17 APRIL 2024
ACEC-CANADA | CANADIAN CONSULTING ENGINEER

A Murray MacKay Bridge Deck Panel Replacement

2024 CANADIAN CONSULTING ENGINEERING AWARDS – PROJECT ENTRY

Submitted to: Canadian Consulting Engineer

Submitted by: COWI

Contact: Aaron Ferguson, P.Eng., P.E.
Email: aafe@cowi.com
Phone: 1-902-418-5442

Client: Halifax Harbour Bridges

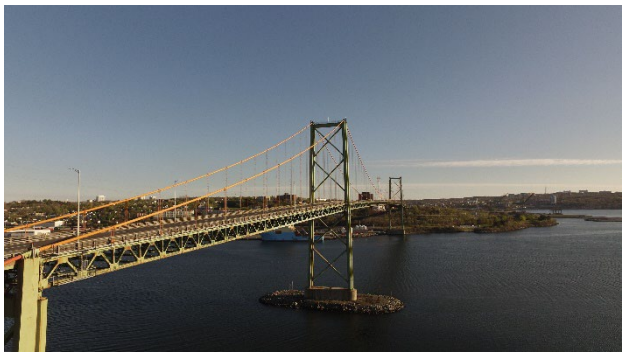
Halifax Harbour Bridges

COWI



1 Introduction

The A. Murray MacKay Suspension Bridge opened to traffic in 1970 and carries four lanes of traffic over the Halifax Harbour between Dartmouth and Halifax. The suspended structure of the bridge is approximately 740 meters in length and deck system comprises longitudinal stiffening trusses, transverse floor trusses and an orthotropic steel plate deck (OSPD). The OSPD consists of approximately 231 panels which are spliced together with hundreds of thousands of bolts. This project involved the design, fabrication, and erection of two replacement OSPD panels during full weekend bridge closures.



Today, there are approximately 65,000 vehicle crossings daily (average weekday), including buses and transporter trucks. The bridge acts as a critical arterial for the residents of the Halifax Regional Municipality and is the most critical of the five throughways on-and-off the Halifax peninsula, especially for heavy loaded trucks. The MacKay Bridge is an essential piece of infrastructure for Halifax Regional Municipality (HRM) and the Province of Nova Scotia representing approximately $120 million of annual economic benefits, and more than 1,110 jobs. Lane and bridge closures are highly disruptive to residents of HRM including the local economy requiring the careful planning, execution, and delivery of important maintenance and rehabilitation work to retain the operational and serviceable use of the structure.

1.1 Background

The MacKay Bridge was a state-of-the-art design when it was opened, an efficient design that incorporated many features that were technological advancements. One of the most significant advancements, which is the main object of the presented project, was the use of a light OSPD. However, at the time of its design, the fatigue life of OSPDs was not yet well characterised. The MacKay Bridge deck plate is 9.5 mm thick which is notably thinner than the design standard requirements of today and has experienced fatigue cracking as a result.

Recently, COWI and HHB have been investigating the impacts of the fatigue life on the MacKay Bridge since 2004 comprising of:

- 2004: OSPD review and recommendations for improved fatigue life performance involving removal of fatigue-prone field-installed OSPD attachments.
- 2009-2019: ongoing annual / detailed inspections.
- 2014: a study was performed to estimate the remaining life of the bridge and concluded the fatigue loading would not likely result in widespread cracking of the OSPD until 2028 to 2038 but that localized cracking can occur sooner.
- 2019: during a repaving project, a detailed inspection of the top surface of the OSPD deck plate identified four isolated cracks. These cracks were repaired. Although not widespread cracking, this suggested the fatigue cracking of the deck had started as predicted in the 2014 study.
- 2022: began augmenting maintenance and inspection activities bi-monthly thermographic drone inspections (by others) to identify water infiltration into troughs, and which helps target further hands-on investigation in difficult-to-access areas. Crack repairs of two 2019 observed crack re-openings.

Since 2019 and to mitigate the risk of further crack propagation, a proactive inspection program was adopted which includes provisions for repairs of identified cracks. However, if cracks consistently reappear in the same location, or if multiple cracks occur within a short distance, it becomes more appropriate to perform a replacement of the affected OSPD panel rather than continuously repair.

