Approach Channel Bridge Rehabilitation

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Abstract

Constructed in 1967 as part of the Mactaquac Hydroelectric Dam near Fredericton, New Brunswick; the Approach Channel bridge carries two lanes of traffic over the Saint John River adjacent the dam's intake structure. The NB Power owned diversion sluiceway forms the south abutment while the remaining bridge is owned by the New Brunswick Department of Transportation and Infrastructure. The seven span superstructure is comprised of seven simply supported prestressed girders and a concrete deck. The six hammerhead piers are in 18 m deep water. A condition assessment was completed in 2019 which included a visual inspection, underwater inspection, ground penetrating radar deck survey, a material testing program, and an evaluation of the superstructure. The resulting renewal strategy includes replacement of the deck overhang and barriers, partial depth deck replacement with a thicker deck and exposed concrete wearing surface, jacking to replace the bearings, strengthening of the hammerheads, repairing the defects associated with alkali aggregate reactivity expansion of the pier shafts, and elimination of the deck joints by converting the simple spans into three continuous spans with a semi-integral conversion of the north abutment. This paper reviews the challenges in design including eliminating deck joints, smoothing excessive camber, and enhancing the rideability of the bridge, using externally bonded carbon fiber reinforced polymer to strengthen the pier hammerheads, and the development of an encapsulation system for the pier shafts in deep water. As the rehabilitation of this bridge approaches the mid-point of construction, this paper will present the status of the rehabilitation.

Project Background and Introduction

Approach Channel Bridge is an integral part of the Mactaquac Generating Station which is a run-of-the river hydroelectric facility near the city of Fredericton, New Brunswick, Canada (see Figure 1). The NB Power owned dam, which began generating electricity in 1968, will not meet the 100-year design life expectancy and a major rehabilitation effort dubbed the "Mactaquac Life Achievement Project" (MLAP) is scheduled to begin construction in 2025 and is expected to have a fifteen-year duration of construction. The bridge owner, the New Brunswick Department of Transportation and Infrastructure (NBDTI), recognized the need for a condition assessment and evaluation of the bridge to take advantage of a window of opportunity to rehabilitate the structure in advance of the MLAP.

Figure 1. Mactaquac Hydroelectric Generating Station (1) Approach Channel, (2) Approach Channel Bridge, (3) Diversion Sluiceway, (4) Head Pond, (5) Keswick Ridge, (6) Intake Structure, (7) Powerhouse, (8) Main Spillway, (9) Rock Island, (10) Embankment Dam, (11) Kingsclear

Source: Énergie NB Power

Original Construction

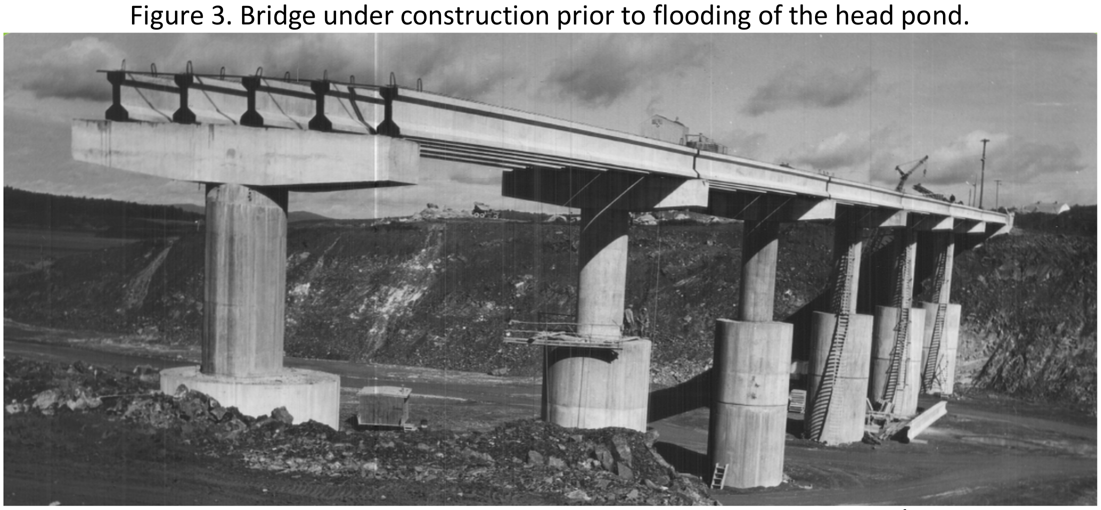
The Mactaquac Dam is comprised of a large earthen dam which terminates at its north end by a large concrete diversion spillway structure adjacent Rock Island. Approach channel bridge spans from Rock Island to the north shore of the Saint John River. The bridge has a 7.9 m clear roadway width and carries two lanes of traffic. The structure is on a north-south straight alignment with a constant grade of 2.3% with the low point at the south end (see Figure 2).

The 192.1 m long bridge is made up of seven simply supported spans with five longitudinal lines of AASHTO IV prestressed concrete girders acting compositely with a 178 mm thick reinforced concrete deck topped with a 50 mm thick asphalt wearing surface. The 9.7 m wide deck has a 610 mm wide concrete curb on the east side and a 1.2 m wide sidewalk on the west side. Both sides of the bridge are protected by a galvanized steel railing system.

