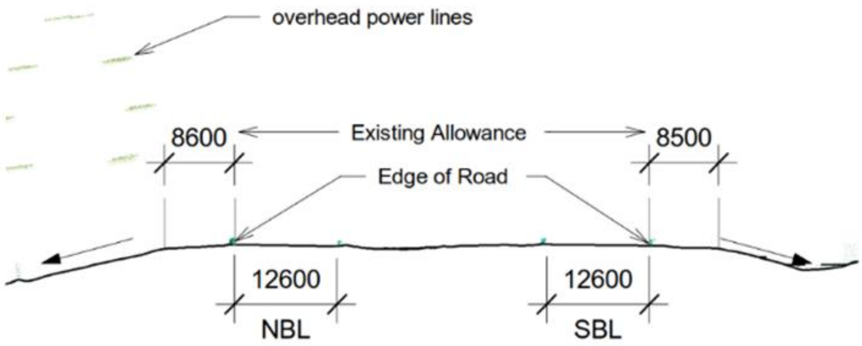


Figure 7. Cross-section of roadway at bridge locations prior to widening

4.2 Substructure widening

The original piers were constructed to their ultimate configuration, allowing for both interim and ultimate stage widening, therefore, no pier widening was required for this project. However, the abutments were not built to accommodate future widening; only steel (HP) piles were driven and left in the ground for potential future use (see Figure 8). For the substructure widening, the following steps were performed:

a) Excavation and assessment:
   - The steel piles at the abutment locations were excavated and exposed.
   - A thorough condition assessment was conducted on these piles, which had been left in situ for 15 years since the initial construction.

b) Condition confirmation:
   - The assessment confirmed that the steel piles were in good condition and could be incorporated into the bridge widening design.

c) Pile capacity verification:
- Selected piles were identified for PDA (Pile Driving Analyzer) testing.
- These piles were restruck (see Figure 9[A]) to ensure they met the adequate design capacity.
- The termination criteria for the piles were established by a Geotechnical Consultant using WEAP (Wave Equation Analysis of Piles) analysis.
- The PDA testing and restriking were performed to validate these termination criteria and confirmed that the piles met the desired design capacity established by the structural consultant.

d) Pile extension:
- The exposed piles after brush cleaning and restriking to confirm the desired capacity were welded to extend all the way to the required height to be integral part of abutment seat (see Figure 9[B]).

Figure 8. Exposed HP steel piles at abutment (TYP)

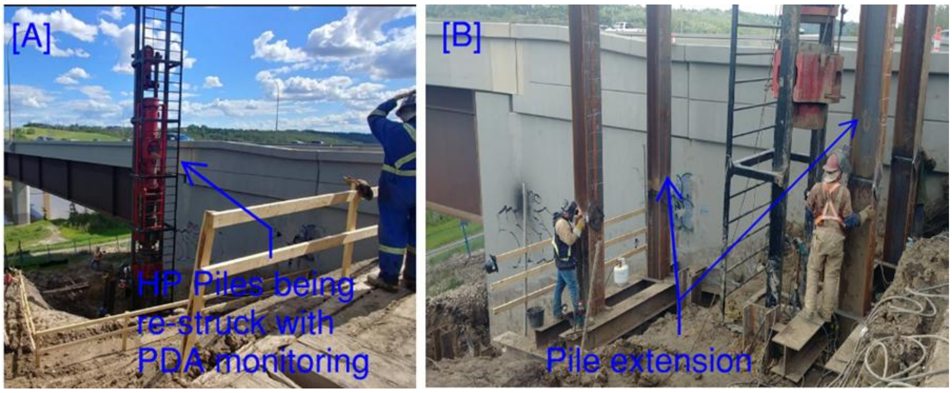


Figure 9. Restriking of existing piles at abutment

4.3 Deck and barrier demolition and widening strategy

A localized demolition strategy was implemented within the shoulder to expose the deck reinforcing steel and remove the outer bridge barrier. This was achieved using a precise sawcut method, as shown in Figure 10, ensuring careful exposure of the deck rebar. The exposed reinforcing steel bars were then evaluated for their condition and subsequently repaired by sandblasting and lapping them to new reinforcing steel.

To prevent any contamination of the river, special provisions were made to include all necessary control measures that the contractor needed to implement to manage water runoff and debris.

