The Big Lift – Air Gap Monitoring During Bridge Reconstruction

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1. Port Description

The Port of Halifax is a full service port, and offers a variety of facilities for bulk, breakbulk, roro and container cargo, as well as modern cruise facilities. Halifax is Canada's fourth largest container port, with container operations located in its South End and Fairview Cove container terminals.

The Port of Halifax boasts the deepest berths on the east coast of North America, capable of accommodating fully laden, post-Panamax vessels. Closer to Europe than any other east coast port of call, the first destination for carriers sailing from Asia through the Suez Canal, and with seamless intermodal connections to and from the heartland of North America, the Port of Halifax is Canada's Atlantic Gateway to the world.

The Halifax Port Authority (HPA) is an agent of the Government of Canada created in 1999 pursuant to the Canada Marine Act. The mandate of the HPA includes: the administration of Halifax Harbour; the regulation of port operations; the management and development of port facilities; the provision of port services; and, the promotion of trade through the Port of Halifax.

2. Introduction

Halifax Harbour bisects Halifax Regional Municipality. Two suspension bridges join the downtown peninsula of Halifax on the west side of the harbour to Dartmouth on the east: the A. Murray MacKay Bridge to the north (AMM); and the Angus L. Macdonald Bridge to the south (ALM). Operated by Halifax Harbour Bridges (HHB), a commission of the Province of Nova Scotia, these bridges together handle over 34 million annual vehicle crossings, and serve as a vital transportation link in the port, the city, and the province.

The oldest of these bridges is the Angus L. Macdonald Bridge, opened in 1955 as a two-lane suspension bridge. In the late 1990s, a reversible third lane was added to ease congestion. At the same time the approach spans were replaced and bicycle and pedestrian walkways were added. In mid-2015 HHB began its largest capital project since the construction of the bridges, replacing the suspended structure of the Macdonald Bridge. The bridge was safe, but after 60 years the deck was reaching the end of its functional life. The project, also known as the Big Lift, will ensure the bridge remains safe and will extend its life for many more decades.

The project includes replacing the road deck, the floor beams, stiffening trusses and suspender ropes on the suspended spans. Once complete the only original components on the suspended structure will be the two towers, the cable bents, the anchors and the main cables

Since this bridge serves such a vital transportation link for Atlantic Canada, a decision was made to keep the bridge open to vehicular traffic except for non-peak traffic times on evenings and weekends. This is only the second time in the world that a re-decking project of this nature was carried out while keeping the bridge open (the first time was on the Lions Gate Bridge in Vancouver in the late 1990s).

While the impact to vehicular traffic is very clear, what may be less obvious is the impact to marine traffic transiting beneath the bridge. With dozens of vessel movements each week, including several post-Panamax vessels destined for the Port's Fairview Cove container terminal, maintaining unencumbered access to the inner harbour was a necessity. The challenge was in coordinating vessel traffic with bridge construction activities and managing bridge air gap in an environment where the geometry of the bridge was changing every week.

To address these challenges, the Halifax Port Authority developed several innovative systems to help insure the safe and unencumbered transit of vessels under the bridge. With the help of these systems, all bridge deck segments within the navigational channel have been replaced with minimal impact on vessel traffic.

3. Goals and Objectives / Business Problem

Vessel delays are very costly and have the potential to disrupt the entire supply chain. The Big Lift project had the potential to cause delays in two ways.

First, the presence of construction barges in the shipping channel and construction travelers hanging below the bridge could interfere with vessel transits under the bridge. This was mitigated through clear communication protocols and proper notifications among all stakeholders, coordinating construction schedules and vessel schedules to insure that all construction equipment was out of the way when a vessel required transit.

Second, because this was a suspension bridge, the geometry of the span changed each time a new deck segment was replaced. This made it very challenging to determine the bridge elevation, and thus air gap, at any given point under the bridge. With many large ships needing access to the inner harbour, including large post-Panamax vessels bound for our Fairview Cove Container Terminal, understanding the available air gap across the span was critical. To address this challenge, HPA, with cooperation from HHB, designed and developed several systems to help monitor air gap in real time, as well as provide a predictive capability for vessel visit planning purposes.

