Design and Construction of Looking Back Creek Bridge

Mike Lau, Ph.D., P.Eng.
Partner, Dillon Consulting Limited

Faris Khalil, M.Sc., P.Eng.
Former Senior Geotechnical Engineer at
AECOM Canada Limited

Brian Beyak, C.E.T., P.Eng.
Civil Engineer
Keeyask Engineering & Construction Department
New Generation Construction Division
Manitoba Hydro

Paper prepared for presentation
at the Bridge Session: Better – Faster – Safer

of the 2013 Conference
of the Transportation Association of Canada
Winnipeg, Manitoba

PAPER ABSTRACT

Manitoba Hydro is proposing to develop the Keeyask Generation Project, a 695-megawatt hydroelectric generating station in northern Manitoba, located approximately 725 km northeast of Winnipeg at Gull Rapids on the lower Nelson River. One of the key components of the Keeyask infrastructure project is the design and construction of approximately 25 km of two-lane access all-weather road from the junction of Provincial Route 280 to the proposed Keeyask Generating Station. The road will provide access to the site during construction and during the operational life of the generating station. The construction of the access road will require a clear span bridge crossing at Looking Back Creek. A clear span is preferred at this bridge site to minimize potential environmental impacts and to avoid damaging fish habitat.

The bridge is a 30 m clear span structure with a clear roadway width of 13.5 m. The bridge deck is 150 mm thick concrete and acts compositely with the 1200 mm deep partially prestressed concrete box girders. The girders are supported at each end by two integral abutments founded on driven steel “H” piles. This bridge is required to carry extremely heavy vehicular loads including a 136,365 kg capacity articulating low-bed tractor trailer that will be used to haul large transformers and equipment to the Keeyask Generating Station. The loading equates to about twice the Manitoba Infrastructure and Transportation Provincial Trunk Highway standard design truck weight. The bridge was also required to be designed to accommodate loads from a CAT 740 articulated truck used in hauling rock and aggregate.

There are many challenges to the design and construction of this bridge at this remote northern Manitoba site including: design to accommodate heavy vehicular loads, shipping and erecting girders, permafrost protection, and protection of a sensitive environmental site.

The construction of the bridge started in March 2012 and was completed and opened to traffic in January 2013.

1.0 INTRODUCTION

Manitoba Hydro is proposing to develop the Keeyask Generation Project, a 695-megawatt hydroelectric generating station in northern Manitoba, located approximately 725 km northeast of Winnipeg at Gull Rapids on the lower Nelson River, as shown in Figure 1. One of the key components of the Keeyask infrastructure project is the design and construction of approximately 25 km of two-lane access all-weather road from the junction of Provincial Route 280 to the proposed Keeyask Generating Station. The road will provide access to the site during construction and during the operational life of the generating station. The construction of the access road requires a clear span bridge crossing at Looking Back Creek, as shown in Figure 2. A clear span is preferred at this bridge site to minimize potential environmental impacts and to avoid damaging fish habitat.

The bridge is a 30 m clear span structure with a clear roadway width of 13.5 m. The bridge deck is 150 mm thick concrete and acts compositely with the 1200 mm deep partially prestressed concrete box girders. The girders are supported at each end by two integral abutments founded on driven steel “H” piles. This bridge was designed to carry extremely heavy vehicular loads including a 136,365 kg capacity articulating low-bed tractor trailer that will be used to haul large transformers and equipment to the Keeyask Generating Station. The bridge was also required to be designed to accommodate loads from a CAT 740 articulated truck used in hauling rock; and to Manitoba Infrastructure and Transportation (MIT) standard design truck loadings; Modified AASHTO MSS 27 (HSS30) Design Truck Loading, AASHTO MS 27 (HS30) Lane Loading and AASHTO-LRFD HL “93” Loadings.

There were many challenges to designing and constructing this bridge in the remote northern Manitoba site, such as shipping and erecting girders, permafrost protection, and protection of a sensitive environmental site.

2.0 GEOTEHNICAL INVESTIGATION AND DESIGN RECOMMENTATIONS

The proposed site was located within a region that has been mapped as containing sporadic discontinuous permafrost. Frozen soil and ice layers were encountered on most of the test holes drilled. The depth, thickness and lateral extent of the frozen soil and ice layers was highly variable and erratic, typical for a discontinuous permafrost region.