4.4 Addressing differential shrinkage cracking

Differential shrinkage cracking between the new and old deck concrete was a potential concern due to the restraint provided by the existing deck at the construction joint and the different ages of the two sections of concrete deck. Several strategies were employed to mitigate this issue.

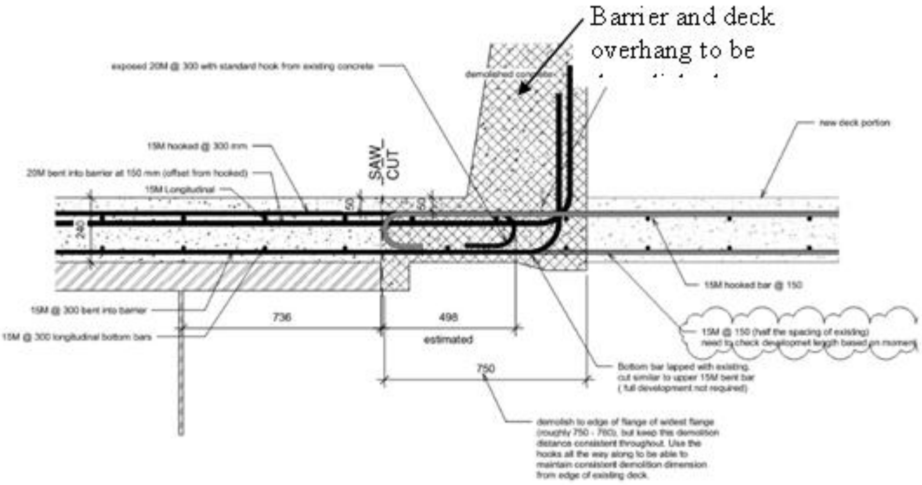
a) **Closure Pour**: A closure pour was used to manage shrinkage differences.
b) **Rebar Detailing**: Good rebar detailing was provided to help control cracking.
c) **Adequate Longitudinal Reinforcement**: Sufficient longitudinal reinforcement was included to evenly distribute any cracks and limit their widths within the allowable code limits.

4.5 Deck pour sequence

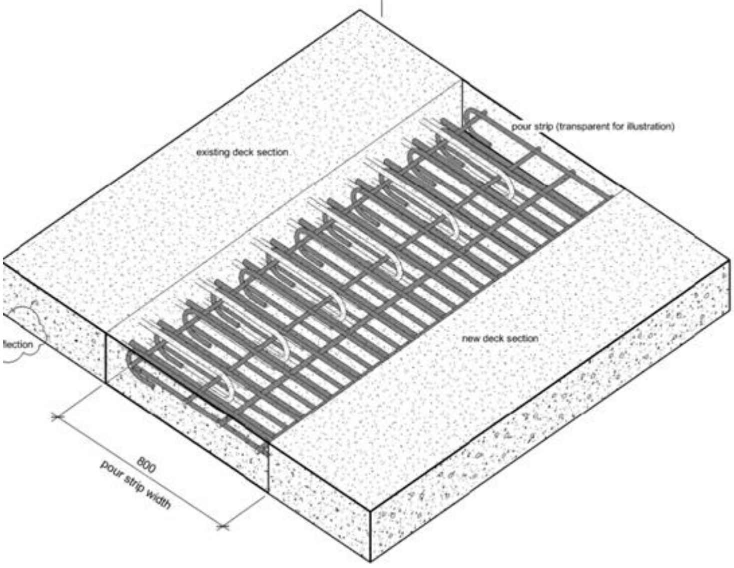
The sequence of concrete placement for the deck was carefully planned to ensure structural integrity and to minimize cracking issues. The planned sequence was as follows:

a) **Positive Moment Region**: Concrete placement began in the positive moment region, where the deck experiences upward bending.
b) **Negative Moment Region**: The next phase involved the negative moment region, where the deck experiences downward bending.
c) **Barrier Segments**: After the main deck sections, concrete was placed in the barrier segments.
d) **Final Stitch Pour:** The process concluded with a final stitch pour to integrate all sections seamlessly.

This systematic approach ensured that the new deck integrated well with the existing structure, addressing potential issues of differential shrinkage, and maintaining the overall integrity and durability of the bridge.