The primary objective of these systems was to insure the safe passage of vessels under the bridge, by providing air gap measurements across the span. This allowed information to be passed on to the harbour pilots to enable them to make decisions regarding the vessel approach, transit underneath the span, and how many tugs may be required to accompany the vessel during its transit. A secondary objective was to insure fluidity of vessel movements under the bridge by providing predictive information regarding future bridge elevations and air gaps. This allowed the ship operators to plan their arrivals for optimum periods, preventing any delays upon their arrival in the harbour or departure from the harbour.

4. Discussion

4.1 Background

The Macdonald Bridge deck consists of a total of 36 deck segments of either 20 meter or 10 meters in length. Each of these segments was replaced in turn, starting at the Dartmouth shore and working west toward Halifax. The main span between the Dartmouth tower and the Halifax tower, which includes the sections over the main navigational channel, consists of twenty-two 20 meter segments, labelled M1 through M22.

To replace each segment, a lifting gantry was positioned on the suspender ropes and the existing deck segment was cut away and lowered to a barge in the harbour. A new segment was then lifted from a second barge, placed in position, and the old and new bridge deck segments were rejoined. Two deck segments were replaced each weekend. Figure 1 shows the replacement of the first deck segment on the east end of the bridge, typical of each deck segment replacement. Clearly, the presence of barges, tugs and crane ropes represents a challenge to navigation under the bridge.

Figure 1 – Deck Segment D1 Being Replaced

Further to this, the differences in design and material between the bridge segments being replaced and the new segments they were replaced with caused significant changes to the arc of the bridge span, and thus its elevation. Figure 2 shows the original arc of the bridge (in red) and the arc after bridge segment M11 (mid-span) was replaced (in blue), indicating the change in the bridge geometry resulting from the deck segment replacement.

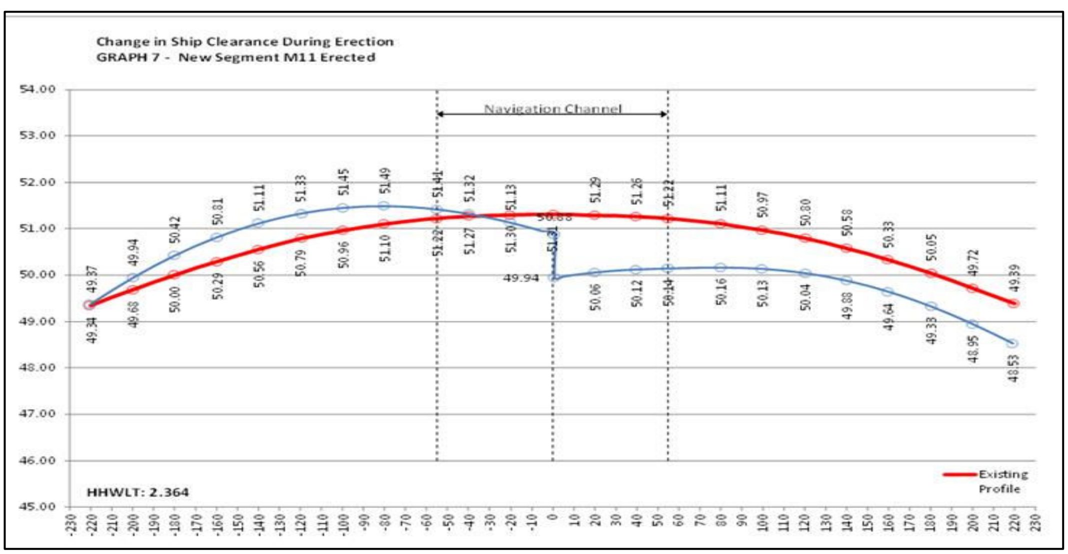

Figure 2 – Change in Bridge Geometry at Mid-Span

The HPA implemented a number of hardware and software solutions to provide the information needed to achieve its objectives of safe and unencumbered vessel movements under the bridge throughout the reconstruction project.

4.2 Objectives and Methodology

Information that was critical to vessel movements under the bridge during the reconstruction project included current readings of air gap, tide level, and bridge elevation. For planning purposes, the critical information included expected temperatures, expected tide levels and expected bridge elevations. HPA developed and implemented a suite of solutions to gather and present this information to HPA's Operations staff.

