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ASSESSMENT AND RENEWAL OF THE CENTENNIAL BRIDGE

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Abstract: The Centennial Bridge, located in Miramichi, NB, was constructed in the 1960s when winter concreting practices were less advanced than modern practice. Major repairs and upgrades are currently underway to bring the structure in line with current standards and prolong its useful life. The Bridge is a 1.1 km long bridge spanning the brackish waters of the Miramichi River. It is a steel superstructure bridge with twenty concrete piers. The bridge is located in a very demanding environment for construction materials; in addition to the impacts of deicer salts and frequent freezing and thawing periods, brackish water and tidal impacts affect the concrete river piers. Furthermore, the substructures are difficult to access; therefore, inspection and maintenance activities have been limited. Following the decision to upgrade and refurbish this structure to prolong its useful life, a multi-phase investigation and repair/upgrading program was undertaken. An investigation of the steel superstructure was undertaken by the structural consultant and upgrades and repairs were conducted between 2013 and 2017. These activities were planned and scheduled in a manner which permitted traffic to continue with minimal interruption. Assessments of the piers were conducted from 2013 to 2017. Upgrading and repair of the piers will be completed in a manner which prevents any disruption in bridge traffic. Demolition and concrete placement will be conducted in stages to ensure that the structural integrity of the bridge is not compromised during construction. The first contract (of two) for pier upgrading is scheduled for completion in the autumn of 2018.

1 CONSTRUCTION OF THE CENTENNIAL BRIDGE

1.1 Design

The Centennial Bridge is a steel superstructure bridge with twenty concrete piers; eight river piers and twelve land-based piers. The superstructure consists of tied arch navigation spans, continuous over three spans, flanked by five deck truss spans, twelve plate girder approach spans and one rolled beam span. The original design of the bridge included significant infilling on the northern shoreline to reduce the required number of river piers. This area is currently protected with armour stone. During severe storm events it experiences flooding.

The bridge was designed to satisfy acceptable design standards at the time; however, changes in the bridge code have necessitated upgrades to the structure, specifically seismic retrofit. Thus, Eastern Designers & Company Limited (structural consultant) was retained for the assessment of the bridge and design of upgrades. Significant deterioration was observed. Subsequently, GEMTEC (concrete materials consultant) was retained for the evaluation of the integrity of the concrete substructures.

1.2 Concrete Construction

Construction of the Centennial Bridge began in 1964 and concluded in 1966. Much of the concrete pier construction was carried out during the winters of 1964-1965 and 1965-1966. The concrete was prepared at a ready-mix plant situated on the south side of the river; the concrete for the river piers and piers on the north shore was placed with crane and bucket from a barge. Construction records indicate that, during cold weather, the aggregates were often heated; however, little to no cold weather protection was provided to the in-place concrete (see Figure 1). Freezing of the concrete soon after construction, and/or insufficient consolidation during placement, often resulted (Spear and Northrup Consulting Structural Engineers 1965). Several locations are noted throughout the piers where repair material was applied over poorly consolidated (honeycombed) concrete. The lack of cold weather protection during construction has likely contributed to the deterioration observed in the piers presently.

Figure 1: View from north bank facing south. March 29, 1965

Little information exists regarding the materials used for the concrete. However, it is evident from an examination of the cores extracted from the substructure that rounded gravel aggregate was used and the concrete was intentionally air-entrained.

2.0 LOCATION AND ENVIRONMENT

The Centennial Bridge spans the brackish water of the Miramichi River in Miramichi, NB. The location of the Bridge is approximately 40 km inland of the Gulf of St. Lawrence, where the River discharges into the Atlantic Ocean. The average daily temperature in Miramichi varies from approximately -5°C to -17°C in the winter months to 13°C to 25°C in the summer. The average daily temperature is at or below freezing for five months (November – March) of the year (Government of Canada 2018); thus, deicer salt usage is extensive. Expansion joints are present in the bridge deck overlying ten of the twenty concrete piers. As discussed later in this report, water and deicing salts from the roadway have penetrated the joints and impacted the underlying piers.