(a) Rebar details for cantilever barrier location



(b) Rebar details within closure pour region

Figure 10. Deck demolition, rebar layout and closure pour details

5 PROJECT SPECIFIC CHALLENGES

5.1 Major challenge: girder erection

During the preliminary design phase, the project team evaluated various options for the erection of a single line girder for the NSR bridges. Given the substantial depth (3.6 m) and length (over 100 m) of the girders, ensuring stability during erection is critical. Table 1 summarizes the explored girder erection. These options were thoroughly analyzed to determine the most feasible method for the erection of the single line girder.

Table 1. Explored options with associated advantages and disadvantages

Option	Advantages	Disadvantages
Erect from Below by Building Ice-Bridge Option	- Ability to erect longer girder sections	- Risk of not being able to sustain ice bridge due to temperature fluctuation
	- Less traffic disruption	- Prolonged schedule
	- Less chance of damaging existing bridge	- Potential impact on water intake
	- Potential cost savings due to use of same machinery	- Access to crane might be an issue
Erect from Deck (Selected option)	- Less environmental impact	- Potential damage to deck
	- Potential for lower costs (if berm not built)	- Higher impact on traffic
	- More definable schedule	- More splices
	- Less risk (known construction method)	
Hybrid Approach Option	- Potential lowest cost option	- Requirement to be ready to react to conditions
	- Potential for shorter schedule	- Potential environmental impact
	- Less impact on traffic than erecting from deck throughout project	
Launch Box Girder Option	- Less impact on traffic	- Specialized construction method
	- Potential for more schedule certainty	
	- More stable	
	- Less environmental impact	

Considering various social and economic factors, along with the risks, availability of capable contractors, logistics, and construction schedule, erecting the girders from the deck was selected as the most preferred option. To reach this conclusion, the design team conducted a thorough analysis using 3D finite element modeling in the Midas Civil (Midas Civil, 2019). This analysis evaluated multiple critical aspects:

a) **Capacity of the Existing Bridge Superstructure**: Ensuring the existing bridge could support the new girder segments during erection.
b) **Crane Specifications**: Determining the appropriate crane to be used, including its capacity and limitations.
c) **Weight and Length of Girder Segments**: Assessing the maximum feasible weight and length of the new girder segments.
d) **Support During Erection**: Planning how the new girders would be supported

by the existing structure during the erection process.

e) **Girder Stability**: Ensuring the stability of the girders throughout the erection process.

This comprehensive analysis allowed the team to confirm that erecting the girders from the deck was the most viable and efficient option, balancing all critical factors and minimizing risks. Figure 11 illustrates the 3D model created in the Midas Civil (Midas Civil, 2019), showcasing the existing bridge with the addition of the new girder segment. This modeling exercise included various factors such as potential construction loads, crawler crane weight with impact factor, counterweight, weight of underslung steel brackets, wind loads during erection, miscellaneous live loads, and the self-weight of the existing structure. Based on these comprehensive analyses in accordance with the Canadian Highway Bridge Design Code (CHBDC), (S6-19, 2019), the following conclusions were drawn:

a) **Girder Segment Length**: Limit the length of the new girder segments to 22-28 m.

b) **Crawler Crane Specifications**: Use a crawler crane with a maximum track weight per track.

c) **Temporary Support**: Add temporary underslung brackets to support the new girder segments during erection.

These conclusions ensure that the erection process is safe, efficient, and minimizes the impact on the existing structure.

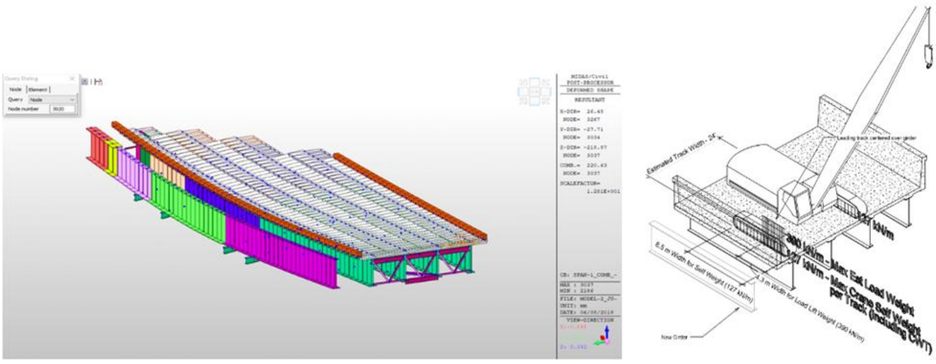


Figure 11. 3D FE model analysis and crane details

5.2 Other project specific challenges

Table 2 below outlines the project-specific challenges faced during the implementation phase. It also details the specific actions taken to effectively address and overcome each challenge, ensuring the successful execution of the project.