1.2 The Project

Based on the complexity of replacing sections of the deck, COWI (in 2019) recommended that HHB proactively prefabricate OSPD panels to have on-hand for installation and to establish erection procedures for their installation. For this project, HHB took this recommendation a step further and mandated that two OSPD replacement panels be prefabricated, and two existing panels be replaced to confirm the feasibility of the project prior to a potential emergency replacement. Additionally, HHB had two additional panels prefabricated to have stored in



case of a required emergency replacement. Without prefabricated panels, if an emergency occurs, HHB would likely be required to partially (or fully) close the bridge for safety for months while the design, fabrication, and installation of the replacement panel resulting in an unprecedented disruption to the city.

Though the exact dimensions of the existing panels vary along the bridge, COWI designed and detailed the OSPD replacement panels as modular such that they would work for the replacement of most of the existing panels. Each OSPD panel is approximately 9.6 m long and 5.5 m wide.

For this project, HHB was the Owner and procurement group representing themselves and the MacKay Bridge. COWI was responsible for the detailed design of the OSPD replacement panels and worked with HHB during tender, fabrication and through construction which concluded in early 2023 December. COWI and HHB's scope included but was not limited to project management, design of modular OSPD replacement panels, inspection of exposed top surface of OSPD deck during repaving, structural analysis of the bridge during erection, and design services during construction.

COWI's design and construction support work on the project represents approximately 2,200 hours of engineering effort and over 90% of which was performed by staff living and working in Halifax. This exemplifies HHB and COWI's commitment to developing the local technical knowledge of long span cable-supported structures.

Representing an entirely local fabrication and construction team, Dexter functioned as the prime contractor for the project with Cherubini Metal Works performing the fabrication and installation of the OSPD replacement panels. The full construction project included:

- fabrication and corrosion protection of two OSPD replacement panels (9.6 mx 5.5 m in size; 10,000 kg each),
- removal of two existing OSPD panels,
- installation of two OSPD replacement panels.

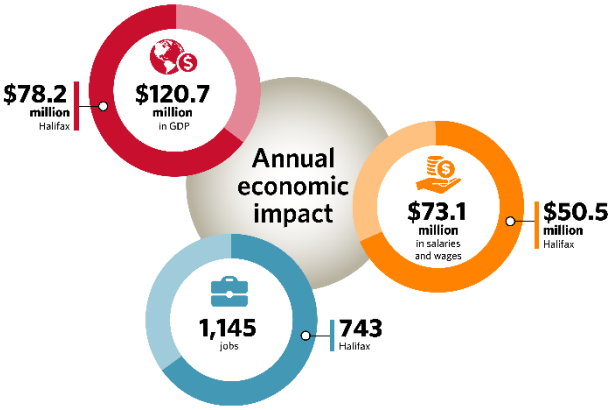
2 Sustainability

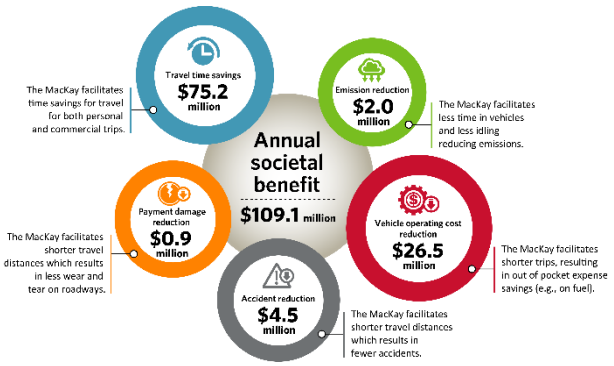
2.1 Extending Service Life

This project represents a collaboration between Owner and Consultant when a detailed scope of work is scheduled, executed, and delivered by parties working towards a common goal. Efficiencies and improvements can be adopted from prior projects to the next to continuously improve the deliverable product. The value achieved through a long-standing relationship permits an unrivalled potential in rehabilitation applications to extend the service life of existing structures and contribute to the shared responsibility of sustainability through mitigation of carbon-intensive new construction.

