Challenges of the Great Bear River Bridge

By: Mekdam Nima, Ph.D., P.Eng,

Michel Lanteigne, M.Eng., P.Eng.,

Zichao Wu, Ph.D., P.Eng.,

Naheed Ahmad, M.Eng., P.Eng. (Pending),

and Nick Bevington, EIT

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Abstract

The Great Bear River Bridge (GBRB) is an important river crossing located on the annually constructed winter road along the Mackenzie Valley, near the community of Tulita, NWT, 1000 km north of the Alberta/Northwest Territories border. In 2004, the Government of the Northwest Territories (GNWT) entered into a 50:50 cost-sharing agreement with the Federal Government, under the Canadian Strategic Infrastructure Fund (CSIF), to build a bridge across the Great Bear River. The bridge will be 460m long, at a site located 800m upstream from the confluence of the Great Bear and Mackenzie Rivers.

The main challenges on this project include:

- Logistics associated with building a large structure at a remote site with limited access.
- Limited availability of local resources.
- Limited number of capable contractors in the area.
- Northern climatic conditions
- Budget constraints in a time of rapidly rising construction costs.

This paper describes the initiatives undertaken to deliver the project within budget, including the option of utilizing a bridge superstructure from Alberta Infrastructure and Transportation's surplus inventory.

Factors that impact project costs are analysed, and the specific approach adopted for design and project delivery is summarized.

Challenges encountered on this project and lessons learned are discussed. The writers conclude that constructability input at the early stages of a project will have a positive affect on project budget and schedule during the construction phase. Finally, recommendations and strategies for future projects are presented.

Introduction

This paper is written in support of the concept of constructability implementation. It comprises a case study and presents constructability lessons learned during the conceptual design and final design phases of the Great Bear River Bridge.

For the past two decades, the construction industry has suffered from the lack of constructability implementation. This has caused many problems, such as increased cost and time required to construct a project, reduced productivity of project personnel and equipment, and low quality construction **[3]**. Because of the size and complexity of projects and the fragmentation of the construction field into specialized roles and expertise, the construction industry urgently needs to implement constructability. Researchers in developed countries, mainly in the United States, the United Kingdom, and Australia, realized the seriousness of this shortfall and suggested solutions to resolve it. In the United Kingdom, the Construction Industry Research Information Association (CIRIA) identified seven concepts. Those concepts were then broadened by CIRIA into 16 concepts. During this period, parallel but unrelated studies were undertaken in the United States. Based on the research of Tatum et al. in 1986 and O'Connor et al. in 1986, 14 concepts in its "Constructability Concepts file" were presented, followed by the research of O'Connor and Davis in 1988 who detailed them. Further elaboration of these 14 concepts in 1993, by the Construction Industry Institute (CII), resulted in the development of 17 concepts. **[5] [6]**. The Australian Construction Industry Institute, meanwhile, developed 12 concepts in 1993 **[1]**. Twenty-Three constructability concepts in the Malaysian Construction Industry were researched by Nima in 2001 **[2]**.

One of the major constructability concepts is maintaining evaluation, documentation, and feedback regarding the issues of the constructability throughout the project, to be used in later projects, as lessons learned **[4,7]**. In the case study, the authors investigate a number of elements found at the GBRB, including transportation of bridge elements, specifications, contracting strategy, limited number of contractors experienced in this type and size of project, and schedule. With a bearing-to-bearing length of 460 metres, the GBRB will be the largest bridge built by the GNWT. The large size of most of the bridge elements added additional constraints to those normally encountered on smaller bridges. It is advisable for designers and constructors to be aware of some of these effects, as discussed in this paper. This paper also describes the challenges encountered by the design team, and the initiatives undertaken to reduce project costs. The final design and approach to project delivery are summarized.

Project Description and Background

The project selected for this case study is the Great Bear River Bridge. The GBRB is located along the Mackenzie Valley Winter Road, near the community of Tulita. A map of the NWT Highway System is presented in **Figure 1**. Tulita is a community of approximately 500 people, located just south of the Arctic Circle, 1000 kilometres north of the Alberta/NWT border.

The Mackenzie Valley Winter Road is constructed annually by the GNWT Department of Transportation (DOT) to connect the communities along the valley to the all-weather road system to the south. The road also provides access to resource exploration and development sites along the Mackenzie Valley corridor, an activity that has become a vital component to the development of the Northwest Territories economy in recent years.