Table 2. Project-specific challenges and actions taken

Category	Issue	Action Taken
Slope Stability	Slope stability issue on the south side of the riverbank.	Engaged geotechnical consultant for evaluation and restoration.
		Implemented restoration recommendations.
Traffic Management Plan	Short-term closures during off-peak hours.	Developed traffic management plan maximizing traffic speed and space.
	Development of minimum lane width and speed requirements.	Incorporated provincial requirements into design considerations.
	Minimizing pedestrian bridge closure under the NSR Bridge.	
Site Access/Construction Laydown Area	Proper site layout plans for access and location.	Identified and developed site layout plans.
Schedule/Seasonal Limitations	Scheduling long lead items and procurement.	Developed schedule working backwards from procurement.
Permitting and Approvals	Securing approvals for chosen construction method.	Included approvals in the schedule with responsible parties.
	Incorporation of ice bridge option in application.	Discussed requirements with EPCOR for the E.L. Smith Water Treatment Plant.
Deck Demolition and Widening	Adoption of saw cutting methodology for deck demolition.	Defined rebar length using preferred methods.
	Review of contractor-proposed alternatives for equivalence.	Ensured contractor's proposed methods were equivalent.
Drainage During Construction	Development of drainage plan for bridge during and post-construction.	Implemented measures to control flow under the bridge.
Construction Staging	Specification of limitations around 135 Street interchange.	Developed initial staging plan and incorporated contractual constraints.
	Initiation of bridge work immediately after project award.	Motivated contractor through contractual constraints and incentives.
	Coordination of bridge and road construction.	
Relative Movement During Concrete Pouring	Concerns regarding bridge movement during concrete pouring.	Allowed concrete curing before allowing traffic.
Girder Differential Camber	Ensuring new cambers matched existing ones.	Used 3D scan to establish camber of exterior girder of existing bridge (on the widening side) and the calculated camber for new

Category	Issue	Action Taken
		girder was adjusted to match that of existing camber to have a smooth deck transition in transverse direction.
	Addressing procurement of lead time items.	Considered grinding or adding concrete for mitigating differential heights.
Deck Joints/Finger Joints	Impact of construction sequence on finger joint specifications.	Incorporated new standards for deck joints in the tender package.
Illumination Requirement and Design on Bridge	Removal of lights during construction.	Designed and replaced lights ahead of removal during construction.

6 CONSTRUCTABILITY CHALLENGES

6.1 Girder erection strategy

The widening of NSR bridges involved adding a single girder line and deck extension to the exterior side of each bridge. However, as-built drawings lacked essential structural details like tying new girders to existing ones, connection specifics, and holes in stiffener plates.

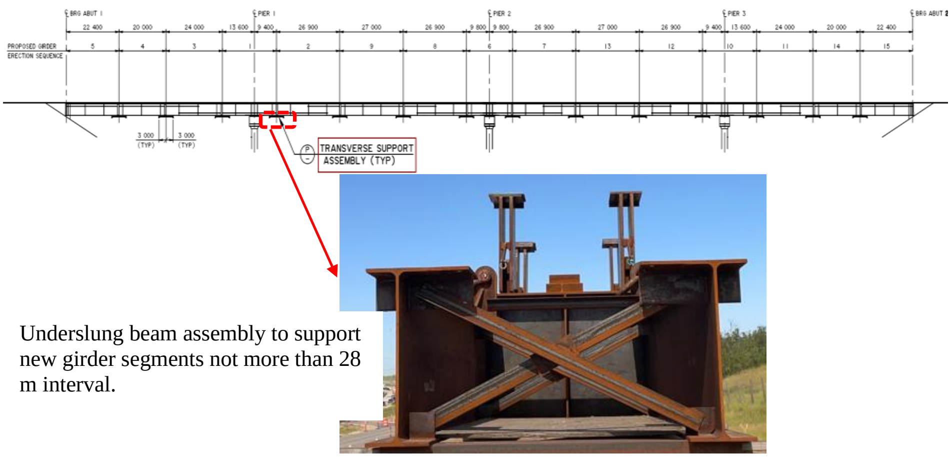


Figure 12. Proposed locations of underslung beam assembly and details

The approach for this project included:

- Site access and erection of additional girders using underslung beams for support, as shown in Figure 12.
- Ensuring reliable stability for new girders during erection and subsequent construction stages.
- Stabilizing girder segments during crane erection using existing girders, with detailed supports allowing for deformations and distortions, especially in

cantilevered pier segments.