The general soil profile from the test holes in descending order is as follows:

- Peat, 200 mm thick;
- Stratified clay and silt, 12 m to 13 m thick with frozen soil and ice layers;
- Sand and gravel, 1 m to 4 m thick; and
- Bedrock, encountered 14 m to 18 m below ground surface.

Bridge Foundation

The weak overburden soil, presence of permafrost, relatively shallow bedrock, and structure type (integral abutment bridge) limit the foundation alternatives to steel piles driven to refusal on bedrock. Practical pile refusal can generally be considered to be three consecutive sets of 15 to 20 blows per maximum 25 mm of pile penetration using a hammer with a minimum rated energy of 50 kJ. An acceptable practice is to design steel piles driven to refusal on bedrock as end bearing piles with an allowable bearing capacity calculated on the basis of a permissible stress of 0.3 fy where fy is the yield strength of the steel.

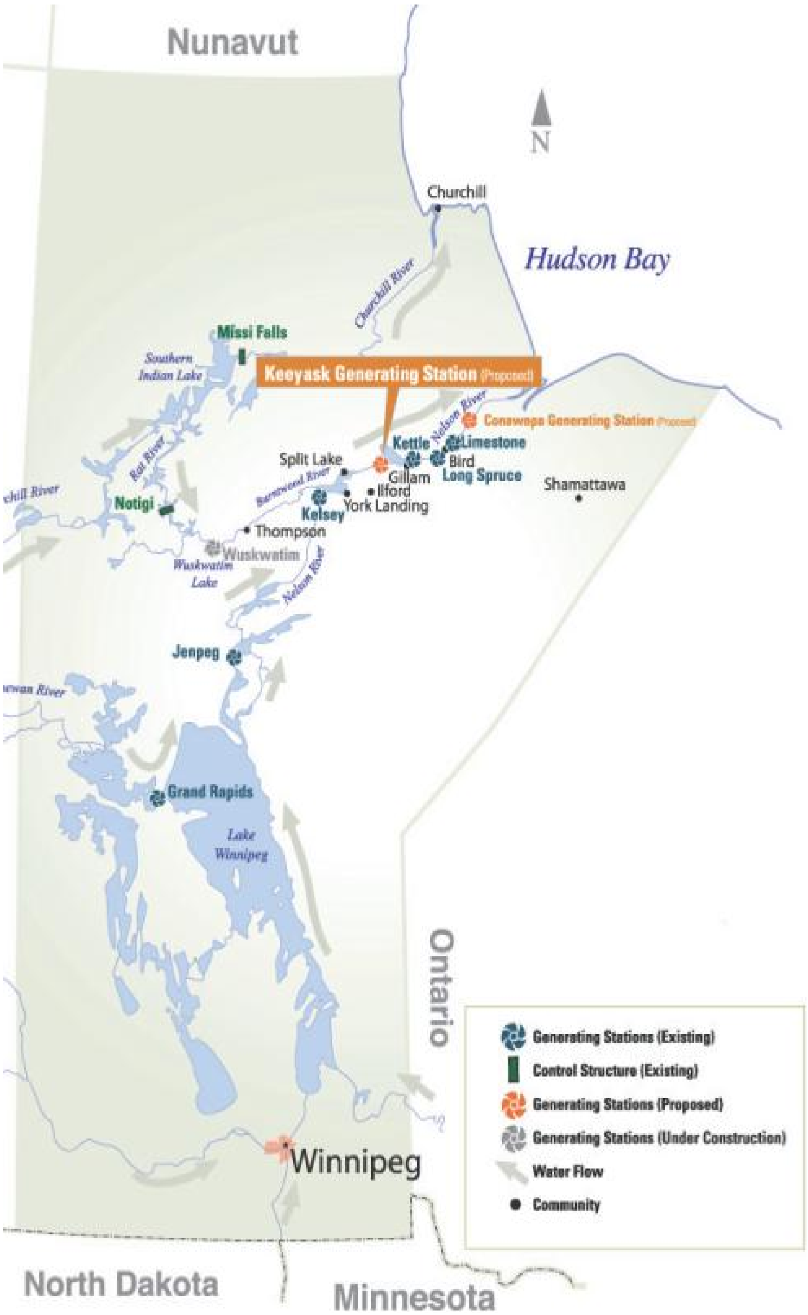


Figure 1: Proposed Location of Keeyask Generating Station
(Courtesy of Manitoba Hydro)