Figure 2. Existing Approach Channel Bridge

The substructure units consist of an abutment at each end and six piers, all of which are on a 20° skew. The spacing of the piers is such that the first and last spans are 27.2 m, and all the intermediate spans are 27.6 m long. The piers are of a “hammer head” configuration. The middle portion is 2.4 m thick, matching the diameter of the upper, variable height, pier shaft. The upper shaft extends down below the water line to rest on a much larger 5.5 m dia. lower shaft. Each pier is founded on a 13.7 m square spread footing cast directly into a pocket excavated into the bedrock (see Figure 3).

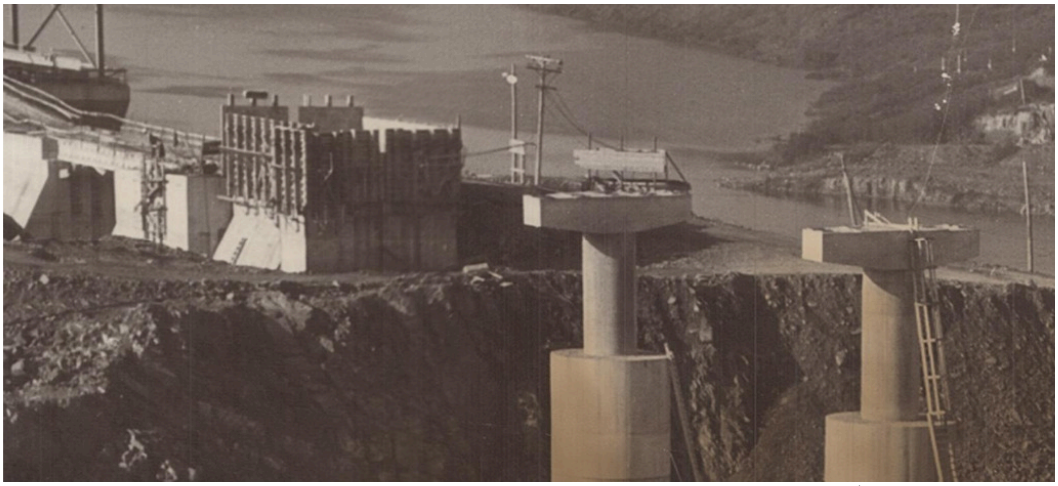
Figure 3. Bridge under construction prior to flooding of the head pond.



Source: Énergie NB Power

The north abutment is a conventionally reinforced cast in place concrete closed abutment on a spread footing with a strip seal expansion joint and approach slab. Little information is available regarding the south abutment as it was constructed under a separate contract as part of the spillway. Based on the bridge record drawings and field measurements and observations, the beam seat has similar geometric properties to the north abutment, however, the foundations are part of the spillway’s deep gravity retaining structure. (See Figure 4)

Figure 4. South Bridge seat is integral to the Dam's diversion spillway.



Source: Énergie NB Power

Bridge Condition Assessment

A detailed bridge condition assessment was completed in advance of detailed design. The condition assessment included an Ontario Structures Inspection Manual (OSIM) based visual assessment of all above and below water elements, a concrete coring and materials testing program, a Ground Penetrating Radar (GPR) scan of the bridge deck and a structural evaluation of the superstructure and select substructure elements.

This information was compiled into a pre-design report which summarized all the assessment's findings and provided a rehabilitation strategy which would enhance the performance and long-term durability of the bridge.

Detailed Visual Inspection

The visual condition assessment resulted in the list of recommended work items summarized in Table 1.

Table 1. Summary of Major Recommended Work Items

Element	Recommended Work
North Abutment	Resurface the abutment wall, ballast wall, bridge seat, curbs, sidewalk, and end posts. Replace the bearings and expansion joint
South Abutment	Inject cracks and encapsulate the concrete breastwall and wing walls. Replace the Expansion Joint.
Piers 1-6	Replace all bearings, Encapsulate all cap beam vertical faces and soffit concrete. Encapsulate the upper shaft with a grouted confinement jacket, repair the delaminated concrete of the lower shaft
Deck	Replace the barriers, replace the deck overhangs and partial depth deck top replacement. Investigate the cause of excessive camber in each span. Replace the expansion joints and repair delaminations and spalls in the end diaphragms.
Beams	Localized repairs to severe defects at the beam ends Repair and re-stress severed prestressing strands in two fascia girders

The following figure 5 provides a sampling of sampling of the high criticality defects observed during the detailed visual inspection.

Figure 5. Condition of existing structure (1) wide pattern cracking in the south abutment; (2) severe scaling at the water line and wide vertical cracks in the upper pier shafts; (3) Exposed rebar in curbs and overhangs; (4) broken and missing rail posts; (5) very wide cracks and delamination of the lower pier shafts

Bridge Structural Evaluation

A structural evaluation for live loading was completed in accordance with Section 14 of CAN/CSA-S6:19 using the CL-625-ONT design vehicle. No special permit vehicles were requested by the client to be included in the evaluation. Additional analysis efforts completed to inform the pre-design decision making included a structural evaluation of the hammerhead pier cap beams as well as analysis of the pier to determine if re-articulation of the bridge was feasible.

<u>Concrete Deck Overhangs</u>

The bridge barrier elements were assigned a high criticality due to their severe defects and concerns for safety. Severe concrete defects at the anchorages and limited availability of the proprietary cast steel elements mandated a full replacement of the barrier system. A Test Level 2 barrier was deemed appropriate for the bridge based on the calculated barrier exposure index, but the client indicated that a tall, four rail Test Level 4 steel system was preferable for safety and conservatism. Details for the preferred barrier system, based on one crash tested by the New England Transportation Consortium, were provided to the designers by the owner.