- Considering fit-up and tolerances of new girders with fixed superstructures, crucial for deck casting and managing deflections as concrete sets and gains strength.
- Focus on safety, clear contract documents with deformation plans, and achieving a durable concrete deck for a high-quality riding surface.

Substructure widening was also part of the project's planning and design considerations.

6.2 Methodology to erect a single girder line

Construction staging and girder erection are critical aspects of bridge widening, especially regarding traffic accommodation. As discussed earlier, the project analyzed various stages of NSR bridge widening and roadway expansion within project limits, considering their impact on overall traffic management. While erecting girders from existing bridge decks posed a major challenge, alternatives like mid-span girder erection from in-river berms or girder launching were explored but deemed unfeasible due to schedule, cost, and regulatory permit considerations. Hence, erecting girder segments from the existing deck was chosen as the most viable option.

The design evaluated a feasible construction method using temporary supports called underslung beams. These beams carried the weight of new girders and stabilized them during erection. They also supported jacks for adjusting the final girder line's camber, ensuring proper fit and alignment. The spacing of these beams was based on supporting maximum loads, including the girder weight, construction equipment, and live loads. This setup allowed for erecting segments up to 28 m at a time.

Load Path: The existing bridge itself was a four-span structure and had indeterminate load paths based on static equilibrium alone. The significance of this statement is that girder erection and assembly sequence while on temporary supports (and partially unaffected by gravity) would affect how the completed new girder supports its own self weight when all temporary supports have been removed. The crucial aspect is to ensure that the girder's self-weight is transferred to the supports as planned in the final stage, maintaining the intended design camber and girder profile.

Fit up: To ensure proper fit-up, it was crucial that the intended shape was achieved when splicing all the girder segments together. If this shape was not achieved, the bolt holes would not line up correctly. Thus, concerns about the girder’s self-weight load path not matching the continuous beam load path were mitigated by the fact that the girder must be built in its intended shape.

The challenge in this situation was to ensure that the girder erection plan could achieve all girder splice end elevations and end rotations that exactly matched the design camber drawing. To address this, underslung beams were provided at all girder end locations as shown in the erection schematic on the design drawings as well as on Figure 12. These underslung beams allowed for the necessary adjustability of the girder ends, ensuring that the required fit-up and alignment were achieved.

Evaluation of critical movements during girder erection: Diagonal braces were not installed to avoid inhibiting vertical girder movement during deck casting. However, at pier and abutment locations, diagonal braces were installed as fixed points for the girder. Concerns were raised regarding horizontal braces possibly experiencing compression during downward girder deflection. These braces have a length of approximately 3.4 m and are estimated to undergo a maximum downward deflection of 115 mm due to added loads. The resulting change in brace length was approximately 2 mm, which can be easily accommodated by bolt hole tolerances or slight girder rotation. This poses no significant concern in this scenario.

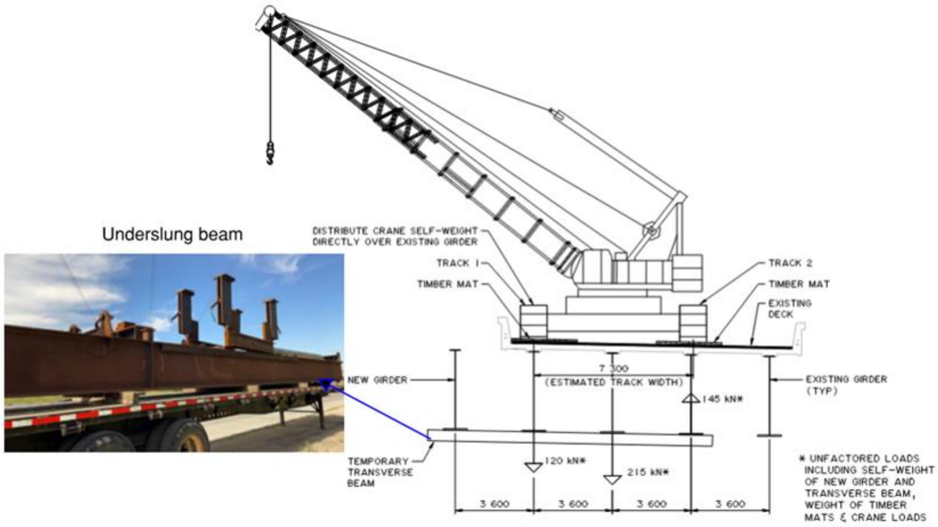


Figure 13. Temporary transverse beam (Underslung beam)