2.2 Socio-Economic Factors - Local Economy

The MacKay Bridge is a vital link joining the communities of Dartmouth and Halifax. The only other vehicular harbour crossing is the Macdonald Bridge, which cannot by itself accommodate all daytime traffic across the harbour or heavy vehicles (excluding buses). The MacKay Bridge provides more than $120 million of economic benefits to the Nova Scotia economy annually by: enabling $73 million in employment income supporting 1,145 jobs (with more information below).





The project was executed considering the impacts other stakeholder and events in HRM, including but not limited to: the Halifax Port Authority (commercial and recreational shipping traffic that pass under the bridge and not closing the channel), Halifax Transit



(updated bus and shuttle routes when bridge is closed), and HRM (2023 Parade of Lights event. Local partners were major participants throughout the project and were invaluable in the successful completion of the work. The majority of the engineering, project management, and construction of the value of the project was based in Nova Scotia.

2.3 Socio-Economic Factors - Public Awareness

The OSPD replacement project was an impressive engineering feat and HHB wanted to share the complexity and necessity of the project in the media to assist the public in understanding the work taking place and the reasons why the bridge needed to be closed. Photos and media clips, including dedicated social media posts, helped achieve this objective by notifying the public with ample notice while "showing" the work via site photos.

Additionally, a priority was placed on the ability to perform the work during a weekend closure to mitigate the effect on daytime traffic throughout the week. This minimizes the effect of this important rehabilitation work on the general public.

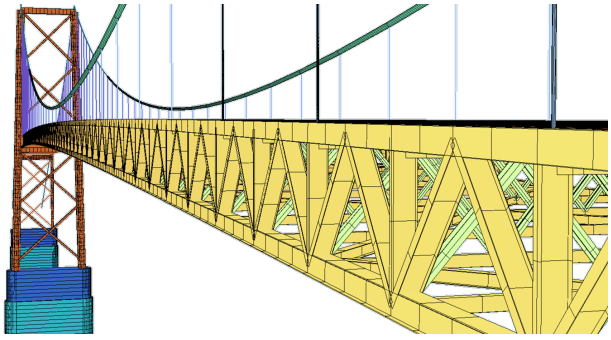
3 Creative Innovation

Replacing deck panels of a suspension bridge is rare, however, on the MacKay Bridge it was performed in 2011 for expansion joint replacements and to a much larger extent in 2015-2017 for the Macdonald Bridge "The Big Lift" project. An innovative approach was required in the application of engineering principles to address the unique set of challenges.

1. **Unknown location of the repairs:** Modular design allows HHB to pre-fabricate replacement panels in advance of replacement on the bridge and install in virtually any location providing HHB the maximum agility in risk management.
2. **Public use below bridge:** An erection method was selected involving crane lifting from deck level with a below-deck access platform and protection below the bridge (buildings, roadways, waterways, etc.)
3. **58.5 Hours:** Construction work occurred during weekend closures between 19:00 Friday and 05:30 Monday. This imposed deadline enhances the need for proper planning, hour-by-hour planning, and extensive contingency assessments to ensure the bridge was safe for use by the public. Once the critical path was identified, resources were allocated to provide the best opportunity to react to the unexpected nature of the work.
4. **Extreme and unpredictable weather:** Suspension bridges are vulnerable to wind, especially while they are in the process of being rehabilitated, so structural integrity during construction was paramount in the design and ensuring public safety throughout the project.
5. **Atypical construction loading:** To prepare for the potential of live load requirements during a panel replacement, the suspended structure was assessed under live loads with an OSPD panel removed. The OSPD is composite with the stiffening truss system and also transfers shear between the stiffening trusses as part of the lateral load resisting system. The analysis was performed using finite element analysis.

4 Structural Excellence

Separate to the local analysis model, COWI leveraged their finite element structural analysis model of the full suspension bridge (created through a separate project for HHB) to perform verifications of bridge behaviour under atypical loading conditions. The model was developed using the commercially available software, SOFiSTiK.