An evaluation was completed to determine if the existing deck overhang geometry was sufficient to resist the code prescribed barrier impact loading and it was determined that overhang strengthening would be necessary to develop the anchorage and strength required to resist these loads.

Prestressed Concrete Girders

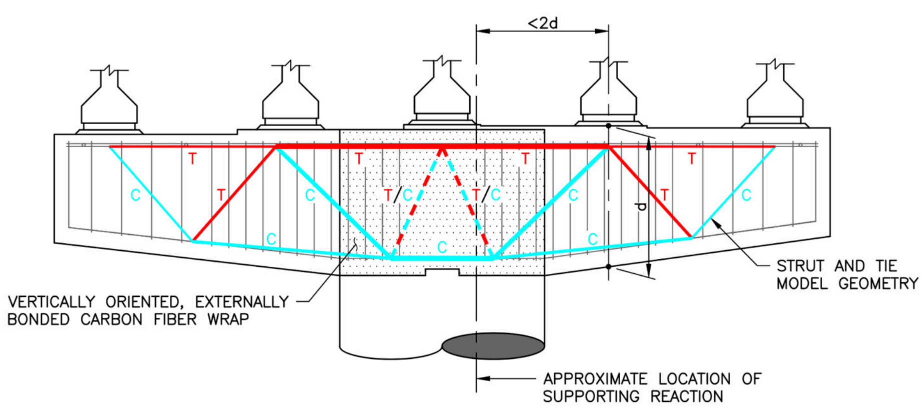
The structural evaluation of the girders was completed on the existing structural configuration to gain a sense of the demand to capacity ratio of these primary elements. A visual condition assessment which deemed the girders to be in good material condition, and a governing live load capacity factor of 2.14, indicated that the girders had sufficient residual life and capacity to be considered for continued use in the rehabilitated structure. Because the rehabilitation altered the girder load effects via the removal of asphalt, the inclusion of a variable depth slab and through introducing semi-continuity, we completed a revised analysis to verify that girder capacities could meet the revised demand. The analysis for the proposed load effects was completed by superimposing the load effects from the various construction stages, considering the locked in shrinkage stresses from the existing deck (scaled down due to partial deck removal), with the shrinkage stresses (reduced due to creep) from the new deck placement.

In the central three-span configuration, hogging moments would be created over the piers by live load in the remote end span. Due to the relative complexity of adding tension reinforcement to the bottom flange of the existing prestressed girders, the reconfigured superstructure was designed for the two span continuous condition with the expectation that nominal cracking may occur at bottom of the pier diaphragms. This cracking would occur in an area with benign environmental exposure and additional longitudinal reinforcement was specified in the pier diaphragms adjacent the girder flanges to control cracking.

Pier Hammerhead Cap Beams

The pier hammer heads were included in the superstructure evaluation due to the structural behaviour of the cantilevers and their apparent slenderness. The initial evaluation was completed by treating the cantilevers as conventional beams and checking both shear and flexure at the root of the cantilever. Using this methodology an LLCF of 0.99 in shear was determined, which, combined with the recognition that the region in question is a discontinuous region, led to a refinement of the analysis using strut and tie modelling. However, due to the lack of reinforcement over the pier shaft, the strut and tie models were deemed inconclusive. As such, it was deemed necessary to provide supplementary reinforcement directly over the pier shaft. Rehabilitation designers collaborated closely with a contractor specializing in the design and installation of externally bonded carbon fiber reinforced polymer reinforcing to develop an appropriate strengthening solution.

Figure 6. Strut and Tie Model of cap beam indicating high tensile forces in the region with little shear reinforcement.



Altered Pier Loading

Altering the bridge articulation to a 2/3/2 span configuration attracts additional load to the piers being fixed. As such, a calculation of the bridge seismic performance was necessary to determine if the new arrangement was feasible. The bridge was determined to be in seismic performance category 2 and is classified by the owner as an “other” bridge which allowed for a force-based design approach. The resulting seismic shear forces were used to evaluate the pier shafts for the additional axial load. It was determined that the bending and axial interaction capacity of the pier shafts exceeds the demand.

Proposed Rehabilitation

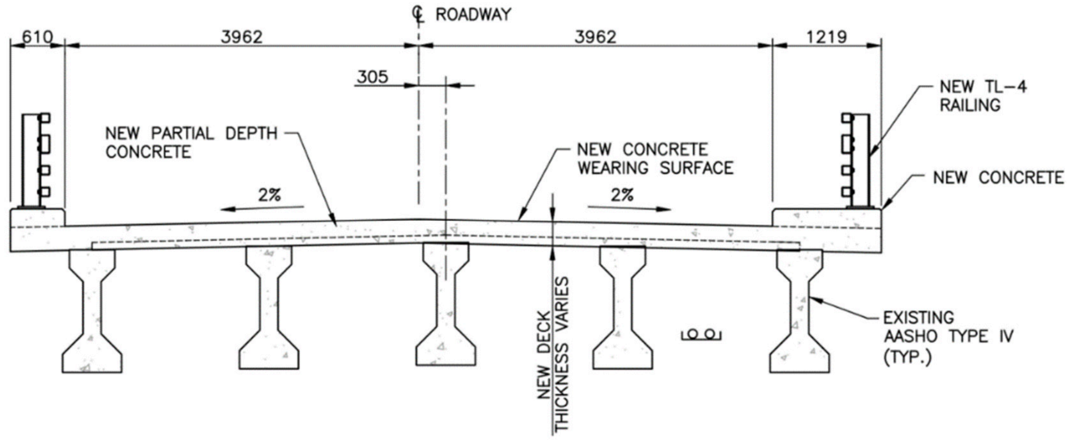
Based on the results of the inspection, testing and evaluation, a rehabilitation strategy was devised which takes advantage of the need to replace a major portion of the deck to enhance the long-term performance and durability of the bridge. The primary elements of this strategy include:

- Complete removal of the deck overhangs, partial depth removal of the deck concrete between fascia girders and replacement with a variable thickness deck (min. 240 mm) with integral concrete wearing surface.
- Reduce the overall number of expansion joints from eight (8) to three (3) by converting the north abutment to semi-integral and changing the bridge articulation from seven simple spans into three spans made continuous for live load.
- Complete replacement of the barrier system with a new TL-4 rated galvanized steel system.
- Replace all bearings on the piers and north abutment. (South abutment bearings had already been replaced in the year 2000 and were in good condition.)
- Stabilization of the south abutment breast and wingwalls by crack injection and post-tensioned grout bonded concrete anchors.
- Encapsulation and strengthening of the pier cap beams using externally bonded carbon fiber wrap as well as the implementation of a hybrid cathodic protection system for the top surfaces.
- Repair the lower pier shaft severe defects by tremie build-out and encapsulate the upper shaft with a grouted steel pipe casing.
- Repair localized severe concrete defects in the girders including replacement and restressing of severed prestressing strands and patching under pre-load.

Variable Depth Reinforced Concrete Deck Overlay

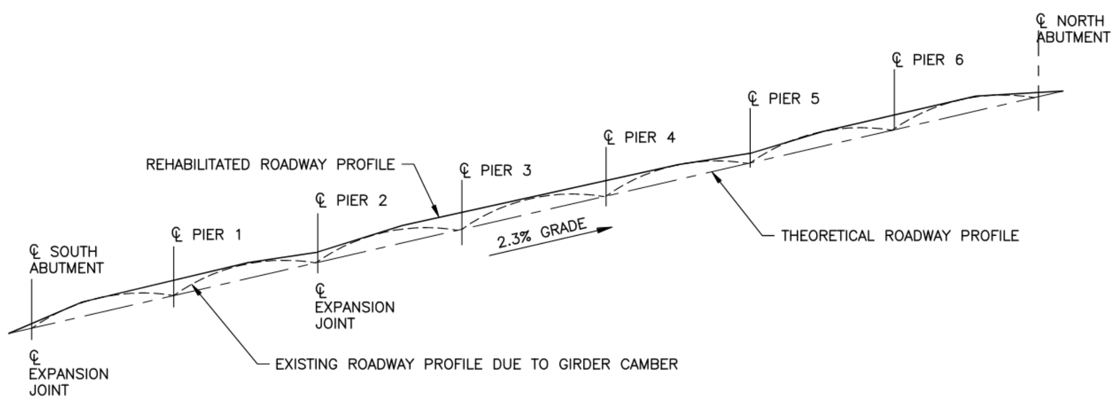
The post-rehabilitation roadway geometry of the bridge remains unchanged. However, the asphalt is replaced with an exposed concrete wearing surface to gain structural depth for the overhang and barrier anchorage (See Figure 7).

Figure 7. Proposed new deck cross section.



The existing deck also has a noticeable camber in each span which is suspected to be due in part to not having any haunches over the girders during original construction. The deck was inset 6 mm into the 178 mm thick deck at the centerline of bearings to compensate for erection camber. Any camber growth beyond that expected would have resulted in a significant reduction in deck thickness over the girders at mid-span. It is likely that the deck was placed to match the girder camber, which has resulted in a bridge with seven "humps." By varying the deck thickness longitudinally and introducing continuity over the piers, the new deck profile will be much smoother (see Figure 8).

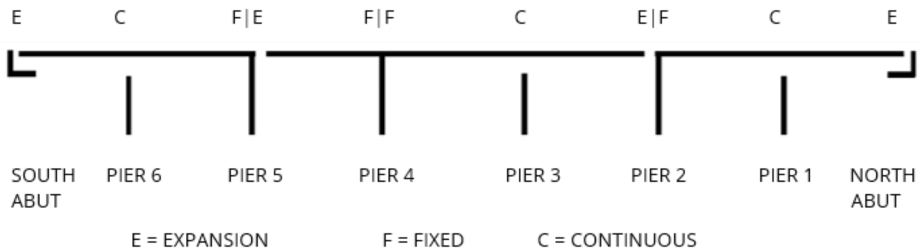
Figure 8. New (diagrammatic) longitudinal roadway profile



Re-articulation of the Superstructure

Recognizing that a thicker deck would increase the mid-span dead load moment in each girder, rearticulating the bridge to make it semi-continuous for live load was used to both redistribute mid-span moments and eliminate deck expansion joints. After investigating several options for providing longitudinal fixity and expansion at different supports, a two-span, three span, two span arrangement was found to provide the best geometric compatibility with the existing structure without requiring significant bearing and abutment reconfiguration to accommodate large restraint forces or large movement joints (see Figure 9).