Figure 13 illustrates how each underslung assembly was attached to the existing girder bottom flanges. The erection scheme proposed in the design drawings utilized the following approach:

a) **Support and Adjustability:** Underslung beams were used to support the weight of the new girders and provide adjustability at all girder segment end locations.
b) **Hydraulic Jacking System:** The underslung beam assembly included a hydraulic jacking system to adjust the girder profile to the correct elevation, ensuring that the camber was maintained as designed.

c) **Field Splices:** This system allows for precise adjustments, enabling all field splices to suit the design intent, and be properly attached.

Using this method, the underslung beams ensured that the new girders were supported and positioned correctly during erection, thereby maintaining the structural integrity and design specifications.

To maintain girder stability during erection, each new girder segment was laterally connected through top and bottom chords, as highlighted in yellow in Figure 14. The process involved the following steps:

a) **Lateral Connections:** Each new girder segment was connected laterally at both the top and bottom chords. These chords were essential for providing lateral stability and ensuring the girders remained in the correct alignment during erection.
b) **Single Bolt Installation:** During this process, a single bolt was used to snugly tighten the chords. This was performed to allow for necessary vertical settlement and rotations of the new girder segments. The snug fit ensured that the girders were connected but could still move slightly to accommodate any adjustments required during the erection process.
c) **Vertical Settlement and Rotation:** Allowing for vertical settlement and necessary rotations was crucial to ensure that the new girder segments could be aligned precisely and connected correctly to the existing structure. This flexibility helped in achieving the intended design profile and camber of the bridge once the erection was completed.

By using this method, the erection process could account for and adjust to any minor movements, ensuring that the new girders were properly integrated with the existing bridge structure while maintaining stability throughout the construction phase.

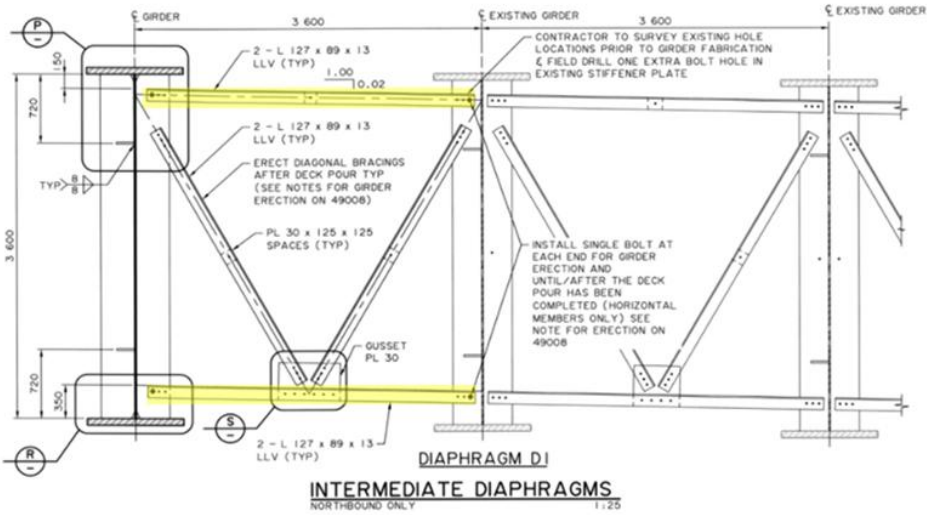


Figure 14. Horizontal braces - installed for girder stability during erection

Since this construction involves cranes lifting girder segments from the existing structure, it was necessary to perform a bridge load evaluation of the existing bridge. This evaluation ensured that the structure could safely handle the construction demands of the lifting operation.