In the 1970's the Federal Government completed the pre-engineering phase for construction of a highway along the Mackenzie Valley, which was to connect with the Dempster Highway near the community of Tsiigehtchic in the Northwest Territories. They selected and surveyed the alignment and prepared conceptual designs for bridges across most rivers, including the Great Bear. However, the highway was built only to Fort Simpson before the project was abandoned.

The Mackenzie Valley Winter Road has a long history. During construction of the Canol Pipeline in the 1940's, the US army hauled their equipment and supplies to Norman Wells by winter road. During the decades that followed, the Federal Government would construct the winter road occasionally, depending on need. Since the 1970's the winter road has been constructed annually.

Constructing a winter road involves allowing the natural terrain and river crossings to freeze sufficiently to carry highway traffic. The terrain freezes quite rapidly in early winter, but river crossings take several weeks longer to freeze sufficiently to carry heavy trucks. Nearly 1.5m of ice thickness is required to carry full capacity traffic over water.

In the early 1990's the GNWT began constructing bridges at river crossings along the Mackenzie Valley Winter Road. Now, 15 years later, bridges have been constructed over the majority of the rivers, except for a few along the northern section and the Great Bear, which is the largest river. Funding to date was largely provided by the Federal Government under various programs.

In 2004 the GNWT entered into a 50:50 funding agreement with the Federal Government, under the Canada Strategic Infrastructure Fund (CSIF), to construct a bridge over the Great Bear River. The total budget allocated for the bridge is $25 million.

After the original budget was established, construction costs across Canada escalated significantly, by more than 50 percent according to some reports. The cost estimate provided in the Conceptual Design report submitted in July 2005 was $40 million.

Under the CSIF agreement all costs over $25 million are to be borne entirely by the GNWT. After reviewing the Conceptual Design report, the GNWT asked the engineering team to review the design and look at options to deliver the project within budget.

The bridge is to be designed to CAN/CSA S6-00 for CL-800 loading, with two lanes on a 10 meter wide deck overall, without sidewalk. The bridge is 460m long, and requires 15m clearance above the high water navigation level. The primary objectives of the project are to provide a low maintenance structure, and to maximize benefits to the community and northerners by providing business opportunities, employment, and training.

SITE CONDITIONS

The GBRB site is located 800m upstream from the confluence of the Great Bear and Mackenzie Rivers. This site was selected by the Federal Government in the 1970's.

Currently, the winter road does not cross the Great Bear River, but is routed on the Mackenzie River around the mouth of the Great Bear, as illustrated in **Figure 2**. Although a crossing over the Great Bear would be substantially shorter, the ice cover is more challenging in terms of ice crossing construction. First, the banks are high and steep, and second, one of its channels refuses to form an ice cover until late winter. Some years the channel remains open all winter. **Figure 3** illustrates open water at this location in late March 2003.

Access to the site is by annually constructed winter road between mid-January and end of March, and by barge from Hay River, Northwest Territories, on Great Slave Lake, between early June and early September. Tulita has a 900 m long gravel surfaced runway, with daily scheduled flight service provided from Yellowknife and Norman Wells.

The soil stratigraphy under the riverbed consists of a loose gravel and sand to a depth up to 5m, underlain by lightly cemented sedimentary rock that extends beyond the depth of exploration of 20m. The riverbanks consist of glacial till containing some bentonitic layers, over bedrock. Permafrost is present under the riverbanks, but not under the riverbed.

The water level in the lower reach of the Great Bear River is controlled by the water level in the Mackenzie River. In late summer the Great Bear River is relatively shallow, but during spring break-up the water level can rise substantially due to break-up activity in the Mackenzie River. When the ice on the Mackenzie River breaks up, an ice-jam invariably forms downstream of the confluence with the Great Bear, causing the water level at the mouth of the Great Bear to rise substantially. The pressure from on-coming ice on the Mackenzie River pushes against the Great Bear River's ice cover, causing it to fail and move in the upstream direction. When the Mackenzie River ice jam releases, the water level drops at the mouth of the Great Bear and its ice cover flushes out normally.

INITIATIVES TO REDUCE PROJECT COSTS

Relocate the Grant MacEwan Bridge

The first option considered to reduce project costs was to relocate the Grant MacEwan Bridge from the Athabasca River in Fort McMurray, AB, to the GBRB site. Although it is in good condition, the bridge is scheduled to be replaced as part of an initiative by Alberta Infrastructures and Transportation (INFTRA) to upgrade Highway 63. Earth Tech is a member of the team providing engineering services for the upgrade.