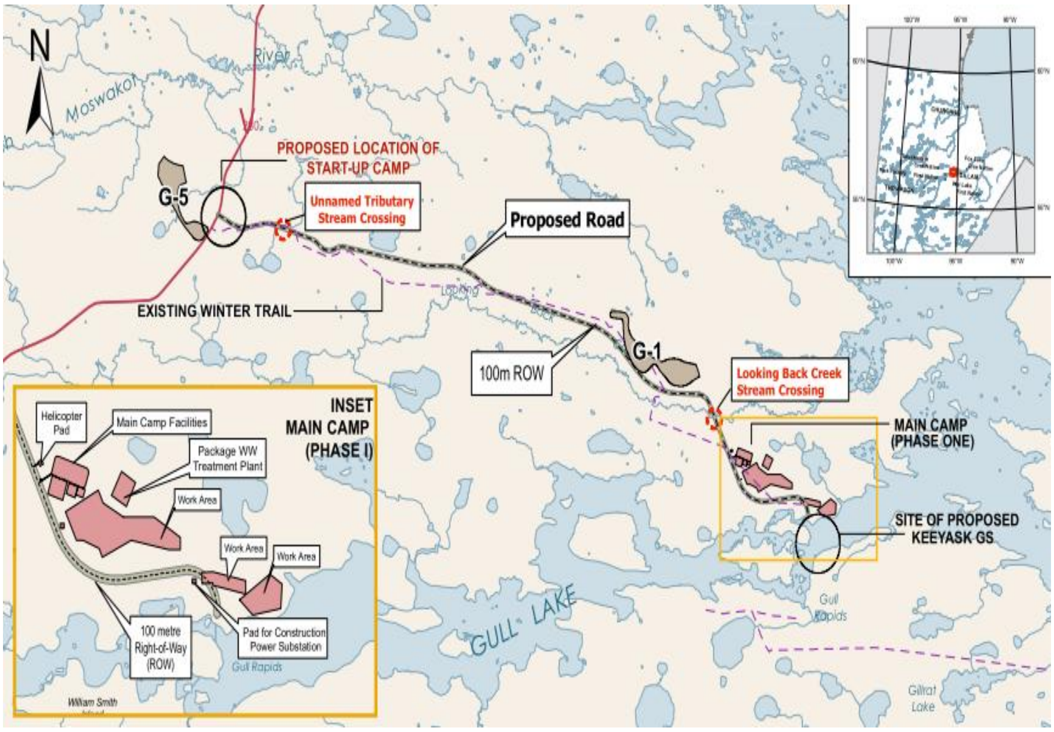


Figure 2: Location of Looking Back Creek Bridge
(Courtesy of Manitoba Hydro)

The allowable bearing capacity can be considered equivalent to the pile bearing resistance at the service limit states. Nominal and factored bearing resistances at strength limit state are determined according to item 10.7.3.5 and Table 10.5.5-2 of AASTO – LRFD Bridge Design Specifications. Recommended values of pile bearing resistance at service and strength limit states for the pile section (i.e., HP 310x110 Grade 300) are shown in Table 1.

Table 1: Recommended Bearing Resistance for Steel HP 310x110 Grade 300 Driven to Refusal on Bedrock

Service Limit States	Strength Limit States			Construction Control Method
	Nominal Bearing Resistance	Resistance Factor	Factored Bearing Resistance	
kN	kN	φ	kN	
1269	4050	0.4	1620	Set Formula
		0.5	2025	Stress wave analysis, PDA measurements and CAPWAP analysis

Approach Fill Embankment

The construction of the new bridge will involve the placement of 4.5 m of fill at the approach embankment. Geotechnical considerations for embankment design and construction include bearing capacity, slope stability and settlement. Of particular concern is any potential for disturbance of the thermal regime whereby degradation (thawing) of the permafrost can occur with the addition of very little heat. Thawing of the ice rich soils at this site would lead to a considerable loss of strength, excessive settlement and soil containing so much moisture that it tends to flow. Because of the nature of the sporadic patches of frozen ground and ice layers within non-frozen ground, it is difficult to determine the thermal stability of the soil under existing conditions and any impacts resulting from construction activities. Thermal degradation could occur not only from ground surface but also from warmer (thawed) soil adjacent to or beneath the frozen patches. In this regard, we have determined that winter construction offers the best scenario with respect to minimizing the potential for degradation of the permafrost beneath the approach fills by allowing the active layer to be partially or completely frozen at the time of fill placement and frozen (rather than warm) material to be placed in the embankment.

