EXTENDING THE LIFE OF THE ANGUS L. MACDONALD SUSPENSION BRIDGE

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Abstract

The Angus L. Macdonald Suspension Bridge crosses Halifax Harbour and connects Dartmouth and Halifax in Nova Scotia, Canada. The bridge was opened for traffic in 1955. The overall length of the bridge, including approaches, is 1,347 m (4,419 ft), and the suspension bridge is 762 m (2,500 ft) long. After almost 60 years of service, the aging bridge deck is experiencing significant corrosion problems and is reaching the end of its service life. Therefore, the owner, Halifax Harbour Bridges, decided to replace the entire suspended superstructure including the hangers.

Bridge inspections showed that all parts of the bridge that are not being replaced (main cables, towers, cable bents and foundations) are in good condition and expected to have a long life. The designs of the new bridge superstructure and its replacement sequence have been completed.

Safety of the public and minimization of traffic disruption have been the central themes driving the design.

The entire suspended structure will be replaced sequentially during night or weekend closures. The bridge will be open for traffic during each working day. An unusual feature of the project is that the Owner's Engineer performed a detailed step-by-step analysis of the erection sequence, has designed some of the key erection equipment, and is providing necessary forces and adjustments to the Contractor for his use during erection. The reason for performing analysis that is normally in the Contractor's scope is to reduce the risk to the owner in terms of cost and delays. Following the replacement of deck segments, the deck will be raised to increase the navigation channel clearance by 2.1 m at midspan.

Dehumidification of main cables is being considered in order to extend their service life.

Keywords:

Suspension bridge; maintenance; rehabilitation; deck replacement; deck erection; cable dehumidification.

1. Introduction

There are two suspension bridges crossing the harbour of Halifax, NS: the Angus L. Macdonald Bridge (Figures 1 & 2) opened in 1955, and the A. Murray MacKay Bridge opened in 1970. Both bridges are administered by a commission known as Halifax Harbour Bridges.

By 2010 it was apparent that the roadway of the Macdonald Bridge needed to be replaced, and this paper outlines the steps that were taken to fully replace the roadway while keeping traffic flowing across the harbour.

2. Regional Traffic

Figure 3 shows the general flow of traffic into the central part of the city. Much of the flow crosses the two bridges, which avoids a substantial detour. The Macdonald Bridge was designed to have two lanes, but since 1999 it has carried three lanes of traffic but excluding trucks. The MacKay Bridge carries four lanes of unrestricted traffic. Both bridges are tolled for vehicles.

The Macdonald Bridge has a sidewalk and a bikeway; the MacKay Bridge carries only vehicular traffic.

Current traffic counts from September 2013 are given in Table 1.

Table 1. Daily Traffic on the two Halifax Bridges

Traffic	Macdonald Bridge (3 lanes)	MacKay Bridge (4 lanes)	Both Bridges
Average Daily Traffic	39,621	53,127	92,748
Average Weekday Traffic	44,201	63,061	107,262
Peak Hourly Traffic	3,471	5,554	9,025

The Macdonald Bridge provides 20% of the lanes to the Halifax central business district. It can be seen from Table 1 that if the Macdonald Bridge were to be closed for repairs, the total peak hourly traffic could not be carried by the MacKay Bridge alone, assuming a maximum capacity of, say 1,500 vehicles per hour per lane. The alternative would be a 20 km long drive around Bedford Basin (see Figure 3) with equally clogged traffic.

It was preferable, therefore, to look for ways to replace the roadway of the Macdonald Bridge without closing the bridge to traffic, at least during peak periods.

3. Scoping Study

The client, Halifax Harbour Bridges (HHB), retained Buckland & Taylor (B&T), working with local consultant Harbourside Engineering Consultants (HEC), to prepare an initial study identifying the various options and their costs and benefits. These options included replacing the roadway only, replacing the entire floor system, replacing the entire suspended structure including the stiffening trusses, and turning the bridge into a four-lane cable-stayed bridge or a four-lane suspension bridge.

Construction of a new bridge alongside the existing bridge and then demolition of the old was not considered because of the cost, including the need to purchase right-of-way in a dense urban area.

On reviewing the scoping study, HHB decided that the best option was to replace the entire suspended structure – roadway, supporting beams and girders and the stiffening trusses. It was decided to replace the hangers that suspend the structure from the main cables at the same time.