The Grant MacEwan Bridge was built in 1965. It is 472 meters long and two lanes wide, and consists of six through-truss spans and three girder spans, as shown in **Figure 4**. It currently carries the southbound traffic of Highway 63.

The bridge was designed in 1964 according to AASHTO 1961. The design live load was AASHTO HS20 with provision for overload of a single HS40 Truck.

A structural analysis of the bridge indicated that several members would need to be strengthened to meet CL-800 loading requirements. It was also determined that the bridge members should be refurbished in order to minimize future operating and maintenance costs.

Transportation Scenarios for the Grant MacEwan Bridge

Two general scenarios were considered to relocate the Grant MacEwan Bridge superstructure to Tulita:

- In large components, refurbished and strengthened in Hay River; or
- Dismantled into individual members in Fort McMurray, refurbished and strengthened in Edmonton or Hay River.

Scenario 1: Transportation in Large Components

This option involves dismantling the truss into components 10m wide, 9m high, and of various lengths for transportation to Hay River, where it would be refurbished and strengthened before continuing to Tulita. Two routes were considered to transport the bridge in large components to Hay River:

In-Land Waterway:

The first route is the inland waterway between Fort McMurray and Hay River, with portage between Fort Fitzgerald and Bell Rock. A small tug and barge operated by Girard Enterprises of Fort MacKay, AB, currently provides service to Fort Fitzgerald in the Northwest Territories. The barge is 33m long and has a carrying capacity of 90 tonnes, which is adequate for this project since each truss component has to be short enough to respect load limits on the roads (portage).

This option was not pursued because a preliminary evaluation indicated that:

- The cost of hiring two barge operators, one at each end of the portage, and the cost of mobilizing and shuttling heavy equipment back-and-forth between Fort Fitzgerald and Bell Rock outweighs the savings that could be realized by marine transportation.
- Continuing by road from Fort Fitzgerald to Hay River is not possible because there are two truss bridges without adequate clearance: one over Buffalo River and the other over Hay River.

Highway:

The second route considered for transporting the bridge in large components to Hay River is the highway. A total of 20 loads would be required in order to limit the length of each component to respect highway load limits. A tied arch bridge located along the route

(Peace River, AB) is believed to provide the required clearance; otherwise an alternate route is available.

The cost estimate for transportation along this segment alone is high because this option requires:

- Specialized transportation equipment;
- Total road closure, restricted travel, and associated permits.

This option was not pursued further because of cost. Moreover, it was concluded that barging is the most economical method of transportation from Hay River to Tulita. The cost of transporting large components along this segment is also cost prohibitive because of the large number of trips involved.

Scenario 2: Transportation in Dismantled Members

Dismantling the trusses into individual members in Fort McMurray is advantageous as it allows for transportation by train or regular truck loads. In addition, this option allows flexibility in the selection of the shop for refurbishing and strengthening (e.g. Edmonton or Hay River).

The cost estimate for dismantling and erecting was developed with the assistance of a retired bridge engineer from Alberta Infrastructure and Transportation, as no recent experience could be found in the private sector.

Economic Assessment

Dismantling the truss into individual components is more practical and economical than transporting the truss in large components. The cost of relocating the Grant MacEwan Bridge to Tulita was estimated at $40M, which is comparable to the cost of a new bridge; therefore this option is not economically viable.

Revisit Original Design

The next initiative undertaken was to study the factors that impact construction costs, and determine whether the original approach could be modified to reduce costs.

Cost Factors

It was determined that the major factors impacting costs are:

Limited Availability of Local/Northern Resources:

All construction materials, with the exception of concrete aggregate, have to be imported from the south. In addition, the number of northern contractors with the capacity to undertake a project of this magnitude and complexity is very limited. In particular, the foundation under the piers is beyond the capacity of northern contractors.

Logistics:

Tulita is a remote site with seasonal access. The cost to mobilize personnel, materials and equipment is very high; and the on-going costs for re-supply, crew changes, potential lost time obtaining equipment repair parts, etc., are also very high.

Limited Number of Experienced Contractors:

To date, bridges along the Mackenzie Valley Winter Road have largely been within the capacity of northern contractors. The majority of bridges typically consist of single span, single lane structures supported on driven steel piles. However, a few recent projects with up to 2 piers have been completed by southern contractors, giving them experience with the conditions along the winter road. Of those bridges, single span Notta Creek Bridge at 982.3km is shown in **Figure 5** and two-span Ochre River Bridge at km 722.4 in **Figure 6**.