The Bridge functions as the river crossing for both NB Route 8 and NB Route 11, as such, this is a heavily trafficked bridge essential for transport on the eastern side of the province. All investigative and repair work had to be coordinated in a manner which minimized disruption to traffic.

3.0 FIELD INVESTIGATION

The investigations of the concrete piers were carried out in phases beginning with an initial investigation of the river piers in 2013. This investigation was limited to those areas which were accessible from the piers' footings. Several cores were extracted from the piers for laboratory testing. The results of this investigation indicated that further investigation, including visual inspection and concrete core extraction at greater heights on the substructures, was required. Subsequently, a remote access contractor was retained to repel from the catwalk, conduct hammer sounding surveys, take photographs, and extract cores from various locations throughout the substructures (Figure 2).

Figure 2: Remote Access Contractor Drilling Core from Concrete River Pier

Following the investigations of the concrete river piers, the upgrading program was designed and the first of two contracts for pier rehabilitation was put out to tender. This rehabilitation work is currently underway and scheduled for completion later this year.

The assessments of the concrete quality of the land-based piers and abutments were carried out in a subsequent investigation. The investigations of the land-based substructures included hammer soundings, concrete core extraction and visual assessments. Overall, the conditions of the land-based structures were similar to, or slightly better than, the river piers.

4.0 RESULTS

The results of the investigations generally reveal that the concrete at depth in the substructures is sound and of suitable quality for this environment. However, extensive chloride infiltration, concrete deterioration, and corrosion-related delamination has occurred in the outer concrete (50 to 150 mm depth) of several of the substructures.

4.1 Visual Assessment

The visual assessments of the substructures revealed a large range in the conditions of the substructures. Several of the piers appeared to be in excellent condition with little to no signs of deterioration despite over 40 years of harsh winter exposure. Other substructures exhibit loss of section and numerous cracks, many of which exhibit seepage of corrosion products (Figure 3a and 3b). Some minor map cracking was also noted. Furthermore, large areas of patched poorly-consolidated concrete were noted at several of the river piers (Figure 3c).

Some discrete areas of the corrosion-induced delamination were observed on piers which did not exhibit deterioration or substantial chloride ingress elsewhere. It was later determined that the concrete cover was insufficient in these areas and that likely contributed to the premature corrosion.

4.2 Hammer Sounding Surveys

The hammer sounding surveys indicate that delamination of the cover concrete, as indicated by a hollow sound produced in response to impact, has occurred throughout several of the piers. The area of hollow-sounding concrete is typically limited to less than 10% of the substructure.

In general, the delamination is most extensive on the southern faces of the piers; however several exceptions exist. For example, approximately 30 – 40% of the north face of pier 10 produced a hollow sound. Pier 10 supports the navigation span and it does not underlie an expansion joint. A deck drain discharges near the northern side of Pier 10 and the concrete cover is reduced, relative to some of the other faces of the piers, on this face. It’s suspected that the discharge from this drain impacts the pier, leading to chloride-induced corrosion and the reduced concrete cover has made this face of the pier vulnerable to premature corrosion.

Figure 3: Examples of Deterioration Observed. a) Corrosion and Corrosion-Induced Loss of Section, Pier 11; b) Cracking with Visible Corrosion Product Seepage, Pier 13; c) Improperly Repaired Honeycombing, Pier 11

4.3 Concrete Cores – Laboratory Results

The laboratory investigation included air void analyses from numerous cores, testing of the compressive strengths and rapid chloride penetrability of cores, and measurement of chloride ion contents at numerous depths.