Although the fill material will in itself act as an insulation layer, it is recommended that rigid insulation be installed underneath the approach fill to provide further protection of the frozen foundation soil against thawing. STYROFOAM Highload insulation or approved equivalent is recommended for this application. The peat should be left in place and covered with a leveling course of sand for placement of the insulation panels. A minimum of 300 mm thick of sand fill should be placed on the insulation panels to protect it from damage from construction equipment. Figure 3 shows typical insulation requirements at the bridge site and Figure 4 shows the insulation details.

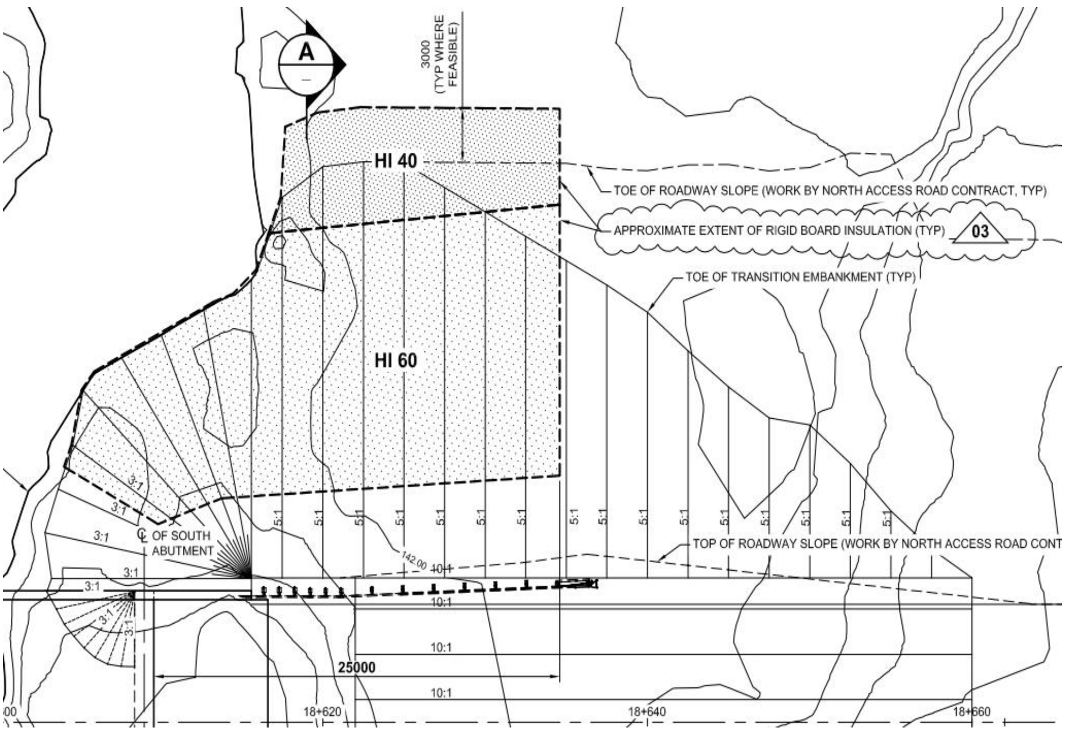


Figure 3: Rigid Insulation Outline Typical

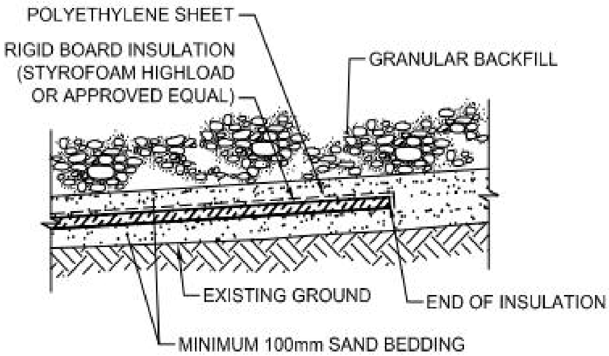


Figure 4: Rigid Insulation Details

3.0 HYDRAULIC ASSESSMENTS

Looking Back Creek flows into Stephens Lake, which is located downstream of Gull Rapids. The Stephens Lake water levels data collected over several years are presented in Figure 5. It is reasonable to assume that the high water level at the Looking Back Creek Bridge would be similar to the Stephens Lake high water level. Thus, the high water level of 142.20 m was used in the design of the Looking Back Creek Bridge. However, the top of ice/water elevation of 145.00 m was used in the final design, as determined by Manitoba Hydro.