Climatic Conditions

The bridge site is located just south of the Arctic Circle so winter conditions are relatively severe.

Market Pressures

Because of the high level of construction activity in the provinces, contractors will only stray from familiar territory if the additional risk involved is well compensated by a superior profit potential.

Design Objective

After analysing the above factors and consulting with a wide range of contractors, it was concluded that the design should achieve the following objectives:

- Be adapted to the capacity of a wide range of contractors, particularly the few smaller contractors that have bridge construction experience in the area;
- Allow the project to be completed as rapidly as possible, in order to minimize risk and costs associated with logistics; and
- Minimize work interruptions, which translate in additional mobilization/demobilization costs, and potential loss of people and profit from lost opportunity elsewhere.

FINAL DESIGN

Substructure

Figure 7 illustrates the pier configuration selected. It is a concrete wall type pier, designed to resist ice forces at the 100 year elevation, which is approximately 18 meters above the pile cap. The pier is 2 meters thick, designed to resist ice forces from both the upstream and downstream directions. The leading edges of the pier along the upper portion are inclined to reduce ice forces where they cause maximum overturning moment.

The pier is supported on a foundation consisting of 16 – 914 millimetres diameter concrete caissons drilled into bedrock, 18m below the pile cap. The pile cap is buried below the maximum scour depth. The 914 millimetres diameter caisson was selected as it meets the project requirements, and is within the capacity of a wide range of contractors.

Another pier type considered consists of vertical caissons extending all the way up to the underside of the girders. Although this type of pier could potentially be more economical, the structural analysis carried out on various sizes of caissons and caissons combinations up to 3.6 meters in diameter indicated that it is not appropriate for the site.

Figure 8 shows the elevation of the abutments. The concrete seat is supported on driven H-Piles. The tip elevation of the H-Piles falls within the permafrost zone. The wingwalls are to be cast integral with the abutment seat and grade beam(s) to increase stability. Geotechnical analysis suggested a 3H:1V common fill for the north abutment and 2H:1V common fill for the south abutment to achieve slope stability. To reduce the span length of the roof slab, a second grade beam was proposed at the north abutment.

Superstructure

The superstructure consists of 3 lines of steel plate girders, continuous over 5 spans. Span lengths are 80 -100 -100 -100 -80 meters. To provide flexibility and minimize seasonal work interruptions, the girders are designed to facilitate installation by erection or launching. The bridge layout is illustrated in **Figure 9** and an artistic rendering is shown in **Figure 10**.

The bridge deck consists of pre-cast concrete panels installed composite with the girders. Other options considered were cast-in-place concrete with and without partial depth pre-cast concrete panels, and open steel grating and the SPS system.

APPROACH TO PROJECT DELIVERY

Contracting Strategy

In order to reduce the contractor's exposure and risk, the size of the construction contract was reduced by removing girder fabrication, pre-cast concrete deck panel manufacturing, and approach embankment construction. These components will be tendered separately.

At the time of writing, the girder fabrication contract has been awarded. The girders will be delivered to site by truck on the winter road in February and March 2007.

Manufacturing of the pre-cast concrete deck panels will be tendered during summer 2006, for delivery by barge in early summer 2007.

Schedule

Although it appears that it will be to the contractor's advantage to complete the project as rapidly as possible, up to 4 years will be allocated for construction in order to minimize risk associated with the schedule.

Other Project Delivery Initiatives

To further reduce the contractor's risk the client will provide:

- Bathymetric information for the river from the mouth of the Great Bear to a point 200m upstream of the bridge site in the tender package.
- Processed concrete aggregate.
- Site preparation, including preparation of a lay down area and camp site.

MAXIMIZING LOCAL INVOLVEMENT

The GNWT's Business Incentive Policy (BIP) will apply to all contracts. The BIP is designed to provide an advantage to Northern businesses on all GNWT procurement and construction contracts. When comparing bids, each bid price is adjusted by reducing the value of work to be completed by Northern and local businesses by 15 and 20 percent respectively.

In order to make outside contractors aware of the BIP and services available locally, a copy of the BIP will be provided in the construction tender, along with a list of local businesses with a description of the services they offer.

The project will provide employment opportunities for labourers and various trades. Resumes of people interested in working will be collected and submitted to the successful contractor.