Replacing the suspended structure, however, means that there will be gaps in the roadway as segments of bridge are exchanged (see for example Figure 4), and the bridge cannot support a temporary bridging across the gap. It was necessary therefore to replace the structure at off-peak hours in order to maintain the flow of traffic (refer to Table 1).

Previous experience with the Lions' Gate Bridge in Vancouver, BC, had shown that it was possible to replace a typical 20 m segment of deck in 10 hours, so the rules developed by HHB are that the bridge must at all times be fully open to three lanes of traffic, except:

- For 10.5 hours from 19:00 to 05:30 the following morning, Sunday night to Thursday night, and
- From 19:00 Friday night up to 05:30 Monday morning for segments that could not be replaced in 10.5 hours. These are typically the segments at each end of each span, and perhaps some others while the erection crew is climbing the learning curve.

4. Safety

It has been stated by Allen [1] that the risk of a fatality on a bridge is 100 times higher during construction than it is when the bridge is finished. Because the public will be using the bridge during construction, it follows that public safety would be reduced unless extra measures are put in place. Some of the measures taken to re-establish normal safety levels include:

Development of Design Criteria

Careful attention was given to the design criteria. This included a site-specific estimate of the traffic loading, suitable for traffic with no trucks permitted on the bridge. It also included design wind forces based on a site-specific wind study by wind specialist consultants RWDI.

A number of B&T's engineers have served on the Technical Committee that writes the Canadian Highway Bridge Design Code (S6-06) [2], and this has been a great help in writing the design criteria so that appropriate safety levels are maintained.

Closing of Sidewalk and Bikeway

For constructability reasons, the sidewalk and bikeway (SW/BW) will be removed early in the process in order to reduce the weight of segments to be removed. Having the SW/BW closed helps to avoid the danger of pedestrians and cyclists being close to an active construction site. HHB will make arrangements for pedestrians and cyclists and their bicycles to be transported over the bridge whenever it is open to vehicles or via the MacKay Bridge when the Macdonald is closed; pedestrians and cyclists can also use the local bus service, and there is a foot ferry not far away from downtown Dartmouth to downtown Halifax.

However, HHB is insisting that the length of time the SW/BW are out of service shall be minimized and in any case may not exceed 18 months.

Erection Analysis by Owner's Engineer

On a normal project the Contractor is responsible for analyzing the bridge and temporary works for all stages of construction. However, experience on Lions' Gate Bridge showed that the large amount of computing to be done was very time consuming, it was on the critical path, and it delayed the project schedule.

There are both safety and schedule concerns if the analysis is rushed, so it was decided that for the Macdonald project the owner's bridge engineer (B&T with HEC) would perform the analysis for all stages of construction. This effort took more than 24 months to develop, but the end result was a fully automated analysis that automatically models every step of the analysis, including optimizing the amounts by which the hangers should be adjusted in order to keep stresses within allowable limits.

As the structure changes, the analysis automatically builds a new model from the preceding one, and then applies traffic, wind and other loads to it as appropriate. In all, over 700 models were created, and 5,500 load cases applied, just for one complete erection sequence from end to end. For an example of one model see Figure 5. The analysis can be run to accommodate small variations, such as the weight of equipment, but major changes to the erection sequence are not permitted. This feature will be very useful during the actual deck replacement when B&T will support the Contractor in his work. An entire run from start to finish of the bridge erection takes about 24 hours using several powerful computers.

Independent Check of Erection Analysis

As a further quality assurance check, HHB retained Ammann and Whitney (A&W) of New York to independently check B&T/HEC's analysis. A&W reported good agreement with B&T/HEC's analysis in April of 2014.

Design of Erection Equipment by B&T/HEC

Because the public will be using the bridge during construction, B&T/HEC designed several key items of erection equipment before HHB issued a request for proposals, and these items were shown on the tender documents. Such equipment included the erection gantries that lower and lift segments as they are replaced on the bridge, the temporary connection at the junction between the old and new parts of the deck, and equipment for adjusting the length of the hangers (which is needed to control stresses).

It could be argued that design of temporary equipment by the Owner's Engineer removes some of the Contractor's freedom to be competitive. On the other hand, it defines the job better at the time of bidding, which should make estimating of the project easier.

B&T/HEC also designed a number of other smaller erection equipment items, most of which are used on the bridge while the public is using it. Some items of equipment were specified as to concept only, to be fully designed by the Contractor, and most of the temporary works that do not affect the public directly will be entirely at the Contractor's discretion.