4.3.1 Air Void Analyses

Concrete bridge components are typically air-entrained to provide resistance to the internal pressure caused by freezing of water within the concrete's pores. According to CSA A23.1, air-entrained concrete shall have a hardened air content greater than 3% and an average spacing factor of no greater than 230 μm with no single value greater than 260 μm (CSA Group 2014). The air void analyses (ASTM C457, Procedure B) indicate that the hardened air contents of the cores range from 1.6 – 11.6%, averaging 4.7% and the spacing factors range from 70 μm to 730 μm, averaging 207 μm. Many of the test results fail to satisfy the CSA A23.1 requirements for air-entrained concrete; however, the average values are within the limits. These results are typical for air-entrained concrete constructed during the 1960s, when air-entraining admixtures were in their infancy.

4.3.2 Compressive Strength

If constructed today, the CSA A23.1 Class of Exposure of the Centennial Bridge concrete piers would likely be C-1, thereby requiring a minimum compressive strength of 35 MPa (CSA Group 2014). The compressive strengths (CSA A23.2 – 14C) of concrete cores extracted from the piers ranges from 26 – 70 MPa, averaging 45 MPa. Therefore, the compressive strength of the concrete used to construct the piers would be deemed adequate (average core strength greater than 85% of 35 MPa with no single value less than 75% of 35 MPa) for this structure.

4.3.3 Rapid Chloride Penetrability Test (RCPT)

Class of Exposure C-1 requires a rapid chloride penetrability of less than 1500 Coulombs with 91 days of construction (CSA Group 2014). The RCPT results (CSA A23.2-23C) measured in cores extracted from the piers range from 1200 – 5560 Coulombs, averaging 2840 Coulombs. The results indicate substantial variability throughout the structures. Although these results are unacceptable for modern construction, they are typical of the concretes and construction practices used during the 1960s.

4.3.4 Chloride Ion Contents

Regarding the laboratory investigation, the chloride concentration at varying depths in the cores extracted from the different substructures was the primary focus of this investigation. As anticipated, the concentration of chlorides among the different substructures is highly variable and is strongly correlated with the presence of deck drainage near the substructures. Due to the large volume of data collected, it is not possible to present all of the data in this paper. The peak chloride concentration measured in each of the substructures, and the depth at which the measured chloride ion concentration decreases to less than the chloride-induced corrosion threshold, are plotted in Figure 4. The vertical and horizontal axes of the Figure are the peak chloride concentration measured in the substructure, and the depth at which the most severe chloride profile (chloride concentration as a function of depth into the structure) decreases to less than 400 mg Cl- per kg concrete, respectively.

The substructures with overhead expansion joints are identified in Figure 4 with an asterisk (*) in the legend and a square symbol in the plot; those which do not underlie expansion joints are indicated with a circular marker in the plot. The river piers are represented by green coloured symbols and the substructures on the southern and northern shorelines are represented in blue and red, respectively.

Figure 4 clearly demonstrates the correlation between higher chloride ion concentration in the substructures underlying expansion joints (square symbols) as opposed to those which do not underlie expansion joints (circular symbols). The Figure also demonstrates the variability among the different substructures of the same bridge and it demonstrates that, despite the absence of expansion joints at ten of the twenty pier locations, chloride concentrations in excess of the widely-accepted corrosion threshold were measured in each of the piers.