Figure 9. New Bridge Articulation

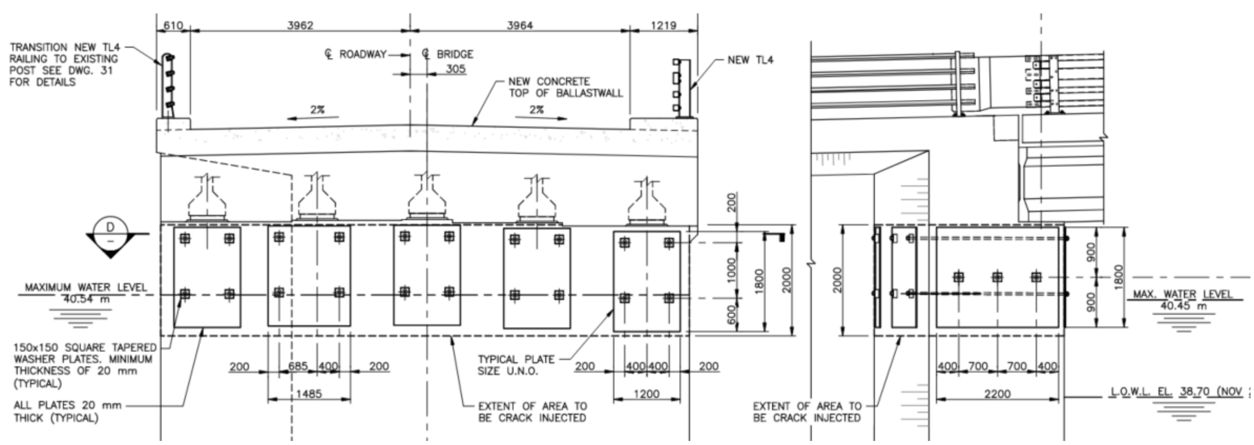


At each location where the bridge is proposed to be made continuous over a support, the girder ends will be encased in a monolithic transverse concrete diaphragm. Link slabs were investigated and ruled out due to excessive skew and girder depth.

South Abutment Stabilization

The south end of the bridge bears on a portion of the Mactaquac dam called the north bulkhead wall which is a gravity retaining structure that has AAR damage including wide pattern cracking and severe scaling of the concrete above water level. A review of record drawings and materials testing revealed that there is minimal reinforcement and unsound concrete in the bridge seat area. A conventional replacement by encapsulation approach would have resulted in extensive concrete removals below the bearings. As such, the approach taken to stabilize the bridge seat was to inject all the medium to wide cracks with a resin-based grout followed by installation of galvanized steel confinement plates anchored to the concrete surfaces using post-tensioned grout bonded anchors (see Figure 10).

Figure 10. South Abutment confinement plates

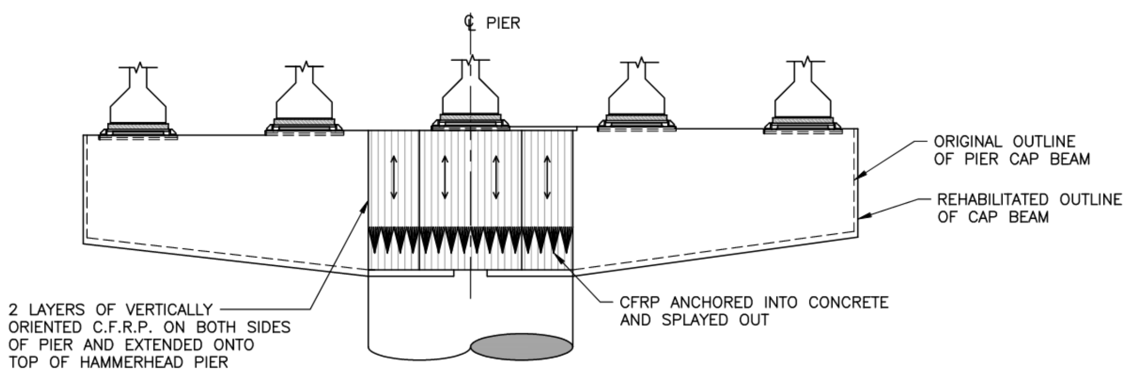


The anchors are 25 mm dia. threaded steel bar in 100 mm diameter holes. Through bars are horizontal and plated at each end and bonded anchors slope downwards at 15 degrees and have a 6 m embedment depth. Plating is located under each girder and, together with crack injection and nominal post-tensioning forces, provides the confining stresses to maintain aggregate interlock and resist the applied bearing forces.

Cap beam strengthening and bearing replacement.

To address the existing pattern of medium to wide cracks in the vertical faces and soffits of the pier cap beams, the existing piers will have the surface concrete removed to the mid-depth of the existing stirrups. The surfaces of the beam will be built out using a layer of self-consolidating concrete anchored to the existing with a doweled-in layer of new reinforcement to control cracking. Galvanic anodes will be incorporated into the overbuild to minimize the corrosion of existing reinforcement. A hybrid galvanic protection system is incorporated into the top surfaces of the pier caps to both protect and repassivate the existing flexural reinforcement against further corrosion.
Vertically oriented, externally bonded, carbon fiber reinforcement will be applied to the pier surface directly over the pier column to provide axial tensile resistance in this area as identified by the strut-and-tie modelling. (See Figure 11)

Figure 11. Externally bonded CFRP strengthening of the pier cap beams.