- **Microwave Range Finders**
  HPA installed two Miros microwave range finders for air gap measurement on the Macdonald Bridge, where the air gap is the distance between the bottom of the bridge structure and the surface of the water below. One was located on the west end of the bridge near the Halifax Tower, where AC power was available. It used a wireless link to communicate its readings back to HPA's network. When construction progressed far enough west that the utilities needed to be removed, this sensor was relocated to a point 55 meters east of mid-span, at the eastern edge of the primary navigational channel. This sensor will be a permanent installation, remaining in place after the bridge re-decking project is complete.

  A second Miros microwave range finder was incorporated into the Temporary Deck Connection frame (TDC), the hardware that joins the old and new bridge sections together. This unit measured the air gap at the construction front, which was always the lowest point of the span. The TDC was moved each time a deck segment was replaced. Since there were no power or communication utilities on the TDC, this unit was entirely self-contained, operating on battery power and using a wireless link to communicate with HPA's server.

- **Radar Water Level Sensors**
  HPA installed a group of three redundant OTT radar water level sensors to measure tide levels in real time. Using a combination of the air gap readings and water level readings allowed HPA to determine the elevation of the bridge at any time.

- **Bridge Elevation Model**
  HHB provided HPA with a mathematical model that indicated the expected elevations across the span as each deck section was replaced. HHB also provided a thermal model which indicated the adjustments that were needed to the elevation model to account for fluctuations in bridge elevation due to temperature changes. The model was updated several times during the project, based on actual data gathered by HPA's sensors.

- **The Big Lift Project Dashboard**
  The Big Lift Project Dashboard was created to consolidate and display information from all the relevant sensors, to allow Operations staff to make informed decisions regarding the passage of high air draft vessels.

- **Vessel Clearance System**
  The Vessel Clearance System was created to allow predictive analysis to be performed for future high air draft vessel arrivals. It incorporated assumptions on tide and temperature readings, known bridge elevations from the two Miros range finders, and the predicted behavior of the bridge from the bridge elevation model.

4.3 Hardware and Software

A variety of hardware and software components were used to achieve our objectives.

- **Microwave Range Finders**
  HPA purchased two Miros SM-140 microwave range finders for use in this project. These devices are capable of measuring air gaps of up to 95 meters. Both range finders were configured with a Campbell Scientific CR800 data-logger to read input from the sensor and transmit the readings back to HPA's network using a Campbell Scientific RF450 radio with Yagi antenna. This combination of hardware allowed HPA to manage the range finders, even allowing a scheduled or on-demand functionality to remotely turn the sensor on when required or off when not needed, to preserve battery life where necessary. Data from the sensor was collected through Campbell Scientific LoggerNet software installed on HPA's server, where it was available for further processing and presentation.

  Figure 3a depicts a Miros SM-140 range finder "out of the box", and Figure 3b shows it installed on the TDC (underneath a protective floor grate).

Figure 3a – Miros SM-140 Range Finder

Figure 3b – Miros SM-140 on TDC

- **Radar Water Level Sensors**

  HPA installed a group of three redundant OTT RLS radar water level sensors to measure tide levels in real time. These sensors use impulse radar technology for non-contact water level measurement. The three RLS devices were installed on HPA property near the base of the Macdonald Bridge. The sensors were configured with a Campbell Scientific CR1000 data-logger to read input from the sensors and transmit the readings back to HPA's network via an Ethernet connection on a five minute polling cycle. Data from the sensors was collected through Campbell Scientific LoggerNet software installed on HPA's server, where it was available for further processing and presentation.

  Figure 4 depicts the installation of the three OTT RLS radar water level sensors.

Figure 4 – OTT RLS Radar Water Level Sensors

- **Bridge Elevation Model**
  HHB was able to provide HPA with a mathematical model that indicated the expected elevations across the span as each deck section was replaced, as well as a thermal model which indicated the adjustments that were needed to the elevation model to account for temperature changes, as temperature changes affected the expected behavior of the bridge due to expansion and contraction of the bridge materials.

  The model was provided in the form of two Excel spreadsheets: one with the elevation model, and a second with the thermal adjustments required at various temperatures. HPA was able to prepare graphs from the spreadsheet data showing the predicted elevation of the bridge at each deck section across the span, as each deck section was replaced.

  Figure 5 depicts a series of graphs produced from the Bridge Elevation Model showing the change in elevations as construction proceeds from east to west across the span.

