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DESIGN AND CONSTRUCTION OF RAILWAY AND ROADWAY LIVE LOAD RELIEF SPANS OVER FAILING EXISTING CULVERTS

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ABSTRACT

The Jean River near Wabush, Labrador is crossed by two railways and an access road by twin 6m diameter culverts. They are heavily strutted inside their barrels to counteract some significant shape deformation, and are deemed not suitable to sustain the increased volume of rail traffic serving the development of the Bloom Lake mines. The owner requested the design and construction of a replacement scheme for an additional design life of 20 years with a time sensitive schedule for completion of the work during the 2013 construction season. This VE concept for the design of live load relief spans over the existing culverts includes short railway spans and a semi-integral roadway bridge supported on micro-piles driven strategically near the existing culverts. In addition, the bridge design includes a modular approach in order to accelerate the bridge installation and limit the field construction activities on both the railway tracks and the road. This paper reviews the railway and roadway structure options and design solutions considered to meet the construction window. Its construction challenges, including coordination of supplier and contractor change requests, including rapid responses to field changes, are discussed to address construction difficulties encountered to meet the delivery schedule.

1. INTRODUCTION

The Jean River existing culverts near Wabush, Labrador support on a 35 degree skew two railway tracks and one private access roadway to the Mining area. These two twin large diameter culverts are approximately 6m in diameter and are heavily strutted inside their barrels with some significant shape deformation and corrosion. The inspection reports recommend replacement and or significant costly repairs in order to sustain the increase volume of rail traffic serving the development of the Bloom Lake mines. The owner requested the design and construction of a replacement scheme for an additional design life of 20 years with a time sensitive schedule for completion of the work during the 2013 construction season. The design of the railway spans were to meet the current AREMA manual (AREMA 2012) for Cooper E80 loading. Similarly, the roadway bridge was designed to the requirements of the Canadian Highway Bridge Design Code (CSA S6 2006) and the bridge specifications of the Province of Newfoundland & Labrador (Government of Newfoundland and Labrador 2011).

2. BACKGROUND

2.1 Project History

The two large culverts carrying the Wabush Lake Railway have been strutted for some period of time on account of significant out of round deformations. While no further deformation has been measured, the increase in railway traffic on trackage supported by the culverts, Wabush Lake Railway historically, then in addition the Bloom Lake Railway since 2009, has brought to the fore the question of factor of safety of the existing structures, along with the increasing impact upon service reliability, should the structures deform further. The owner of the two railways
crossing at this location, Cliffs Iron Ore Quebec wished to enhance safety and reliability in the medium term, in order to prepare for an eventual long-term solution. Classic alternatives had been examined since the time of design and construction of the Bloom Lake Railway. The most recent evaluation which involved diversion tracks, temporary bridging, then permanent bridging or new culverts was very expensive, environmentally disruptive, and would have had created high risk of traffic disruption.

AECOM was approached to provide alternatives to the conventional solution, addressing a medium-term planning horizon (20 years). Two solutions were proposed:

1. Insert small diameter relief and low-flow culverts threaded through the strutting elements, and provide flood flows by tunnelling construction adjacent to existing culverts

2. Construct bridging above the existing culverts upon non-driven piling adjacent-to and between the existing culvert barrels. The railway structures basic layout remained the same; numbers of piles in foundation elements were adjusted as design was refined (5 in each abutment, 6 for piers). The roadway bridge was changed to a single span, but abutments were changed to semi-integral, in order to permit pre-fabrication of as many elements as possible.

2.2 Design Constraints

The primary design constraints were simple, but demanding:

- No disruption of regular train service
- No damage to existing culverts
- No disruption of roadway usage.
3. VALUE ENGINEERING BRIDGE DESIGN REVIEW

3.1 Railway bridges

The relief bridge option was selected for the following reasons:

- **Costs** – low and controllable; conventional detour track options were subject to a number of cost-driver risks born out in an initial bidding process where bid costs were well above estimates. Insert and tunnel options are subject to geotechnical risk drivers. Both the conventional and tunnel options required critical temporary shoring arrangements requiring in-water or below water-table work which is inherently risky.

- **Schedule risks** – Disruptions to railway operations must be minimized. The selected option had the lowest risk because of simple components, minimal geotechnical risk, and the minimum number of steps involving out-of-service conditions.