5 Elegant Solutions

The immediate reflection by HHB after project completion is the value and effectiveness of a well-executed risk reduction project to minimize disruptions to the public and mitigate maintenance expenses for aging infrastructure. In the case for this project, the genesis of the idea was formulated in 2019 and delivered four years later in 2023. Although cracks were observed OSPD, and subsequent repairs were documented and monitored, removing the risk of propagation prevents the matter from developing into a situation involving more repairs and additional traffic disruption.

COWI's onsite presence enabled troubleshooting and collaboration with HHB and the contractor for:

- verification of crane outrigger positions,
- review of updates to crane arrangement and assessment of effect on existing bridge components,
- fouling and conflict resolution during removal of the existing panel and installation of the new panel,
- direction on resolution for field modifications to suit existing conditions (note: there were over two thousand of bolts to install and tension).

Regarding the project's execution from design through installation, the table below summarizes the project's use of past lessons learned to remain agile and adaptable for this OSPD replacement project:

Design Approach
Replace panel "in-kind" • Match existing panel geometry/details for constructability. • Prevent additional weight to limit changes to a structure near its limit of capacity.
Detail modular panels that can be fabricated and installed at any location on the bridge. • Detail connection layout, including oversized and slotted holes to permit pre-fabrication of panels prior to knowing where they are required. • Assess effect of including slotted holes on the connection capacities.
Perform erection sequencing analysis and provide suggested procedure. • Mitigates schedule impacts and simplifies tender process for bidders.
Design Approach
Assess the capacity of the existing suspended structure to withstand the loads imposed due to erection. • Establish the requirements for crane loading on the existing bridge deck. • Work closely with the contractor to achieve a successful removal and installation.

Construction Approach
Shop visit reviews to allow designer (COWI) to perform structural reviews of panels in-progress and provide feedback directly to fabricator. • Facilitates a communication line between designer and fabricator to resolve technical matters swiftly.
Mandatory technical pre-closure meetings to troubleshoot anticipated challenges prior to installation. • Technical facilitation meetings to allow owner, designer, and contractor to have collaborative discussions prior to commencement of work.
Scheduling of work during weekends and with ample contingency • 58.5-hour weekend closures (Fri 19:00 to Mon 05:30) offer limited construction period with zero tolerance for late bridge openings requiring time contingency for unexpected delays (e.g., weather, high winds, etc.)
Post-panel replacement technical debriefing sessions to facilitate opportunities for improvement by all parties. • Continued pursuit of increased efficiency and effectiveness for implementation during next OSPD replacement.

The removed OSPD panels have been retained by HHB with plans to use them for future investigations and fatigue testing with the potential for future publications on the behaviour of existing OSPD panels.

6 Excellence In Engineering

One of HHB's ongoing goals for their projects is to foster knowledge transfer of cable supported structures to the Nova Scotia engineering and construction industry. The majority of the project staff are engineers, inspectors, technicians, drafters, and



project management staff who live and work full-time in the community.

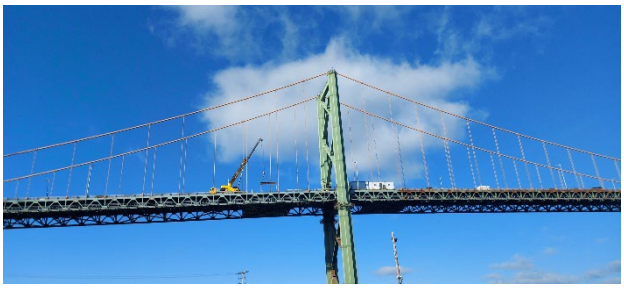
COWI's design and construction support work on the project represents approximately 2,200 hours of engineering effort and over 90% of which was performed by staff living and working in Halifax. This exemplifies HHB and COWI's commitment to developing the local technical knowledge of long span cable-supported structures.