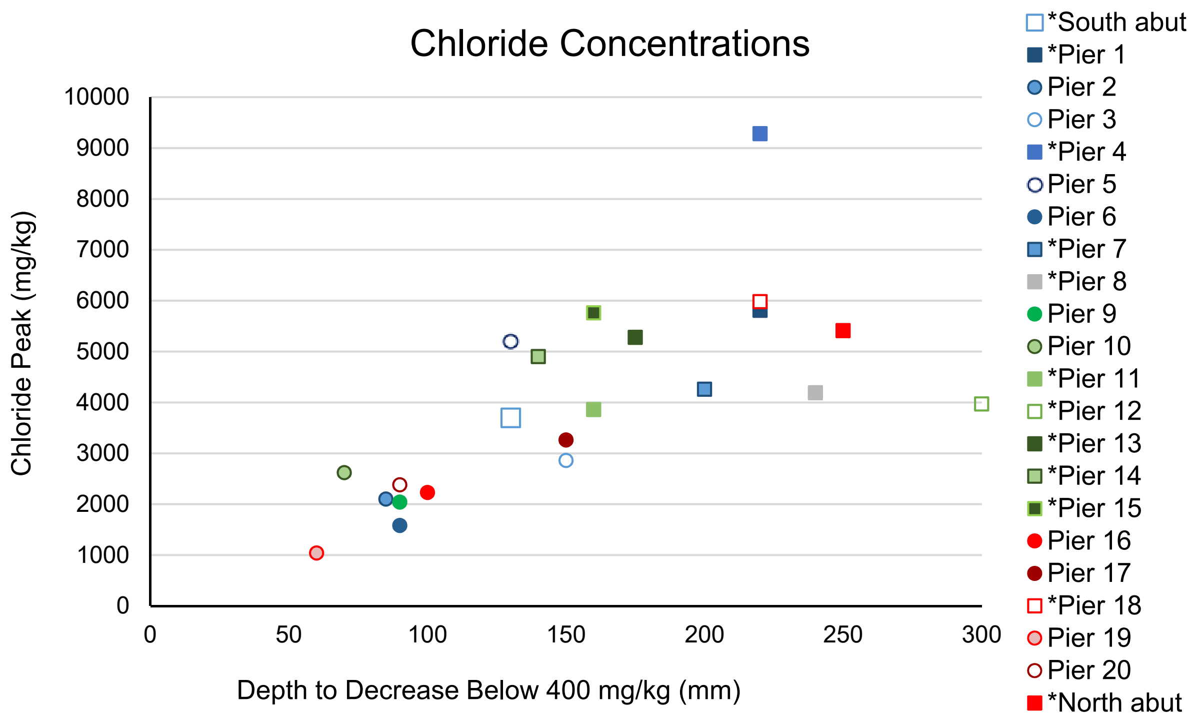

Figure 4: Peak Chloride Concentration as a Function of Depth to Decrease below 400 mg/kg (mm)

5.0 CONCLUSIONS AND RECOMMENDATIONS

The primary conclusions from the investigation are:

- Extensive chloride ingress has occurred at numerous locations throughout the substructures, particularly those which underlie expansion joints. Discrete locations with elevated chloride contents were measured in piers without overhead expansion joints; this is likely caused by water from deck drains being sprayed onto the piers.
- Corrosion of the reinforcing steel has caused delamination at many locations throughout the substructures.
- The compressive strengths and air void structures measured throughout the cores are indicative of a concrete which is adequate for this environment.
- If remedial measures are not taken to direct deicing chemicals away from the substructures, chloride ingress is likely to continue at an unacceptable rate (as indicated by RPCT results).
- Honeycombed concrete with some patching was observed at several locations on the river piers. These areas need to be repaired properly.
- Insufficient cover, likely caused by movement of the reinforcing steel cage relative to the concrete forms, was noted at several locations.

To address these deficiencies and restore the structure to a suitable condition for extending its life and meeting the structural upgrading requirements, the following recommendations are made:

- At locations where the chloride ion concentration, at the depth of the reinforcing steel, exceeds the corrosion threshold, concrete should be excavated to a depth of at least 25 mm beyond the

reinforcing steel and replaced with suitable concrete properly doweled into the underlying structure. The reinforcing steel should be examined and replaced or cleaned, as necessary, at this time.
  - This includes large patches in some areas and full jackets (entire pier) in other locations.
- Honeycombed areas should be excavated and replaced with suitable concrete properly doweled into the underlying concrete.
- The concrete in the delaminated areas should be excavated to a depth of at least 25 mm beyond the reinforcing steel and replaced with suitable, properly-bonded concrete.
- Repair concrete should be designed to minimize shrinkage and mimic the mechanical properties of the underlying concrete in so much as this is practical.
- Areas of the substructures which do not require excavation and replacement of concrete should be treated with a surface sealant to slow the future ingress of chlorides.
- The drainage throughout the structure should be revised and improved to prevent salt-laden water from impacting the substructures in the future.
- The tops of the cap beams and footings should be sloped to shed water.