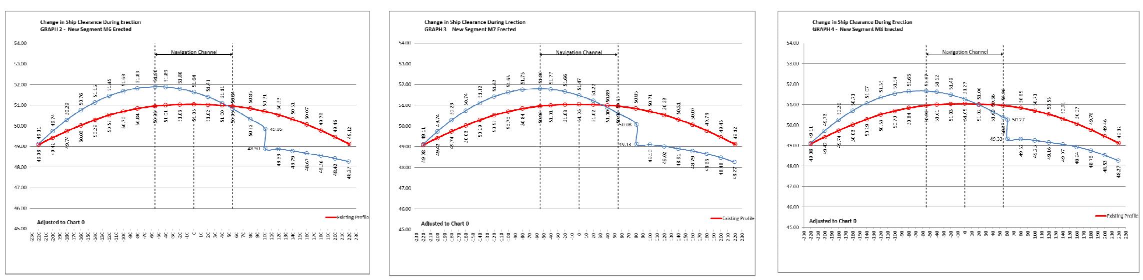

Figure 5 – Bridge Elevation Model Sample as Construction Proceeds East to West

- **The Big Lift Project Dashboard**
  The Big Lift Project Dashboard was created to consolidate and display information from all the relevant sensors, to allow Operations staff to make informed decisions regarding the passage of high air draft vessels. The dashboard was developed using the Campbell Scientific Real Time Monitor and Control (RTMC Pro) development environment.

  RTMC Pro is used to create and run the graphical screens that provide real-time monitor and control capabilities. In this case, the Big Lift Project Dashboard displayed data that was collected and stored on HPA's server using the Campbell Scientific LoggerNet software. Using the Big Lift Project Dashboard, HPA Operations personnel were able to tell at a glance the current air gap, tide, and bridge elevation situation. The display is depicted in Figure 6.