Prequalification of Proponents

HHB decided that only prequalified Contractors would be allowed to tender for the project. Five applicants submitted their qualifications, and the top ranked three were prequalified to submit proposals for the job.

These three were further qualified when their proposals were submitted. Qualifications and price were submitted in separate envelopes in 2014 April, and a proponent's price envelope was only opened if the proponent's qualifications passed a certain threshold.

Proposals, not Tenders

In order for HHB to select what it deemed the best value, it requested proposals rather than tenders. This meant that although price was very important, it did not have to be the only determining factor, and if two or three prices were similar, HHB could consider other benefits, such as economic benefits or a better safety record.

5. Minimizing Disruption of Traffic

After safety, the over-riding consideration is minimizing interference with traffic. HHB required that the work be done overnight or on weekends to avoid workday traffic.

From the 1999 addition of a third lane to the bridge, HHB was familiar with the issues, stakeholders and impacts that overnight and weekend closures would have. Some of the considerations are active transportation users (cyclists, pedestrians), transit (about 90% of cross harbour routes use the Macdonald Bridge), and emergency services (fire and ambulances). For the Redecking project vessel traffic must be coordinated due to the reduced vertical clearance below the bridge and restricted safety zones directly under the work area.

The sequence of replacing segments of the bridge is similar to the process used when the deck of the Lions' Gate Bridge was replaced in 2000-2001. The Contractor for Lions' Gate Bridge, American Bridge/Surespan consistently replaced segments in 10 hours or less, so it was known that a similar procedure could be completed in 10 hours. For the Macdonald Bridge 10.5 hours of closure are permitted because there are some differences that may require slightly more time. In the early stages of the design it was thought that it would be necessary to replace both of the first two segments during the first weekend closure. The first segment is the most difficult to replace because it projects into the cable bent that supports the end of the side span. Then the erection gantry would have to be moved (for the first time) and a second segment would then be replaced, all in one weekend before the construction crew would be familiar with the procedures.

Later in the design the permanent connection of the first segment to its cable bent and the temporary connection between the old and new segments were developed to the point that it was safe to replace only one segment during the first weekend closure. This allows the erection gantry to be moved later, at night, and the second segment can be replaced either at night or, at worst, during a partial weekend closure, thus greatly reducing the likelihood of opening the bridge late on the first weekend closure.

6. Replacement Procedure

Details of the deck replacement procedure are summarized here. Further detail can be found in [3].

Typically, for the Dartmouth side span and the centre span a 20 m segment of deck structure will be cut free and lowered onto a barge, and a new segment will be lifted into place (see Figure 4). The Halifax side span is over buildings, so the deck there will be removed in 10 m segments, lifted, rotated 90^o and carried off the bridge by a special vehicle. New segments will be installed in a similar manner.

A cross-section of the existing bridge is shown in Figure 6. It shows the present stiffening trusses rising above the roadway on each side, the sidewalk and bikeway cantilevering from each side, and a 24 inch water pipe located off-centre below the deck.

The finished cross-section is shown in Figure 7. It shows that the new stiffening trusses are now entirely below the deck, which is an orthotropic steel deck with 40 mm of epoxy paving. The sidewalk and bikeway are integral with the main deck plate, and together they form the top chord of the stiffening trusses. A new water pipe is placed centrally under the deck, and an access catwalk is on the south side.

When the new segments are installed, the headroom for ships' clearance over the navigation channel will be increased by 2.1 m.

7. Benefits of the Deck Replacement

When the project is completed, the following benefits will have accrued:

a. The bridge will have been refurbished with minimal interruption of traffic, including no interruption of peak hour traffic Monday to Friday;

b. The entire suspended structure will be new; those components left in place (cables, towers and foundations) were inspected and found to be in good condition with many years of service life remaining;

c. The new deck is lighter than the existing one, so the demands on the main cables and towers are reduced resulting in a greater safety factor for the major existing bridge elements;

d. Key electric and communications services will be kept active during construction;

e. The roadway lanes will be slightly wider;

f. The paving will be improved and more durable;

g. Ships' vertical clearance will be increased;

h. Expansion joints in the road will be quieter;

i. Sustainability will be enhanced by reducing maintenance in four ways:

    1. Smooth welded joints instead of riveted will reduce crevice corrosion;

    2. The area to be painted will be reduced by half;

    3. Almost all the steel to be painted will be under the deck, protected from deicing salt spray; and

    4. If budget permits, a dehumidification system will be installed to effectively protect the main cables from corrosion; and

j. The new deck structure will be stronger and will have much better aerodynamic stability than the existing one.