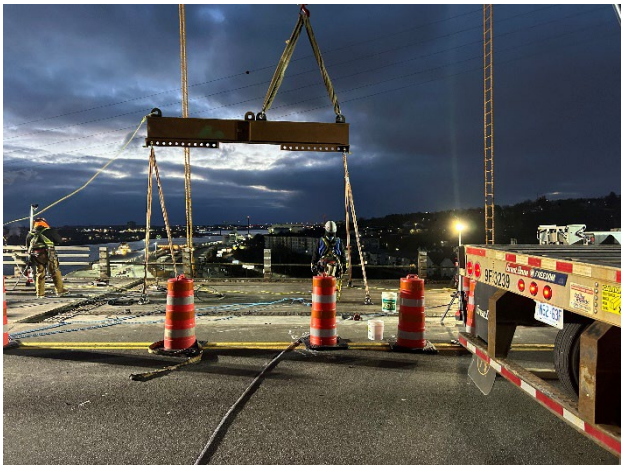
7 Results and Reflection

There were two primary phases of OSPD panel construction: materials procurement and fabrication for the two OSPD panels (2023 August to November) and installation of the panels onsite (2023 November to 2023 December). The timing and schedule of the work was critical to complete prior to winter weather to avoid freezing temperatures and complications for coating and asphalt placement. Although the bridge was and remains in a safe and serviceable condition, the timely rectification of the observed cracking permits HHB to re-allocate their resources to other maintenance matters. Eliminating the need for unexpected emergency repairs performed through sudden bridge closures has far-reaching positive impact on the residents of Halifax and Dartmouth. With the project to replace the two deficient panels complete, HHB's focus turns to pre-fabricating two panels to hold in reserve for future panel replacement (if and when needed) to mitigate the risk and potential of long-term closures if another panel were found to have cracks.

Residents of the Halifax Regional Municipality have relied on the MacKay Bridge to provide safe, reliable passage over Halifax Harbour since the bridge opened in 1970. Knowing that the bridge is showing signs of its age, residents have adapted to it being closed at occasional nights and weekends as HHB undertakes necessary maintenance work. The challenging work that comprises the replacement has been a perfect example of the importance of staying ahead of the natural deterioration process of structures, promptly acting before deterioration is too severe. Although full bridge closures will likely be required for future work, HHB continues improving the structure safety through careful planning and execution of rehabilitation programs and COWI remains as a trusted advisor to HHB's efforts.

This project has succeeded in both extending the useful service life of the MacKay Bridge and validated an OSPD replacement (emergency) program that HHB can resume at a future date if the maintenance needs arise. Additionally, though the work was performed on an in-service bridge, the impact to public was minimized by completing each panel replacement during single weekend closures. Looking ahead, removed deck panels will be investigated to identify remaining fatigue life and validate and/or modify the 2014 fatigue life investigation, which provides critical information for the future of the MacKay Bridge. As this project has enhanced the image of the profession in both the eyes of the public and the profession through technical excellence, COWI believe that this project is a strong candidate for the 2024 Canadian Consulting Engineering Award of Excellence under the Transportation category.