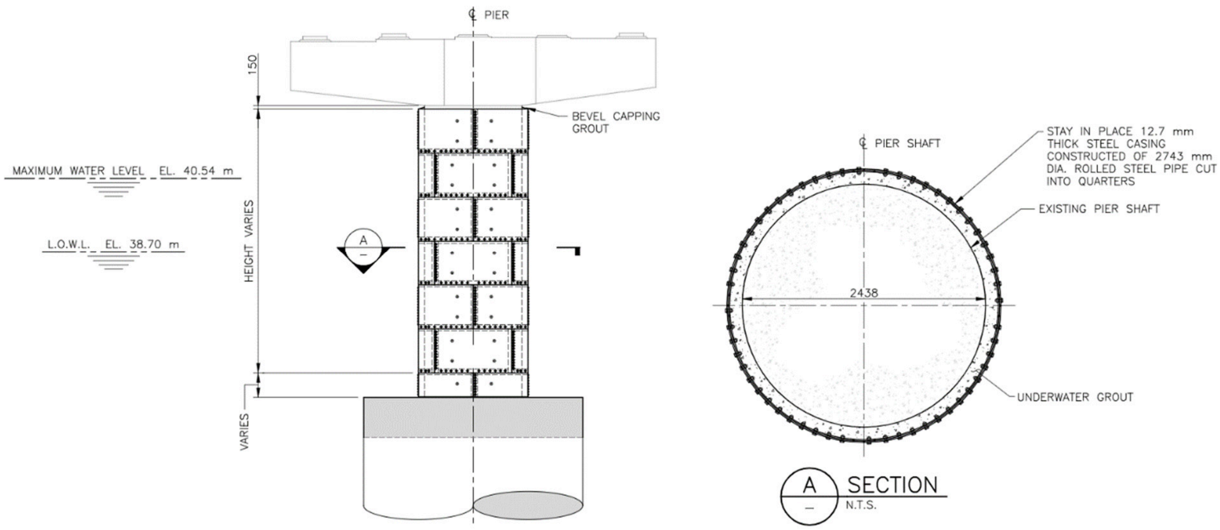


Lower pier shaft build-out and upper shaft encapsulation

The upper shoulder of the lower pier shaft has extensive concrete delamination and disintegration due to AAR expansion and lack of confinement steel. The top 600 mm of this element will be reconstructed and a new 1.0 m thick reinforced tremie concrete cap added to provide confining hoop stress to the lower shaft.

Above this, the upper shaft has extensive wide vertical cracking due to AAR expansion and severe scaling at the water line due to freeze-thaw and an inadequate air void system. To confine the cracking and protect the shaft from further deterioration, the shaft will be encapsulated using 13 mm steel casing plates fabricated from sections of 2743 mm dia. rolled steel pipe. The casing will be filled with a shrinkage compensated underwater grout.

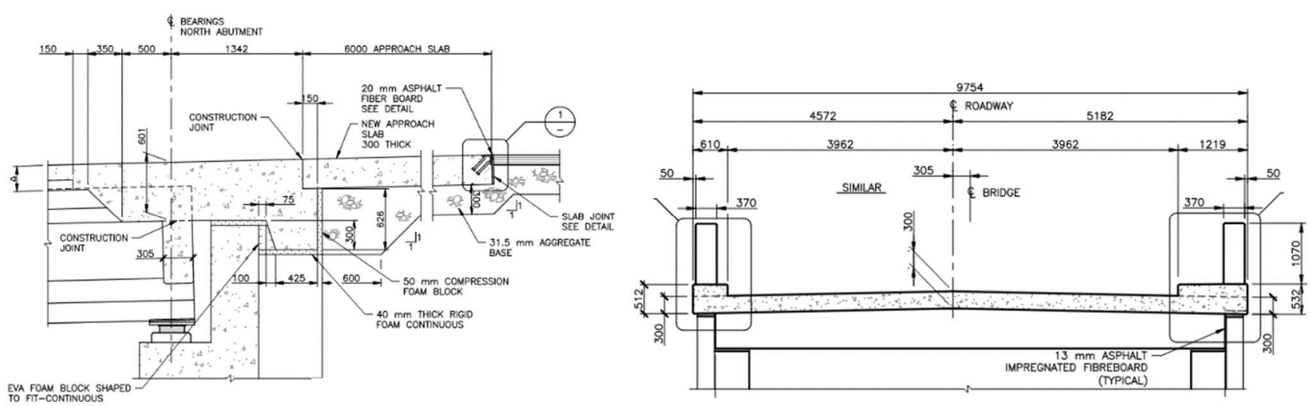
Figure 12. Grouted steel pipe encapsulation of the upper pier shafts



North Abutment semi-integral conversion

The end posts, curbs, sidewalks, and expansion joint were all in poor condition and both the end posts and wingwalls were found to be insufficient to resist the desired TL-4 barrier loading. As such, a semi-integral conversion was investigated whereby a new approach slab would be supported by an extended deck edge stiffening element. The approach slab extends over the existing wingwalls, thereby isolating the wingwalls from barrier impact forces. The sidewalk, curb and end posts are integral with the approach slab.