6.3 Contractor’s erection approach

In this project, the contractor’s erection engineer used a combination of methods to support the girder segments during erection. Two shoring towers were employed in spans 1 and 4, where the bridge was not over water as shown in a schematic in Figure 15. For girder segments at the piers, support was provided by the pier itself, with temporary diagonal braces at the girder diaphragm locations to handle the vertical demand. These braces were removed once the girder segment over the pier and next installed girder were spliced together to form a simply supported beam. Additionally, two underslung beams were used to support girder end segments over the water on spans 2 and 3. The entire project was successfully completed including bridge construction and the entire route was opened for traffic in early 2024.

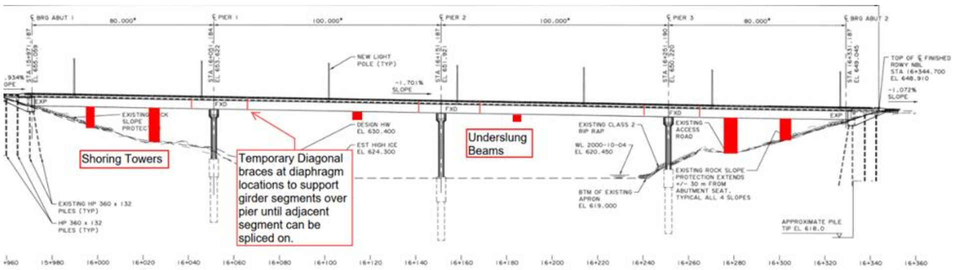


Figure 15. Contractor’s proposed support conditions during erection

7 CONCLUSIONS

The following summarizes the major design considerations and lesson learned from this project:

- Survey methods may include LiDAR, point clouds, or visual techniques such as total station surveys. Additionally, it is crucial for the contractor to conduct an independent survey of the existing bridge girders to ensure successful girder erection and establishing appropriate elevations at the bearing locations.
- The existing deck edges and girders, including the deck, supports, exterior girders, and bearing locations and elevations, should be surveyed, and compared with the as-built records. This ensures that any design discrepancies are identified and addressed early in the widening design process. A 3D scan survey would also provide additional information along the girder length,

which was used in this project to make camber adjustment.

- There are conflicting needs during girder erection and deck placement regarding the use of temporary bents or temporary stiff diaphragms. Bridge designers have more time and resources to develop a clear, well-thought-out scheme. While contractors can propose alternatives, they benefit from being better informed about these issues and more capable of coordinating with other parties involved in planning and executing the fabrication, erection, and construction.
- Fit-up and relative deformations during construction are often overlooked, leading to increased risks of delays and claims. New girders are erected in an undeformed shape, considering only the girder dead load (DL) without the deck concrete weight, which will change throughout erection and construction.
- It is essential to consider initial fit-up and changing deformations in the detailing early in the design phase and clearly communicate these on the drawings. This allows for proper detailing and fabrication of steelwork (shop drawings) with tolerances in hole sizes and arrangements. It ensures that the fabricator, general contractor, erector, and others understand and address these effects, leading to a smoother construction process.
- The girders will experience deflections during erection stages due to their self-weight, and when deck concrete is placed, this must be carefully analyzed, designed, and detailed with consideration for the prescribed staging of concrete placing and timing.
- Girder deflections along the entire length of the bridges, accounting for staging and time-dependent concrete properties, must be carefully considered to achieve the final deck profile and riding surface.
- Reliability and coordination in the as-built survey data, design, detailing, fabrication, erection, formwork design, concrete placing stages, and survey methods are crucial in the preparation for successful girder erection.

AVAILABILITY OF DATA AND MATERIAL

The authors state that all data, models, and codes that support the findings of this study are available from the corresponding author upon reasonable request.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHOR’S CONTRIBUTIONS

Dr. Arasaratnam served as the Engineer of Record (EoR) for this project, overseeing its development from concept through final design and construction support. Dr. Arasaratnam led design decisions and ensured engineering

compliance. Dr. Roy extensively contributed to preparing the manuscript, including literature reviews, data analysis, and writing. Their combined efforts resulted in a thorough and well-documented study.

ACKNOWLEDGMENTS

The authors extend their heartfelt gratitude to the entire design team, project managers, client and contractors for their invaluable insights and guidance throughout the project's inception through completion. Additionally, the authors deeply appreciate the dedication and efforts of the various discipline, subtrades and stakeholder who were involved throughout the project delivery.

FUNDING

This project received funding from the Government agencies, Canada.

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