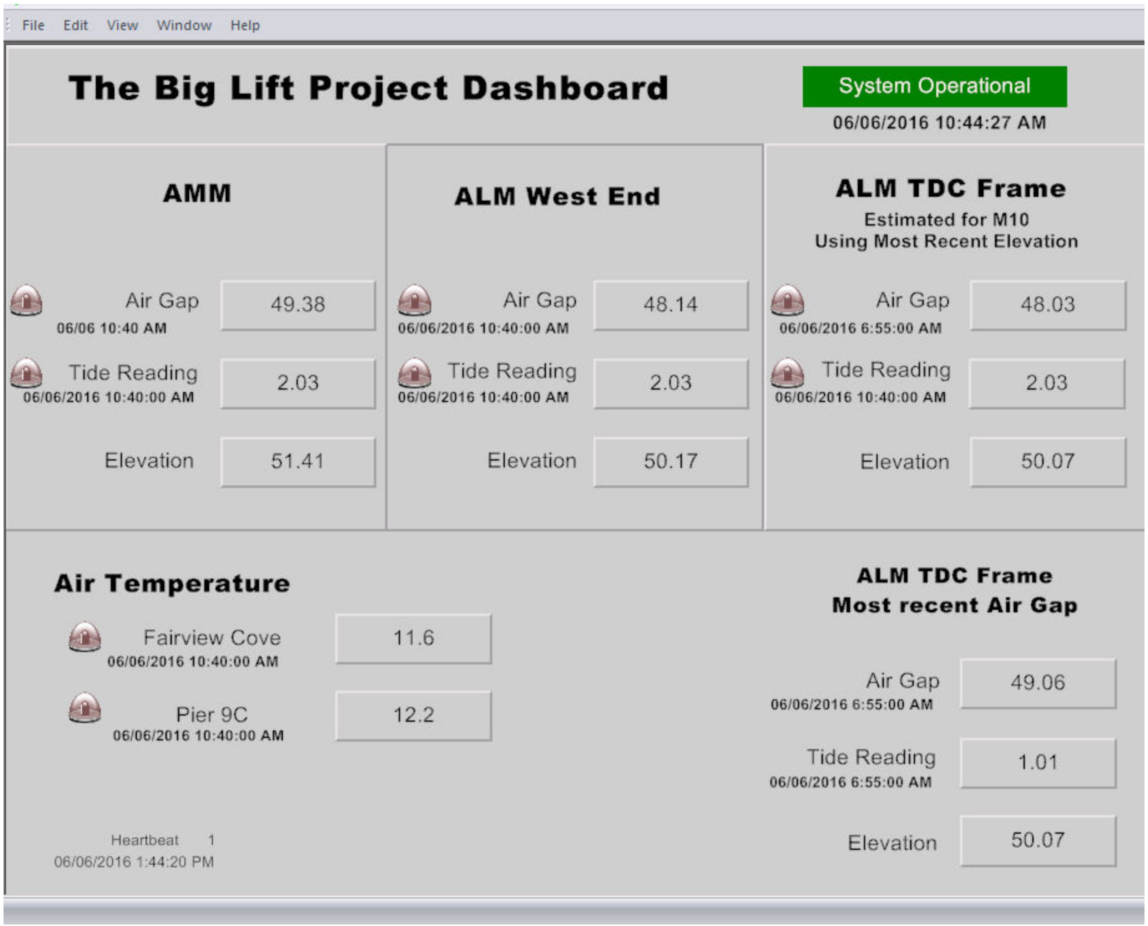

Figure 6 - The Big Lift Project Dashboard

The two top leftmost panes of the Big Lift Dashboard provide a snapshot of the air gap measured by the Miros range finders installed on the MacKay Bridge (**AMM**) in an earlier project, and on the west end of the Macdonald Bridge (**ALM West End**), updated every 5 minutes. The dashboard also displays the tide reading as measured by the OTT RLS tide gauges, also updated every 5 minutes. It then calculates and displays the corresponding bridge elevation as the sum of the air gap plus the tide reading.

Since the Miros range finder installed on the ALM TDC frame is only operated intermittently to save battery power, it is not possible to update its measured air gap every 5 minutes. Instead, the most recent air gap reading is displayed on the lower right pane of the dashboard (**ALM TDC Frame Most recent Air Gap**), along with the tide reading taken at the same time as the air gap reading. This allows the dashboard to calculate and display the Macdonald Bridge elevation at the TDC as the sum of the most recent air gap reading plus the tide reading taken at the time of the last air gap reading.

The assumption is that in the absence of a deck segment replacement, the elevation of the bridge remains fairly constant, and any variation is accounted for by factoring a 1.55 meter safety factor into clearance decisions. Given this assumption, the current values at the ALM TDC Frame can be estimated and displayed in the upper right pane of the dashboard (**ALM TDC Frame Estimated Using Most recent Elevation**). The estimated elevation is the elevation determined the last time data was collected from the TDC Miros. The tide reading is the current OTT RLS tide gauge reading. And the air gap is calculated as the elevation less the tide reading.

The dashboard also displays other relevant information, including the current air temperature collected by temperature sensors at nearby locations and the date and time of each reading. And alarm symbols next to each reading will light up if a reading is older than 5 minutes to alert the operator that these values may not be current.

HPA's Operations personnel used the Dashboard to monitor air gaps, water levels and bridge elevation on an ongoing basis.

- **Vessel Clearance System**

Whereas the Big Lift Project Dashboard was intended to provide real-time data from the various sensors, the Vessel Clearance System was created to allow predictive analysis to be performed for future high air draft vessel arrivals. It does so by applying data entered by the operator to the HHB Bridge Elevation Model, and displaying the resulting projected air gap at all points across the bridge span. The software can identify the point of maximum clearance as well as highlight situations where there is insufficient clearance. The Vessel Clearance screen is depicted in Figure 7.

The vessel Clearance System allows the Operator to enter current temperatures, the bridge elevation at the Miros on the west end of the bridge and at the TDC Frame, and tide levels, as derived from the Big Lift Dashboard. The software then applies these parameters to the bridge elevation model to determine the projected elevations at the west end Miros and at the TDC Frame. It calculates any variance between the actual bridge elevations as measured by the Miros range finders and the projected elevation from the bridge elevation model, and applies this variance to the model for the specified clearance location. To provide the most conservative estimate of bridge air gap, variances are only applied if the actual measured values are lower than the values in the model. This value is displayed as the Clearance Location Air Gap.