- **Environmental risks** – All infrastructure project alternatives face significant threshold or entry barriers associated with potential environmental disruption. Diversion track and tunnel options would create significant requirements for environmental protection and, in the case of the track diversion option, significant environmental restoration costs. The selected simple bridging option creates no additional environmental footprint, with only standard “good housekeeping” types of measures during construction.

- **Geotechnical risks** – The conventional diversion and replacement structures were designed with driven pile foundations; given the unknown cause of the culvert deformations, any vibration by impact-driving would inherently include risk of ground loss and unpredictable disruption to railway operations, or to construction operations. Similarly tunnelling options can either induce vibrations, or lead to uncontrolled ground loss. The selected simple bridge structure used drilled foundations which inherently control ground loss and include the means of mitigation and repair, should unforeseen conditions arise (Palynchuk et al, 2007).

The elements leading to lowest risk and lowest cost are explained in greater detail in following sub-sections.

3.1.1 Shorter span

The bridge spans selected are classic beam spans, with short individual span lengths. This minimized the foundation footprint and pile load demand associated with the railway bridge foundations, and led to the simplest field assembly, requiring only readily available lifting equipment.

3.1.2 Micro-pile foundations

Micro-pile foundations were selected because their installation requires the smallest equipment footprint, combined with rapid set-up and removal of equipment, so that foundation construction may easily fit within available time between trains. Design can be adjusted to suit found conditions. Bearing strata was a firm, over-consolidated till at about 2 meters below the streambed.
In order to address longitudinal loads induced by braking and acceleration, sub-vertical grouted anchors were included in abutment foundations. One of the key micro-pile advantages is that they can be drilled at a severe batter and act as tie-backs. Hence the same construction equipment can be used for the load bearing piles and the tie-back anchor installation.

3.1.3 Modular design

Conscious effort was applied during the design process to produce uniform, interchangeable elements, with as much pre-fabrication as possible.

- Piling was of uniform size,
- Pile caps were pre-cast concrete, of sizes easily lifted with locally-available crane equipment,
- Structural steel elements were, in spite of a skew imposed by the culvert alignment, mirror images between the two spans for each bridge, and between the two bridges.
- Decks were of simple standard open deck construction.
3.2 Roadway bridge

3.2.1 Semi-Integral Abutment

Standard roadway bridges are often designed with deck joints over the abutment bearings. In northern climates, these deck joints are exposed to de-icing salt and mix of salt and sand to clear the road during winter. This climatic condition creates an aggressive environment for the proper performance of the deck joints. It also requires regular maintenance to clean and remove all dirt in order to achieve the expected life span of these joints without premature durability issues. Other Canadian provinces (i.e. Alberta, Québec) have developed standard alternative bridge types such as semi-integral abutments to mitigate and remove this deck joint durability issue. The semi-integral abutment was hence found the most desirable bridge structure for this project to meet the medium term planning horizon set by the client. In addition, this option also removed the costly and relatively lengthy fabrication and installation of deck joints. Figure 7 shows the standard semi-integral abutment detail design adapted from the Alberta Government bridge publications (Alberta Government 2012) and used for this bridge.

![Figure 7: Semi-integral Abutment Design](image)

3.2.2 Square ends

In combination with semi-integral abutments and the modular concept, the additional cost of longer steel girders to provide a square end abutment over a skew crossing was well off-set by the simplicity and symmetry of construction during a short construction window. This VE concept allowed a complete symmetry for all 4 corners of the roadway bridges, hence limiting the number of different type of precast elements. It also ensured a better operability of the semi-integral bridge behaviour.

Figure 8 shows the bridge deck under construction and the completed structures.

![Figure 8: Roadway bridge deck under construction and completed](image)
4. TENDERING AND CONSTRUCTION CHALLENGES

4.1 Aggressive Schedule

In order to remove uncertainty as to residual culvert capacity, and to ensure low risk for planned capacity expansion of the Bloom Lake mine and railway, the schedule was to ensure completion of works during a planned train traffic shut-down operations in late September for the mines serviced by the two railways. The modularity of design partly addressed schedule, but project delivery method was critical in ensuring schedule compliance. The EPCM (Engineering, Procurement, and Construction Management) model was chosen as the means of delivery, and AECOM maximized the benefit of this approach by breaking the work into 4 major contract packages:

1. Piling
2. Structural steel and timber bridge decks
3. Railway track services
4. Site civil, pre-cast concrete, and overall installation

There were many advantages of this approach in comparison with a conventional general contract:

- No one party could hold the project to ransom; a non-performing party could be removed, without jeopardizing overall delivery
- Critical paths, created by fabrication lead-times for example, could be controlled or eliminated by timing issuance of tender documents appropriately.
- Procurement process is not “all-or-nothing” as feedback was received from invited tenderers, documents and conditions could be adjusted, and improvements fed-forward to next phases.