8. Summary

The Angus L. Macdonald Bridge suspended spans deck replacement project shows how a major bridge can have its life extended by many years by replacing the entire structure hanging from the main cables safely and with minimal disruption to the travelling public.

At the same time, sustainability is enhanced by reducing maintenance, and the port of Halifax will benefit by being able to accommodate larger vessels travelling under the bridge, which will bring economic benefits to the city.

9. References

[1] Allen, D.E., *Canadian Highway Bridge Evaluation: reliability index,* Canadian Journal of Civil Engineering, 19(6), pp 987-991, 1992

[2] Canadian Standards Association*, Canadian Highway Bridge Design Code, CHBDC, CAN/CSA-S6-06 with Supplement No. 1 (S6S1-10*), Toronto, 2006.

[3] Radojević, D., Eppell, J., Kirkwood, K.F., and Buckland, P.G., *Deck Replacement of the Angus L. Macdonald Suspension Bridge,* presented to ASCE Structural Engineers International Conference, Boston, MA, 2014 April.

Figure 1: Angus L. Macdonald Bridge, Halifax, Nova Scotia, Canada

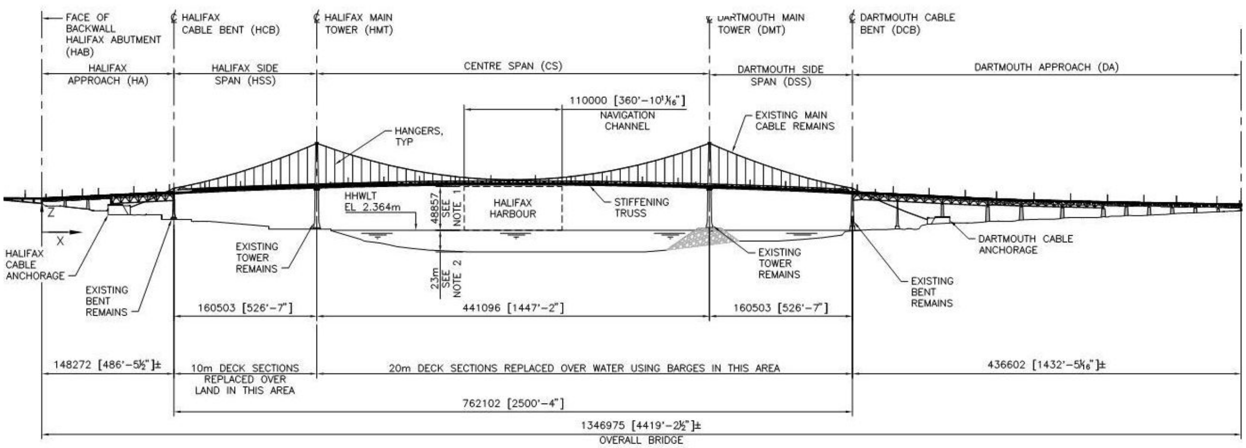

Figure 2: Bridge General Arrangement

Figure 3: Major traffic routes into the central business district of Halifax, NS.