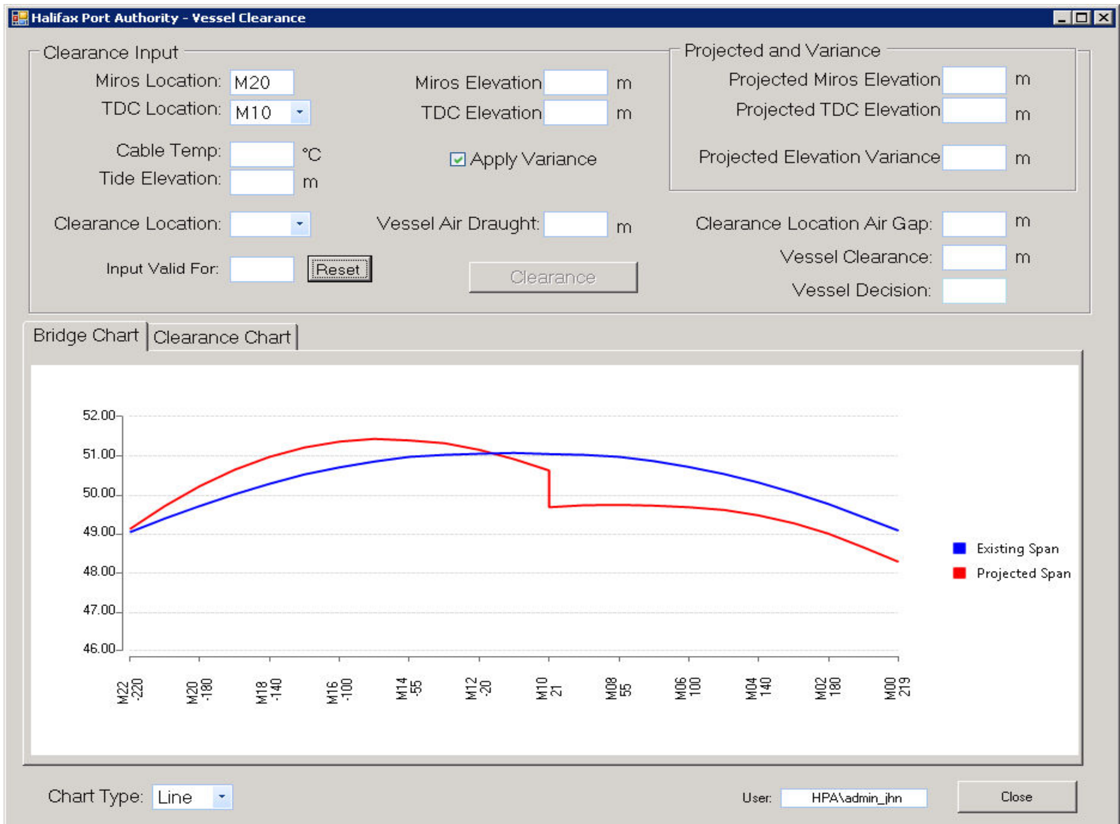

Figure 7 – Vessel Clearance System Screen

The operator may also enter the Vessel Air Draft, in which case clicking on the Clearance button will cause the system to calculate and display the Vessel Clearance and a Go/No Go decision based on a safety factor of 1.55 meters.

Two graphs will also be displayed.

The Bridge Chart**,** depicted in Figure 8, indicates the elevation of the bridge at each bridge deck segment as calculated by the HHB Bridge Elevation Model, corrected by the calculated variance. The Existing Span is shown in blue, and represents the bridge elevations before the re-decking project began. The Projected Span is shown in red, and represents the bridge elevation as determined by the HHB Bridge Elevation Model at the given temperature. Moving your mouse across the span will display the elevation values for both curves at each point across the span.

The Bridge Chart can also be displayed as a Bar Chart by selecting the Bar Chart option from the Chart Type drop down list at the bottom left of the screen.