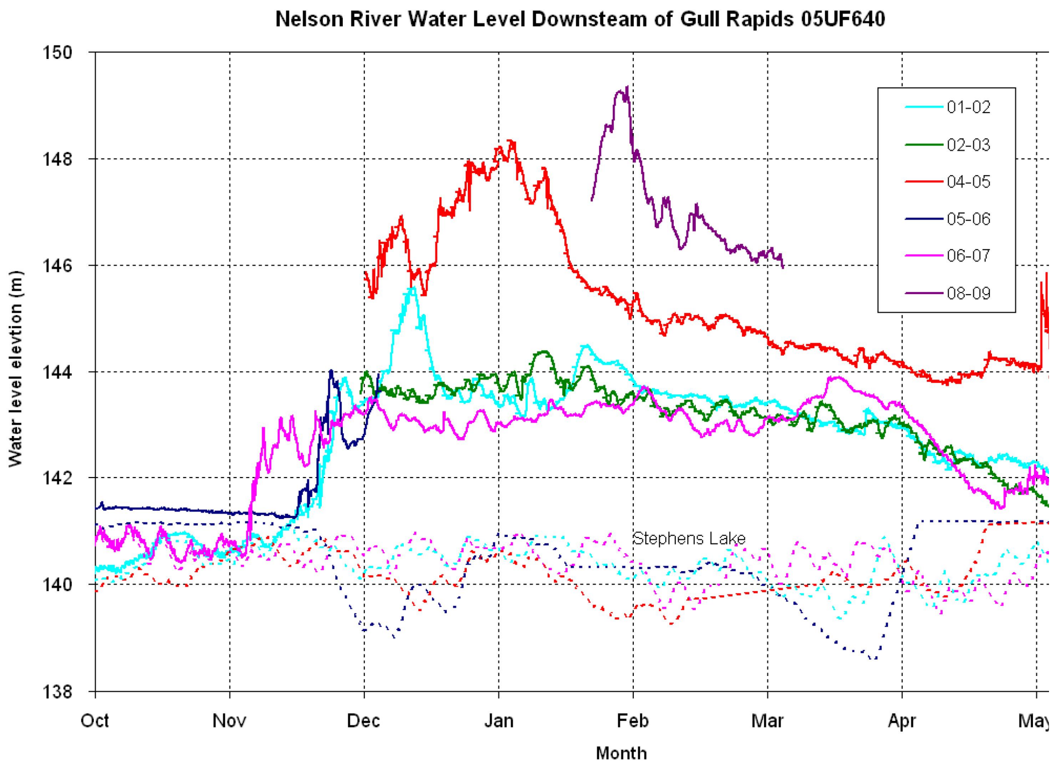


Figure 5 Stephens Lake Water Level Elevations

4.0 FOUNDATION SYSTEM

Integral Abutment

The economic and functional advantages, and improved durability of integral abutment bridges due to the elimination of costly and maintenance prone expansion joints and bearings, are generally recognized by bridge engineers. Deck joints in a bridge are the source of many problems over its lifetime. In time, chances are good the joints will leak, permitting water and deicing salt to leak through. Often this leads to deterioration of the concrete abutment and pier caps, bearings, and superstructure beneath. Other problematic issues associated with the expansion joints include rough ride, noise and snow plow damages. Negative economic impacts due to the expansion joints have led to the development and advancement of the jointless bridge deck. The new Looking Back Creek Bridge on the North Access Road was designed and constructed using the jointless bridge deck technology to accomplish the following objectives:

- Long-term serviceability;
- Minimal maintenance requirements;
- Economical construction; and
- Improved overall performance.

As shown in Figure 6, the integral abutments utilize a single row of HP steel piles supporting an abutment pile cap. The HP steel piles are designed to accommodate thermal expansion and contraction movement of the bridge. The approach slabs are connected to the integral abutment, which in term are connected to the girders. As such, the thermal movement of the bridge would occur at the end of the approach slab. It is estimated that the maximum thermal movement at the end of the approach slabs is about 12 mm.