Figure 4: Temporary gap in Lions' Gate Bridge as a segment is being replaced

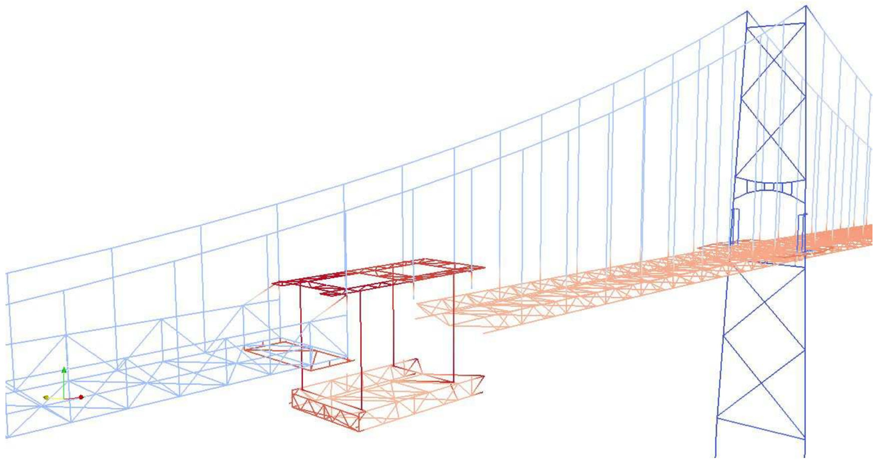

Figure 5: Analysis Model for Erection Engineering Sequences

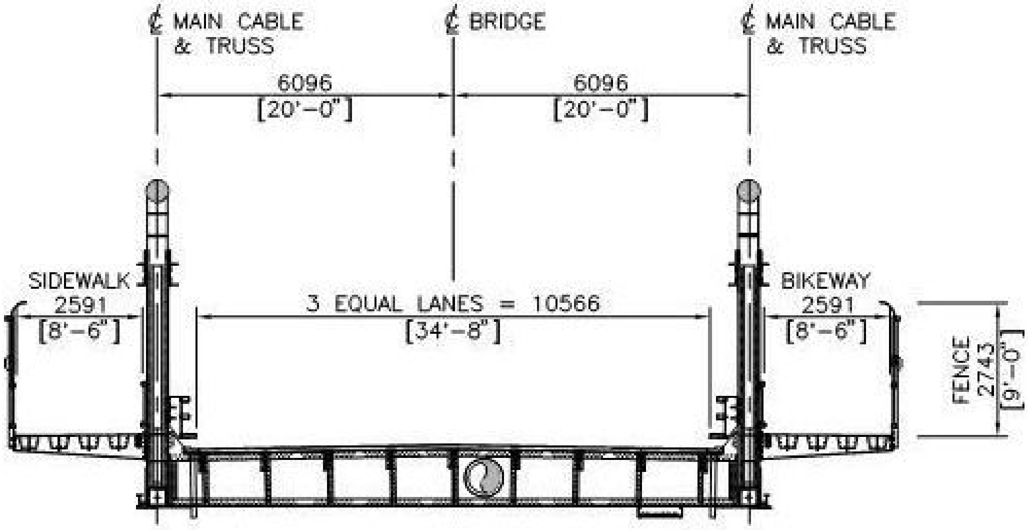

Figure 6: Existing Deck Cross-Section

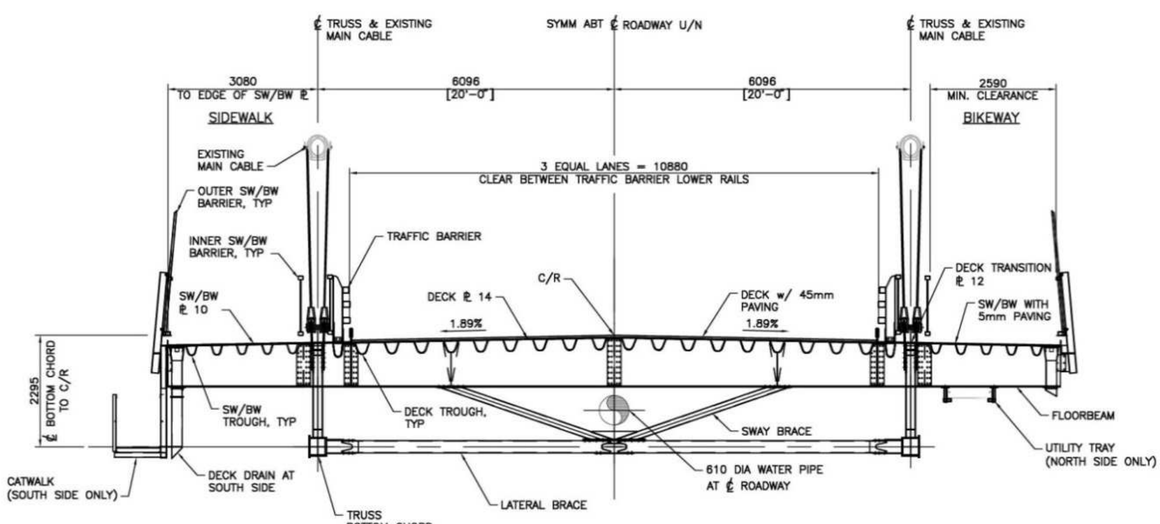

Figure 7: Finished Deck Cross-Section