Figure 13. North Abutment semi-integral conversion section (left) and approach slab configuration (right)



Project Schedule

The deliverables for the project included the provision of a preliminary construction schedule to help identify risks to the project schedule, consider the work sequencing from a structural perspective and for annual budgeting of the work over the predicted two and half years of construction. In all instances, the primary goal was to complete the bridge rehabilitation prior to NB Power commencing the MLAP project in 2025.

The project team explored two primary work breakdown/schedule options in developing the P&S (Plans and Specifications). The first was to completely close the bridge for a full year to give the Contractor an opportunity to complete all the superstructure work in the first year free from the encumbrances of traffic control and to have the two full lanes open in year two with all in water work being completed in parallel but with minimal impact to the travelling public. The second option included rehabilitation of the superstructure one lane at a time over two consecutive years. In water work would happen in parallel with the superstructure work. The bridge ADT is 4420 and the shortest detour is about a twenty-minute drive.

The project team hosted meetings with local stakeholders who might be impacted by a full bridge closure including local businesses, the adjacent provincial park, the adjacent first nations community and regional emergency services and bussing coordinators. The meetings identified a preference for a full bridge closure for one year to restore the bridge to two-way traffic in year two. The owner instructed the Consultant to proceed with the development of the Tender package assuming a full bridge closure, thereby eliminating the need for more sophisticated work phasing and resulting in lower engineering and traffic control costs. The tender package (estimated cost of $11.6M) was advertised in March of 2022 and subsequently cancelled shortly thereafter. The consultant was asked to reconfigure the project P&S to maintain a lane of traffic throughout construction. The revised P&S (estimated cost of $12.3M) were submitted at the end of June 2022. Several delays occurred during the tender period to review the potential impacts of high unit price items resulting from supply chain issues during the Covid pandemic including a preliminary design to change the deck reinforcing from stainless steel to GFRP. As tenders for other major rehabilitations in the region closed, the estimated unit prices were revisited, and a decision was made to continue with the preferred stainless steel deck rebar option. The project was awarded to the sole bidder, Julmac Contracting limited for $17.74M on September 1, 2022, giving the Contractor approximately 27 months to complete the work.

Construction Sequencing

A sequence of major construction stages was provided in the tender documents to define several key contract parameters:

1. The elements with highest structural criticality would be repaired first to enhance roadway safety and avoid load posting.
2. Complete repairs in a logical sequence with respect to structural considerations.
3. Align estimated milestone work completion dates with annual budget allotments.
4. Complete as much work in the remainder of the 2022 construction season as possible while addressing high-criticality safety concerns.

The sequencing resulted in three major work stages corresponding to the available construction seasons:

Stage 1 (Fall of 2022):
- Close northbound lane to install a temporary guide rail on the east side of the bridge and complete concrete repair and restressing of severed strands in east fascia girders.
- Stabilize the south abutment breastwall via crack injection and the installation of the anchorage and confinement system.
- Complete all concrete work on pier one including lower shaft concrete repairs, upper shaft encapsulation and cap beam removals and repairs.

Stage 2: (2023 Construction):
- Complete concrete repairs and encapsulation of remaining five piers.
- Complete localized girder concrete repairs,
- Complete partial depth replacement of north abutment breastwall
- Strengthen all pier cap beams using externally bonded CFRP.
- Replace all bearings.
- Replace west half of deck, sidewalk, and barriers.

Stage 3: (2024 Construction):
- Replace east half of deck, curb, and barriers.

Specific Project Risk – Water Flow

There are many risks associated the rehabilitation of bridges: availability of skilled Contractors and their willingness to bid, structure of the contract, weather delays, unexpected issues identified during construction, environmental issues, to name but a few. One of the specific major risks identified early in the conception of this project was how seasonal and storm variation in water levels and flow rates through the dam's inlet channel might affect the Contractor's ability to schedule and complete the significant amount of in-water work associated with this rehabilitation.

To address the challenge of unpredictable water flow, the project team needed a way to quantify the frequency of high-flow events. This information would help limit potential disruptions for the contractor and provide a clearer picture of windows for completing in-water work. By quantifying potential high-flow events, the project offered potential bidders a better understanding of realistic opportunities to conduct crucial in-water work during construction.

NB Power were able to provide total hourly inflow data arriving just upstream of the dam over a six-year period from June 1, 2015, to December 30, 2021. Fortunately, this period overlapped with times when the project consultant had previously conducted multiple rounds of underwater bridge inspections utilizing a local diving contractor. In very general terms, under summer flow conditions (i.e. no spilling) the flow rate in the channel is controlled by the number of turbines operating to meet electricity demand. While the divers completed their work, records were kept as to how many turbines were operational and how difficult it was to continue the inspection. We were then able to use this data as an aid to estimate how many days out of the year underwater construction activities could occur. This data was provided to potential bidders for information only to help define the risk to schedule delays associated with underwater work.

Project Status

As of early September 2024, the project is significantly behind schedule with a revised expected completion date of May 2026. Progress to date includes:

- Suspended scaffolding and swallow netting has been erected under the north half of the bridge (Fig. 14)
- Four of the six lower piers shafts have been repaired and tremie concreted. (Figures 15 & 16)
- The south abutment breastwall cracks have been epoxy injected.
- The north abutment breastwall partial depth concrete repairs have been completed. (Fig. 17)
- Hybrid fusion anodes have been installed in the west half of the pier cap beams (Fig. 18)
- All replacement bearings have been fabricated and are on site (Fig. 19).
- All upper pier shaft casing plates have been fabricated and are on site (Fig. 20).
- The west half of the bridge deck, sidewalk and barriers have been placed (Fig. 21) and traffic has been switched to the west lane, allowing demolition of the east half of the deck to proceed (Fig. 22).