Delivery ultimately hinged upon effective construction site management, and rapid response and adjustment to site conditions.

4.2 Piling issues

In order to fast-track design, geotechnical investigation was carried out concurrently with design, making use of nearby borehole records as foundation design basis. Design required little revision in any case, and final details of micro-pile design were the responsibility of the selected contractor. As with any work on and around active railway tracks, access and track occupancy required tight scheduling and coordination with railway operational parties. However, the small footprint and flexibility of the drilling equipment allowed work schedules to be adapted to the needs of train operations.

The only technical problems that arose were related to the difficulty in retracting casing at one location from the till bearing strata, in order to achieve the required bond length between the grouted pile body and the adjacent till. Casing at this location had been left in place overnight, and could not be retracted sufficiently. The contractor, GeoFoundations Canada, developed an innovative solution, installing two helper piles perpendicular to the axis of the main pile group, welding connecting sleeves between the “stuck” casing and the casing of the adjacent helper piles.

4.3 Asphalt Pavement

The construction of the roadway bridge deck came near the very end of the construction season pouring concrete and the placement of the asphalt overlay was found to be unachievable before the local supplier closed their operations. Since the completion of the bridge deck was critical to schedule compliance, Value Engineering discussion took place to find alternative design. The most efficient way was to replace the designed 65mm asphalt layer with an equivalent 60mm concrete layer cast monolithically with the deck, which was about to take place. The additional cover was de-facto an additional sacrificial concrete thickness to ensure durability for the planned life span of the bridge. The design team prepared rapidly revised drawings for the contractor in order to comply with the schedule.

4.4 Bridge Tests

Typically, bridge tests are seldom requested to validate the deflection of the bridge in relation with the design. However in this particular case, it was paramount for the client to ensure positive compliance with the design. The
goal was to validate that the existing culverts were indeed free of any live loads and that the roadway bridge was able to handle the special design vehicle shown on Figure 9.

![Special Design Vehicle](image)

Figure 9 Special Design Vehicle

State-of-the-art digital altimeters (Zip-Level Pro 2000 by Accuratab) were used at mid span of the girders with a secondary simple survey apparatus for validation. The test train cars and test truck with known weight and measured axle spacing were positioned to pre-determine axle and front wheel locations marked on the bridges to provide the maximum deflection for the span as shown in Figure 10.

![Test Train Cars and Test Truck](image)

Figure 10 and Roadway 150t Rock Test Truck and Railway Test Car Wheel Positioning Marker

Table 1 below reports the principal test results which show excellent agreement with the design and the anticipated computed deflection.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Test Vehicle</th>
<th>Anticipated Static Deflection (mm)</th>
<th>Field Measurement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway Span</td>
<td>266 kips car</td>
<td>7.8</td>
<td>8.1</td>
</tr>
<tr>
<td>Roadway Span</td>
<td>150t Rock Truck</td>
<td>14.0</td>
<td>10.7</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS AND LESSONS LEARNED

The order to proceed for the detailed design of this project was provided in early February 2013 and the construction was completed as planned before the construction winter season shut-down in November 2013. The key points and lesson learned associated with this successful project can be summarized below:

1. Define the problem early and methodically
2. Evaluate multiple alternatives in brainstorming sessions with decision making personnel and senior design staff
3. Design with constructability in mind
   a) Simple structural elements do not mean unsophisticated design; but allow a focus upon problem solution
   b) Simple design components, disciplined construction management led to 15% savings on construction cost compared to the initial estimates.
4. Provide flexibility during tender process to allow design changes and revisions
5. Involve local stakeholders rapidly, and at the highest level with clear lines of communication
6. Encourage field personnel to provide constructive feedback during pre-construction and project set-up in order to:
   a) Develop ownership from all the party involved
   b) Incorporate any site requirements into the design

6. REFERENCES