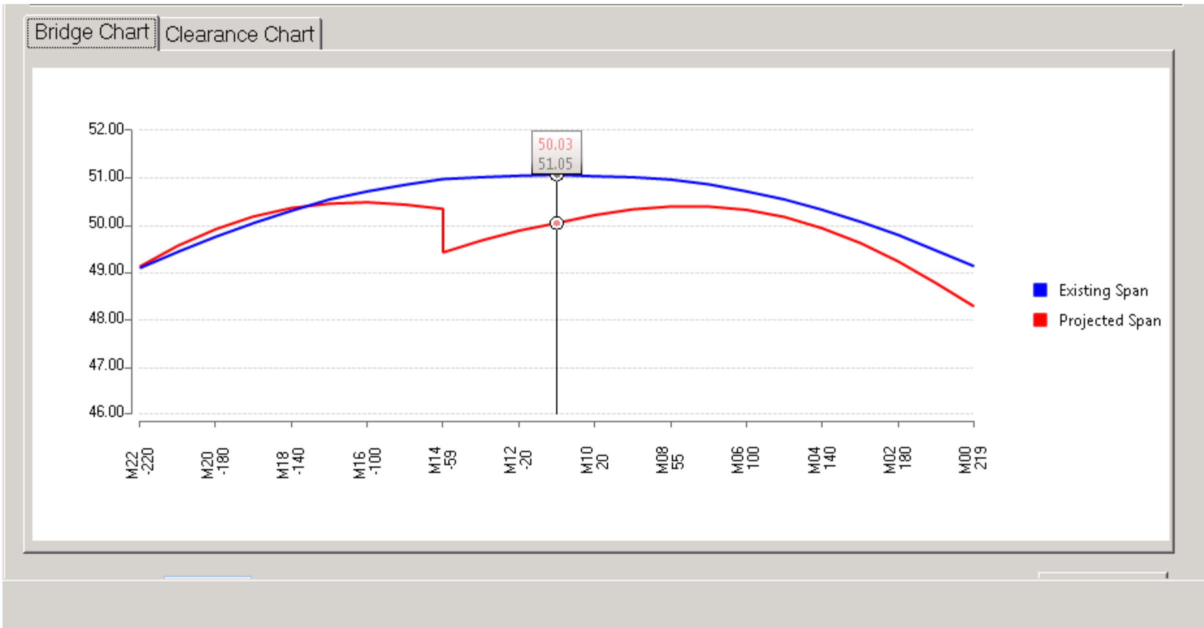

Figure 8 – Clearance Software Bridge Chart

The Clearance Chart, depicted in Figure 9, indicates the air gap of the bridge at each bridge deck segment as calculated by the HHB Bridge Elevation Model, corrected by the calculated variance. The Air Gap is shown in blue. The red line indicates the Vessel Air Draft as entered by the operator. This allows an easy visual representation of the areas of the bridge under which the vessel can safely pass. Moving your mouse across the span will display the elevation values for both curves at each point across the span.

The Clearance Chart can also be displayed as a Bar Chart by selecting the Bar Chart option from the Chart Type drop down list at the bottom left of the screen.

The operator can use the Vessel Clearance Software to predict the bridge elevation and air gap by entering the expected temperature and the predicted tide level for the expected time of vessel arrival or departure into the corresponding data entry fields in the Clearance Input section of the Vessel Clearance System.