6.0 REHABILITATION AND UPGRADING PROGRAM

Following the assessments of the substructures and the provision of repair and rehabilitation recommendations, a rehabilitation and upgrading program for the substructures was developed and put out to tender. The upgrading that is required to satisfy seismic loading demands includes the addition of concrete shear walls between the columns of the piers as well as a 3.0 m tall, 500 mm thick reinforced concrete encasement at the base of each pier column. Analysis of the piers indicates various pier columns require an additional 200 mm thick reinforced concrete encasement to extend up above the 500 mm thick encasement in order to resist the flexural stresses caused by seismic loads in the longitudinal direction. The final elevation of the concrete encasements is based on structural requirements and aesthetics.

To ensure that the structural integrity of the pier is adequate throughout construction, the shear wall is constructed prior to beginning excavation of the concrete on the other faces of the pier columns. Several of the piers do not require substantial rehabilitation in conjunction with the required structural upgrades.

To install the shear walls, the concrete on the interior faces of the pier columns is excavated in the affected area and the exposed reinforcing steel is replaced or repaired as necessary (Figure 5a). Horizontal dowels are installed in the existing columns and vertical dowels are installed at the undersides of the cap beams and in the existing pier bases in order to provide an integral connection between the new and existing structural elements (Figure 5b). Following the construction of the shear walls, the other faces of the columns and pier cap are rehabilitated in a phased process which ensures that the structural integrity is preserved throughout construction.

The concrete specified for use in the rehabilitation program was a low-shrinkage CSA A23.1 Class of Exposure C-1 concrete. The specification requires a minimum depth of removal of 25 mm beneath the reinforcing steel. A packaged grout material was specified for pressure injection at the tops of the shear walls; this is intended to ensure a proper bond between the shear wall and the underside of the cap beam.

Several areas with visible honeycombing or loss of section are identified in the specifications. Excavation of concrete until sound concrete is encountered, at a minimum depth of 25 mm beneath the reinforcing steel, is required in these areas.

The pier rehabilitation program, including excavation beyond the reinforcing steel and replacement of the damaged concrete with suitable material, is largely similar to the program undertaken during the pier rehabilitation of the Angus L. Macdonald Bridge in Halifax, N.S (Chowdhury, Chatzifoti and Eppel 2016). The piers of the Macdonald Bridge had undergone damage due to alkali-silica reaction (ASR) in addition to the deterioration mechanisms noted at the Centennial Bridge; however, it was determined at the time of assessment that the ASR had nearly exhausted itself, thus encapsulation was recommended.

As part of the substructure rehabilitation, all drainage downspouts attached to the piers are to be replaced with temporary PVC pipes with the discharge directed away from the structure. Many of the existing corrugated steel downspouts were corroded and could no longer adequately keep the discharge off of the structure. Upgrades to the drainage system will be considered during the deck replacement portion of the bridge rehabilitation scheduled to begin in 2019. Upgrades may include using stainless steel downspouts to improve durability, extending the length of the downspouts and directing the discharge away from the substructure.

The upgrading and repairs thus far have been carried out very successfully. The full substructure repair program is expected to be completed in 2020. The repairs and upgrades are expected to provide another 50 years of life to this critical infrastructure component.