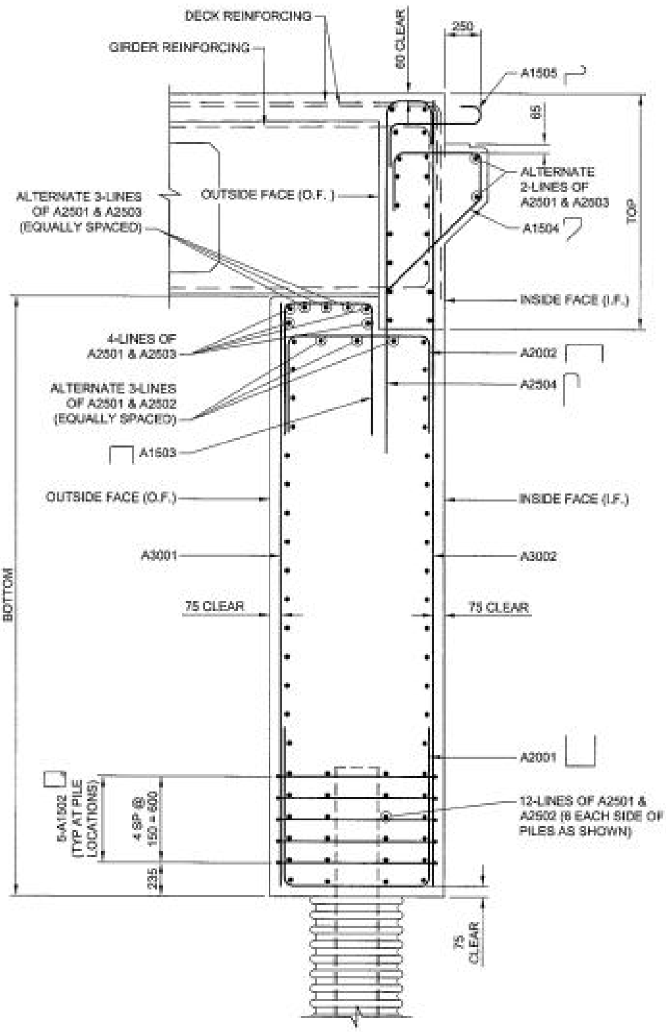


Figure 6: Looking Back Creek Bridge Integral Abutment

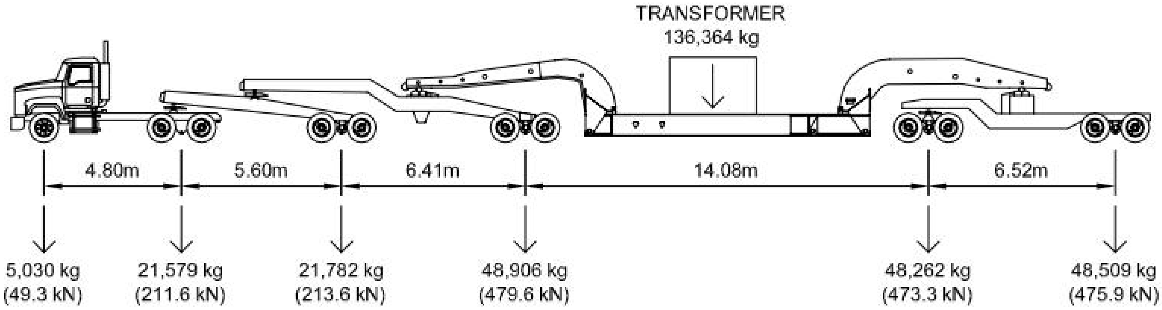
5.0 SUPERSTRUCTURE

Design Vehicular Live Loads

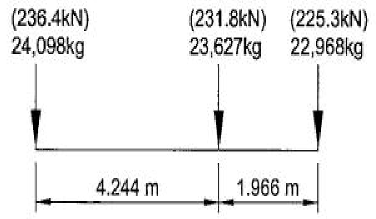
The design vehicular live load was based on the extreme force effect of the following:

- 136,365 kg capacity articulating low-bed tractor trailer;
- CAT 740 articulated truck; and
- Modified AASHTO MSS 27 (HSS30) design truck.

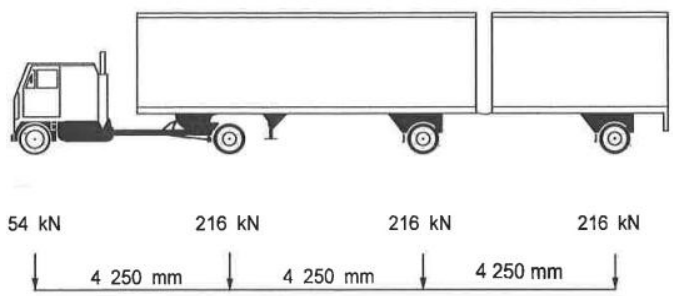
All the design trucks are shown in Figure 7.