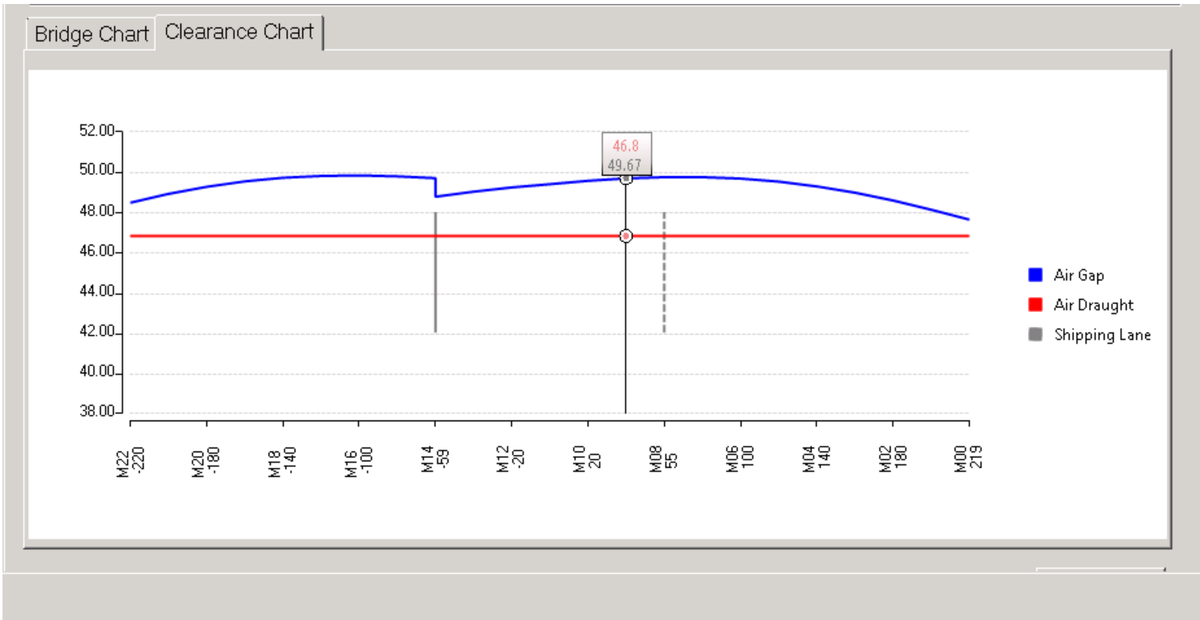

Figure 9 – Clearance Software Clearance Chart

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4.4 Project Costs

The air gap monitoring systems used during the Big Lift Project have been evolving over the last two years, and leverage previously existing technology within the port. Total development costs specific to the Big Lift Project were approximately $200,000CDN. Ongoing operating costs during the Big Lift Project are estimated to be approximately $30,000, primarily for maintaining batteries and relocating equipment. The equipment and the Big Lift Project Dashboard will remain in place after the project is complete, with both Miros microwave range finders operating on AC power. Ongoing operational costs after the Big Lift Project is complete are anticipated to be minimal.

4.5 Performance Measures

Since the Big Lift Project commenced, over 100 vessels have safely transited under the bridge without any incidents or delays, including over a dozen very high air draft vessels. In addition, one vessel chose to berth at the South End Container Terminal rather than risk a transit under the bridge, based on information provided by HPA's Vessel Clearance System. In summary, the systems put in place to help manage vessel traffic under the Angus L Macdonald Bridge have performed as expected and have enabled fluidity of vessel movements into and out of the inner harbour throughout the duration of the bridge re-decking project to date.

4.6 Award Criteria

- **Level and nature of benefits** – The Air Gap Monitoring systems have provided an immediate and direct benefit to the HPA in the form of unencumbered access to the inner harbour throughout the bridge reconstruction project. In an environment where delays could easily have been incurred, the ability to maintain fluidity of vessel movement resulted in cost avoidance for our customers, and prevented reputational damage that could have been incurred had delays been experienced.

- **Creativity of solutions** – The Big Lift project is a multi-faceted project presenting some unique challenges. The changing geometry of the bridge as the project progressed, the lack of power on the bridge to operate sensors, and limited access to the bridge were just some of the issues to be dealt with. Given that this type of project is rarely carried out, there were no precedents to guide us. The combination of hardware, software and engineering models developed by HPA and its partners worked together to present a unique solution to these challenges.

- **Apparent project results** – The Air Gap Monitoring systems have met their primary objectives. The predictive capability of the systems has allowed ship operators to plan their arrivals for optimum periods, preventing any delays. The real-time display of air gap and bridge elevation data has allowed the safe transit of vessels beneath the bridge throughout the re-construction project.

- **Cost effectiveness of the program** – The value proposition of the Air Gap Monitoring System, as implemented during the bridge re-construction project, is significant. The systems have provided a necessary service, one for which there was no alternative solution. The development of these systems also provides a legacy in that the hardware and much of the software deployed in this project will remain in use after the re-decking project is complete, providing real-time and predictive visibility into air gap, tide levels, and bridge elevations on an ongoing basis.

- **Transferability of the technology or idea to the port industry** – The specific application for use during a bridge re-decking project is quite unique, and the dependence on the bridge elevation model is specific to this one bridge. However, the concepts on which the Air Gap Monitoring System is based are very simple, and the technology with which it is built is readily available, proven to work, and reasonably priced. From this perspective, it could easily be adopted by any port for the purposes of air gap monitoring and management.

5 Conclusion

The Air Gap Monitoring System developed by the Halifax Port Authority is an example of an innovative approach to the use of technology for the effective monitoring of bridge air gap, particularly in the context of a suspension bridge re-construction project where vessel schedules and construction schedules need to be closely coordinated. The technologies employed in this project have proven to be accurate and reliable. The relatively low development and operating costs associated with the Air Gap Monitoring System, and the critical function which it serves makes this system an attractive investment for any port who must manage and monitor vessel traffic transiting under a bridge.