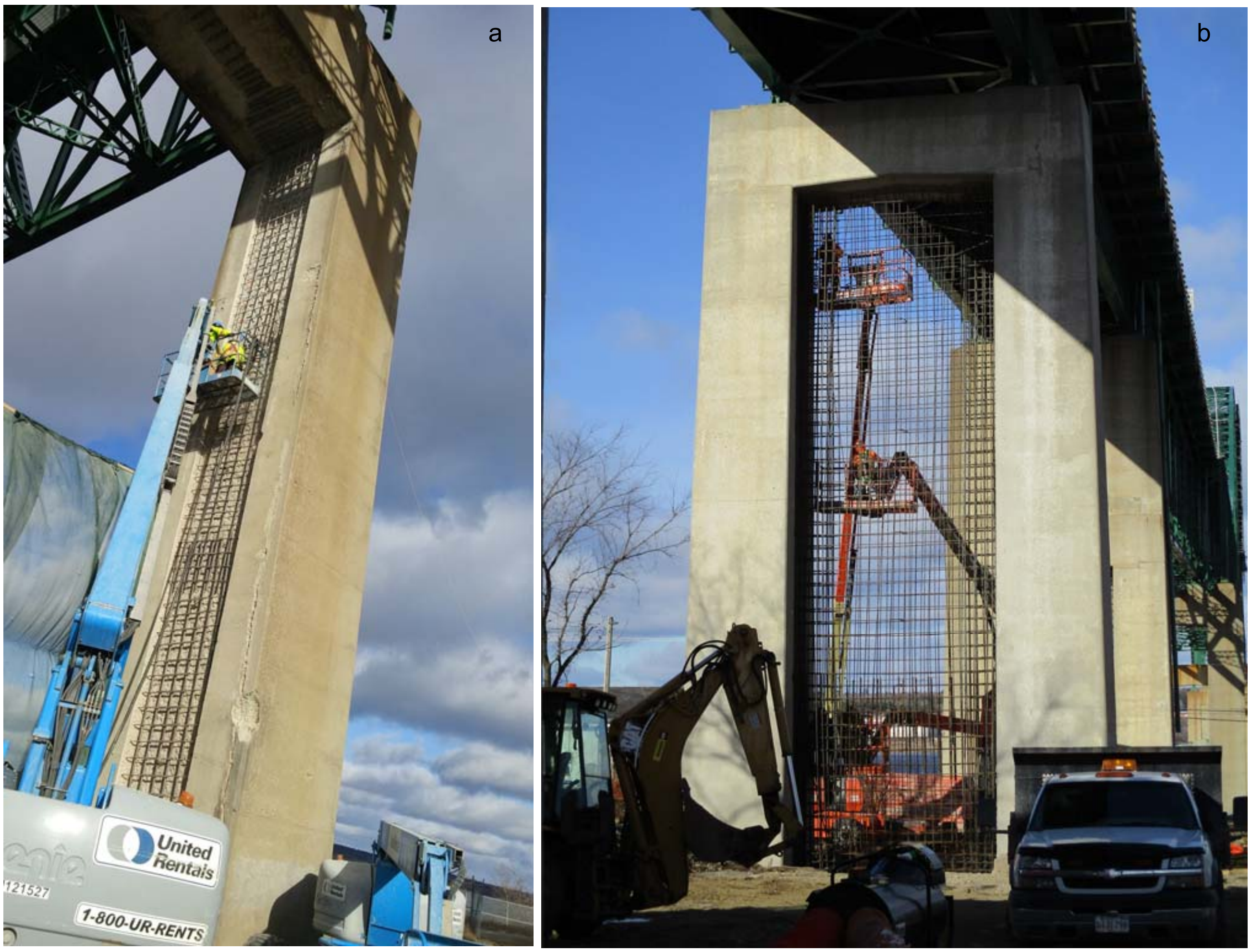

Figure 5: Pier Rehabilitation Underway a) Concrete Excavation and Steel Renewal in Preparation for Infill Wall; b) Construction of Reinforcing Steel Cage for Infill Wall

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