136,365 kg Capacity Articulating Low-Bed Tractor Trailer



CAT 740 Articulated Truck



Modified AASHTO MSS 27 (HSS30) design truck

Figure 7: Design Vehicles

The unfactored and undistributed bending moment and shear force envelops per design lane for various design vehicles are summarized in Table 2. The governing design vehicle is the 150 ton capacity articulating low-bed tractor trailer.

Table 2: Bending Moment and Shear Force Envelop per Lane for Various Vehicular Loads

Span	0.0L	0.1L	0.2L	0.3L	0.4L	0.5L
	Bending Moment (kN-m)					
150 Ton Capacity Articulated Low-Bed Tractor Trailer	0	2561	4265	5112	5724	5786
CAT 740 Articulated Truck	0	1680	2944	3792	4323	4474
Modified AASHTO MSS 27 (HSS30) design truck	0	1535	2653	3399	3911	4074
	Shear Force (kN)					
150 Ton Capacity Articulated Low-Bed Tractor Trailer	1018	849	707	564	464	369
CAT 740 Articulated Truck	629	558	489	419	350	281
Modified AASHTO MSS 27 (HSS30) design truck	581	510	440	371	348	278

Partially Prestressed Precast Concrete Box Girder

The passage of the 136,365 kg capacity articulating low-bed tractor trailer, almost double the typical highway design truck, for transporting transformers to the Keeyask Generating Station will occur infrequently. Cracks may form during the passage of the 136,365 kg capacity articulating low-bed tractor trailer, but these cracks may close completely when the load is removed. Partially prestressed precast concrete box girders are girders reinforced with a combination of prestressing strands (Photo 1) and conventional longitudinal reinforcing steel (Photo 2). The combination allows some tension cracking under full service load while maintaining sufficient ultimate strength. There is sufficient design information available for general acceptance the combination of prestressing tendons and conventional longitudinal reinforcing steel in the design of partially prestressed precast concrete members; cracked at service loads.

The advantages of partial prestressing are:

- Better camber control (short term and long term) results in a more uniform vertical girder layout;
- Greater resistance to failure through ductility and energy absorption; and
- Lower cost resulting from the use of conventional reinforcing to reduce the number of stressing operations.

Photo 1: Prestressing Strands

Photo 2: Non Prestressed Longitudinal Reinforcing Steel

Lateral Post-Tensioning

To improve lateral load distribution, the partially prestressed precast concrete box girders are post-tensioned transversely with high strength prestressing strands. Upper and lower ducts are used in each girder at either end (Photo 3) and at mid-span, and a single duct is used in each girder at quarter points of the girder span. This lateral post-tensioning system combined with the 150 mm thick reinforced concrete deck provides an improved and monolithic lateral load distribution.

Photo 3: An Upper and Lower Lateral Post-Tensioned Ducts

6.0 CONSTRUCTION

Melting Permafrost

The original geotechnical recommendations for the crane pad were based on winter construction, therefore the frozen soils encountered during girder erection were deemed capable of withstanding the crane loading pressures. Due to delays, the construction began during the warm months of 2012 and as result the exposed crane pad foundation soils were partially thawed and became very soft in places. The maximum downrigger pressure of the 500-ton Mammoet crane was determined to be 172 kPa using conventional sized mats. The crane operation had identified limited settlement tolerances for operating the crane.

The potential settlement under the downrigger support mat for a range of base preparation thicknesses was analyzed based on the following assumptions:

- The relative density of the thawed foundation soil was very loose (N values of 4 or less);
- The 150 mm granular fill was readily available;
- Groundwater level was at the bottom of the compacted granular fill;
- The granular fill was assumed to be compacted to 100 percent of its maximum dry density by an appropriate method; and
- The granular fill elevation shall be constructed to an elevation equal to or higher than the crane pad for a minimum of 3.0 m in the horizontal in all directions around the outside of the wing walls.

The potential for settlement was calculated for a range of granular thicknesses as summarized in Table 3.