GROVE
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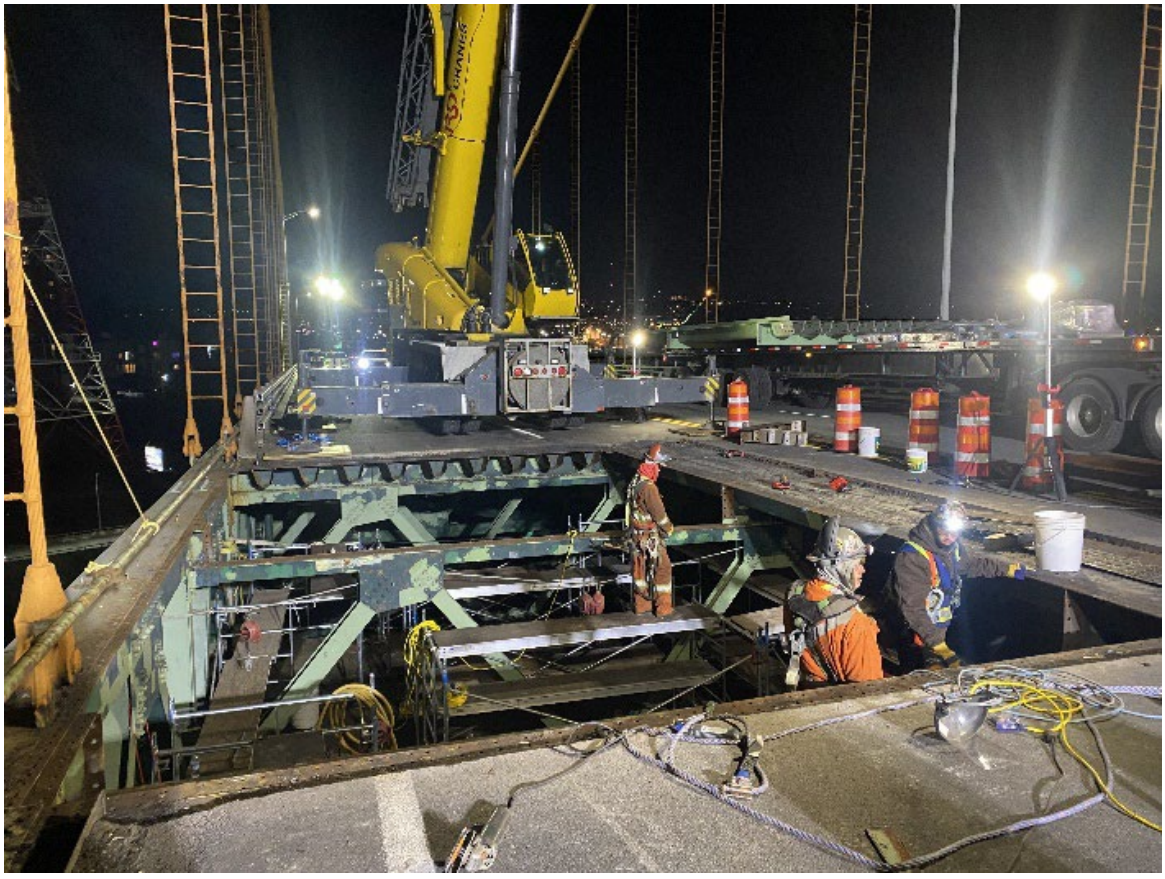