An astute reader will recognize that some of the high-criticality items intended to have been completed in the fall of 2022 have yet to be completed. This has resulted in the posting of the bridge to 30 tonnes to allow emergency and passenger vehicles only to cross the bridge and the posting will remain until all high-criticality repairs have been completed. Items such as severe cracking in the south abutment and the severed strands in the girders are being monitored for movement/cracking as the rehabilitation proceeds.

Figure 14. Suspended scaffolding erected under bridge for pier encapsulation and bearing replacement work.

Figure 15. Lower pier shaft concrete removals completed exposing embedded pile steel. Note circumferential saw cut. The removals in this area will be reinforced and tremie concreted.

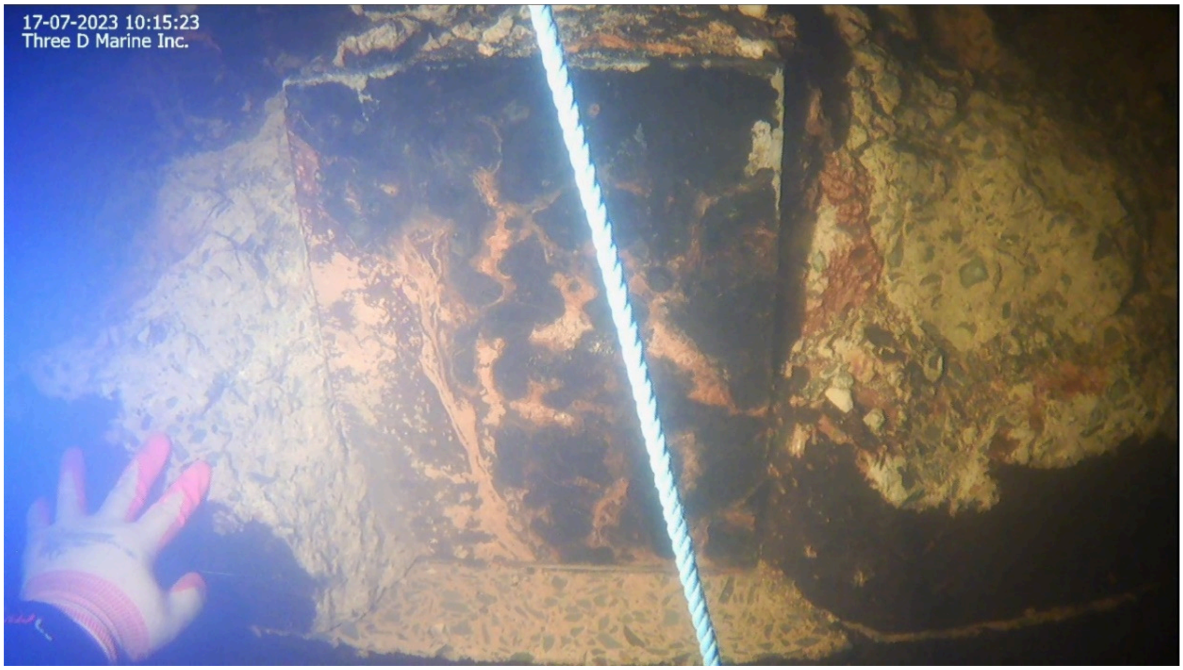


Figure 16. Dry fit of circular EFCO form on grade before lowering segments and installing form on lower pier shafts underwater for eventual tremie concrete placement

Figure 17. North Abutment breastwall has been reconstructed incorporating a distributed anode system. Bearing replacement will be completed later.

Figure 18. Hybrid Fusion galvanic anodes being installed into the top surfaces of the pier hammerheads by Vector Corrosion Technologies.

Figure 19. New bearing assemblies have been fabricated and delivered to site.

Figure 20. Coated upper pier shaft casing plates have been delivered to site and await installation.

Figure 21. West half of deck rehabilitated and open to traffic.

Figure 22. East half of deck asphalt and barrier partially removed.

Conclusion

The Inlet Channel Bridge is critical to the success of the Mactaquac Life Achievement Project which is slated to begin major phases of construction in 2025. Work on the bridge rehabilitation started late fall of 2022 and is nearing the mid-point of construction. Though originally scheduled to be completed by November of 2024, the current revised schedule estimates a May 2026 completion. The Contractor's current priority is to place the second half of the deck, to complete the south abutment stabilization work and repair the severed prestressing strands on two fascia girders such that the bridge can be reopened to full unrestricted traffic by the end of 2024 such as to avoid negatively impacting NB Power's MLAP work scheduled to begin in the spring of 2025. Once unrestricted traffic is restored to the bridge, work will continue for the substructure rehabilitation, including the tremie grouting of the remaining two lower pier shafts, the encapsulation and grouting of all six of the upper pier shafts, the hammer head cap beam over-builds, and the replacement of the pier bearings.

The rehabilitation will improve user safety, roadway ride quality, and structure durability and allow for the MLAP to proceed utilizing the bridge without load restrictions. While there are still some portions of the bridge which will require monitoring, the renewal of the Approach Channel Bridge will minimize future maintenance requirements.