Table 3: Compacted Granular Thickness vs. Estimated Settlement

Compacted Granular Thickness (m)	Estimated Settlement (mm)
1.5	50
2.0	40
2.5	30
3.0	20
3.5	15

Based on this geotechnical analysis, the partially thawed soil was removed and replaced with the 150 mm granular fill and compacted to 2.5 m thick. This support base would limit the estimated settlement to 30 mm at the crane downrigger. This estimated settlement was acceptable for this crane operation. Photo 4 shows the 500 ton capacity Mammoet crane that was used to install the girders and Figure 8 shows the downrigger loads.

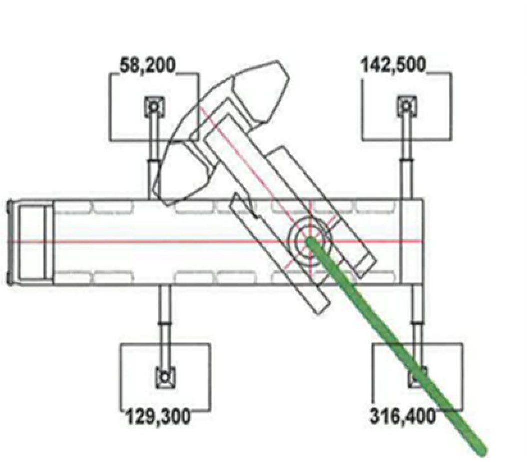


Figure 8: Downrigger Load in Pound

Photo 4: 500 Tons Capacity Mammoet Crane Erecting Girder

Protecting Permafrost

It was important to provide a consistent foundation under the bridge embankment. The design intent was to maintain frozen ground by providing the insulation protection. For the thawed conditions under high fill, greater than 3 m, will be trapped weather insulation. On the other hand, freeze/thaw cycles were anticipated under low fill areas, and in the vicinity of the toe (the first 3 m outside the toe embankment). This dilemma was resolved by placing the insulation in the zone from 3 m fill height outward to 3 m horizontally beyond the toe embankment. This prevented the short term weather-related issue and reduced the long term impact of annual freeze/thaw cycles; the short term issues were reduced bearing capacity and shallow instability within the top thawed zone. Settlement will occur over a longer period of time, but the settlement is anticipated to act uniformly, and avoids a settlement cycle associated with seasonal freeze and thaw cycles. The potential of global instability along the interface of thaw saturated soil in the foundation cannot be ruled out, but it should get better with time as more consolidation and drainage occurs. Photos 5 and 6 show sand bedding installation and insulation installation respectively.

Photo 6: Sand Bedding Installation

Photo 5: Insulation Installation

High Water Level

The water level elevation of the Looking Back Creek is dependent on the Nelson River water level elevation and the annual ice regime. Unexpected high water levels of the Looking Back Creek would have negative impacts in terms of construction delays and added costs.

Predicting the water levels at Looking Back Creek during the construction of the bridge presented a challenge in terms of location of temporary works that were required to building the bridge, so that they did not become flooded. The unexpected high water levels (see Photo 7) during foundation work had a negative impact on the construction schedule.

Photo 7: High Water Level During Construction

Social/Economic/Environmental Impact

The new bridge has a minimum design life of 75 years. With the application of the latest technology for jointless bridge deck design, the lifespan was increased, and maintenance costs were reduced significantly. The bridge owner can utilize their maintenance, human, and financial assets elsewhere. Less frequently scheduled maintenance will result in less interruption to commuter public and will reduce owner and user costs.

This clear span bridge was designed and built in a way that reduces the impact on the environment and reduced the damage to the fish habitat. The Construction Phase Environmental Protection Plan (CPEPP) formed an integral part of the construction contract and required the contractor to adhere to an enforced environmental protection plan as outlined in the CPEPP for all known and identifiable risks and their mitigation measures. This project was successfully completed in accordance with the CPEPP and had the least negative impact on the environment. See Photos 8 and 9.

Photo 8: Undisturbed Stream Crossing

Photo 9: Undisturbed Looking Back Creek

7.0 CONCLUSION

The design team provided preliminary and detailed designs and contract administration services for the construction of the Looking Back Creek Bridge on the North Access Road. The design team and contractors were able to work around the challenges presented by this remote and environmentally sensitive site in northern Manitoba. This new infrastructure (Photo 10) met Manitoba Hydro's need to provide a vital link from the Manitoba Provincial Route 280 to the proposed Keeyask Generating Station.

Photo 10: Looking Back Creek Bridge