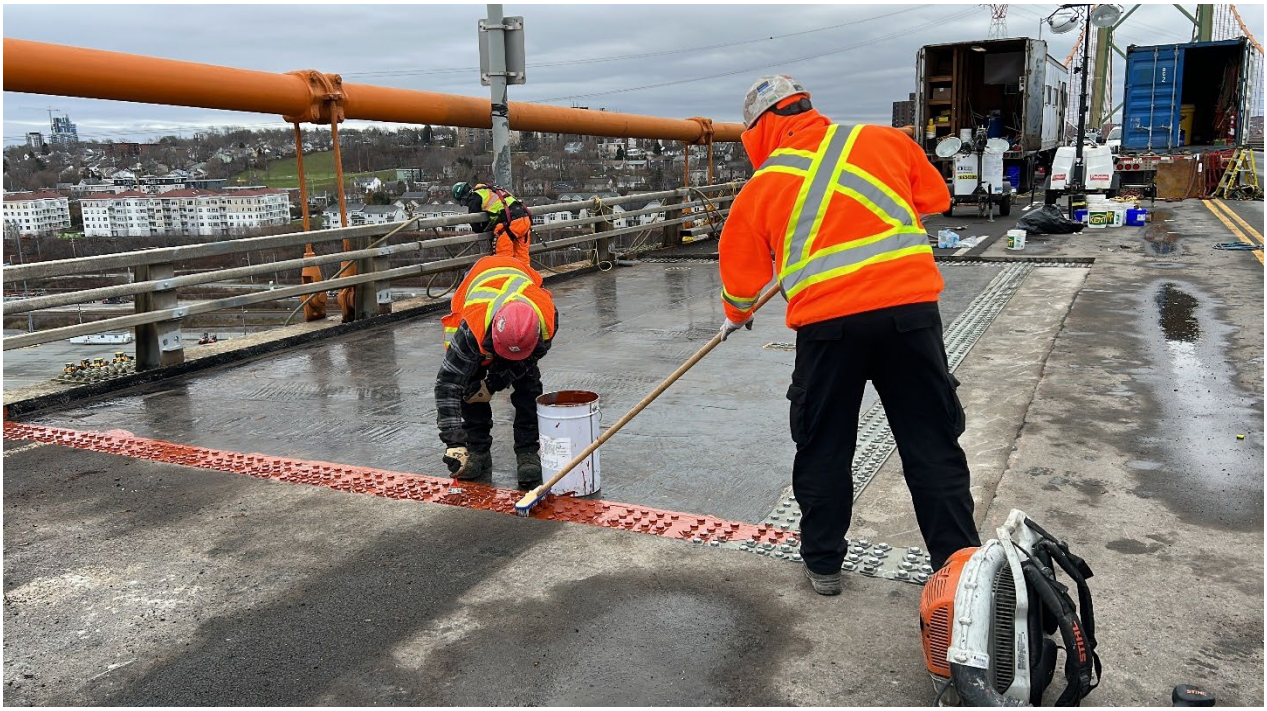
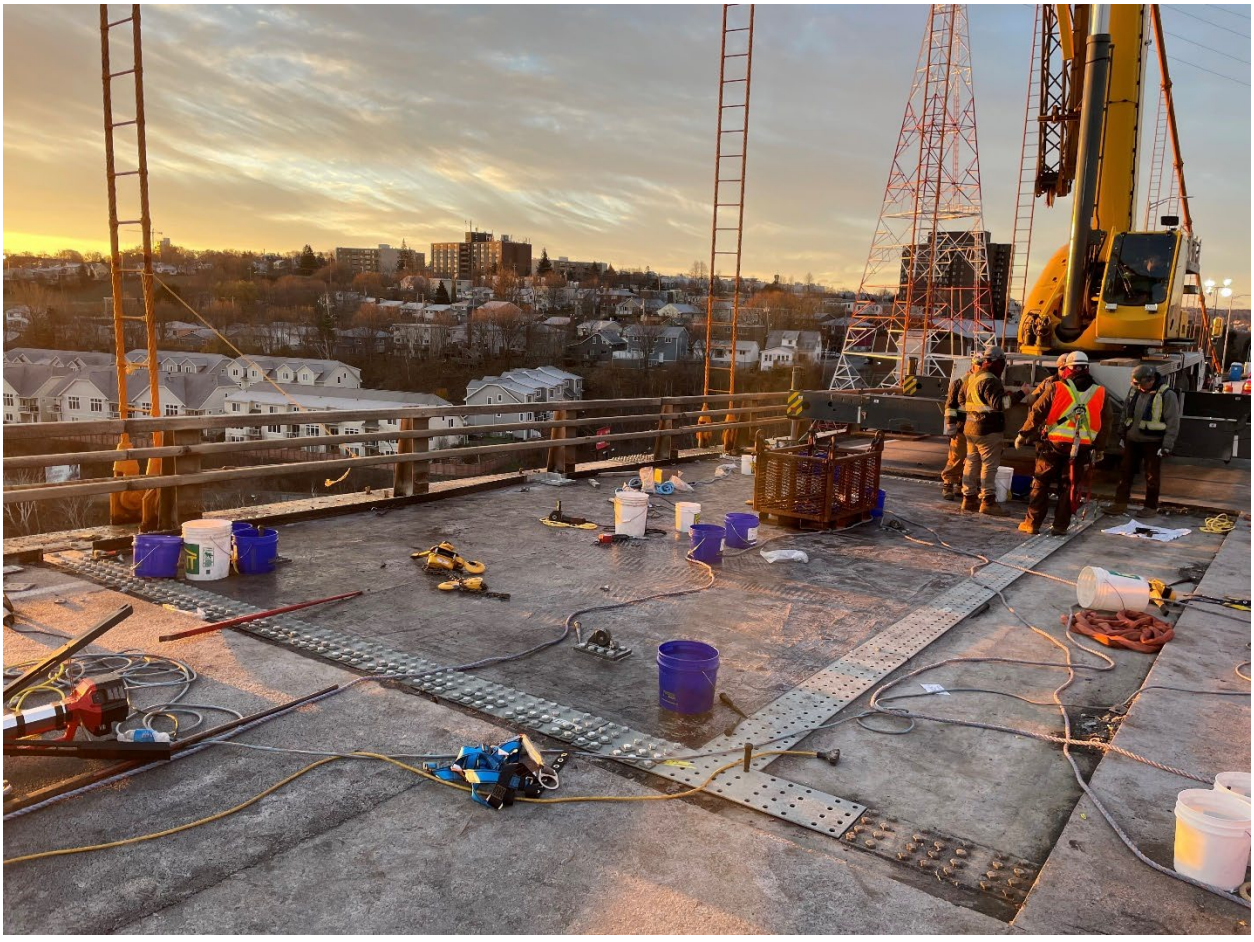
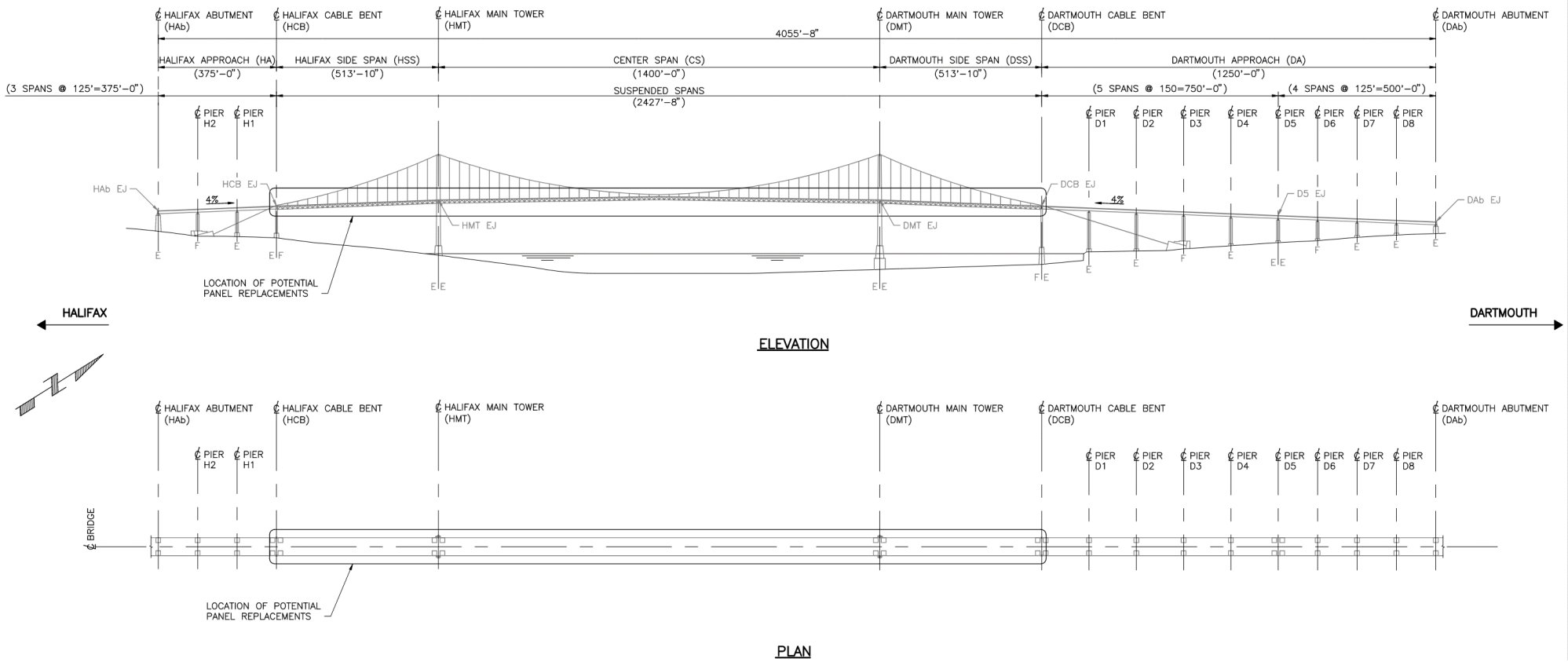








BRIDGE GENERAL ARRANGEMENT



ELEVATION

PLAN