GNWT Department of Education Culture and Employment (ECE) have several training programs in place that lead to certification. Some of ECE's programs also provide financial incentives to qualifying contractors by way of wage subsidies. The project team is working with ECE to maximize training opportunities for local and northern residents.

Conclusions and Recommendations

As a result of the specific design and project delivery initiatives undertaken, the construction cost estimate for the Great Bear River Bridge was reduced substantially and is now in line with the budget.

This paper illustrates a case study of one of the constructability concepts related to the construction of the GBRB. It demonstrates that both designers and contractors can enhance constructability by maintaining evaluation, documentation, and feedback regarding the issues of constructability throughout the project to use in later projects. Many lessons learned that could benefit similar large bridge projects in the North were explored in this paper.

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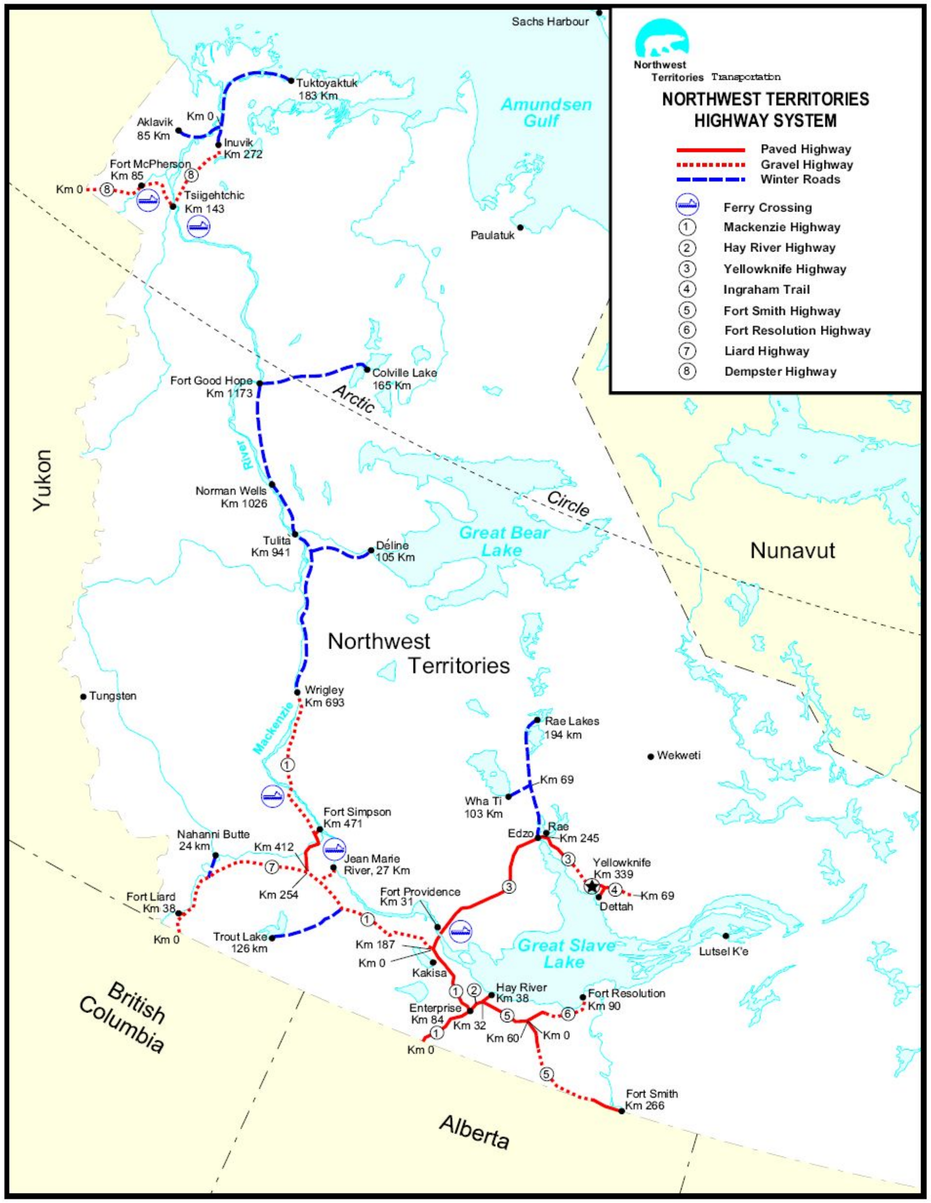

Figure 1: Map of the NWT Highway System

Figure 1

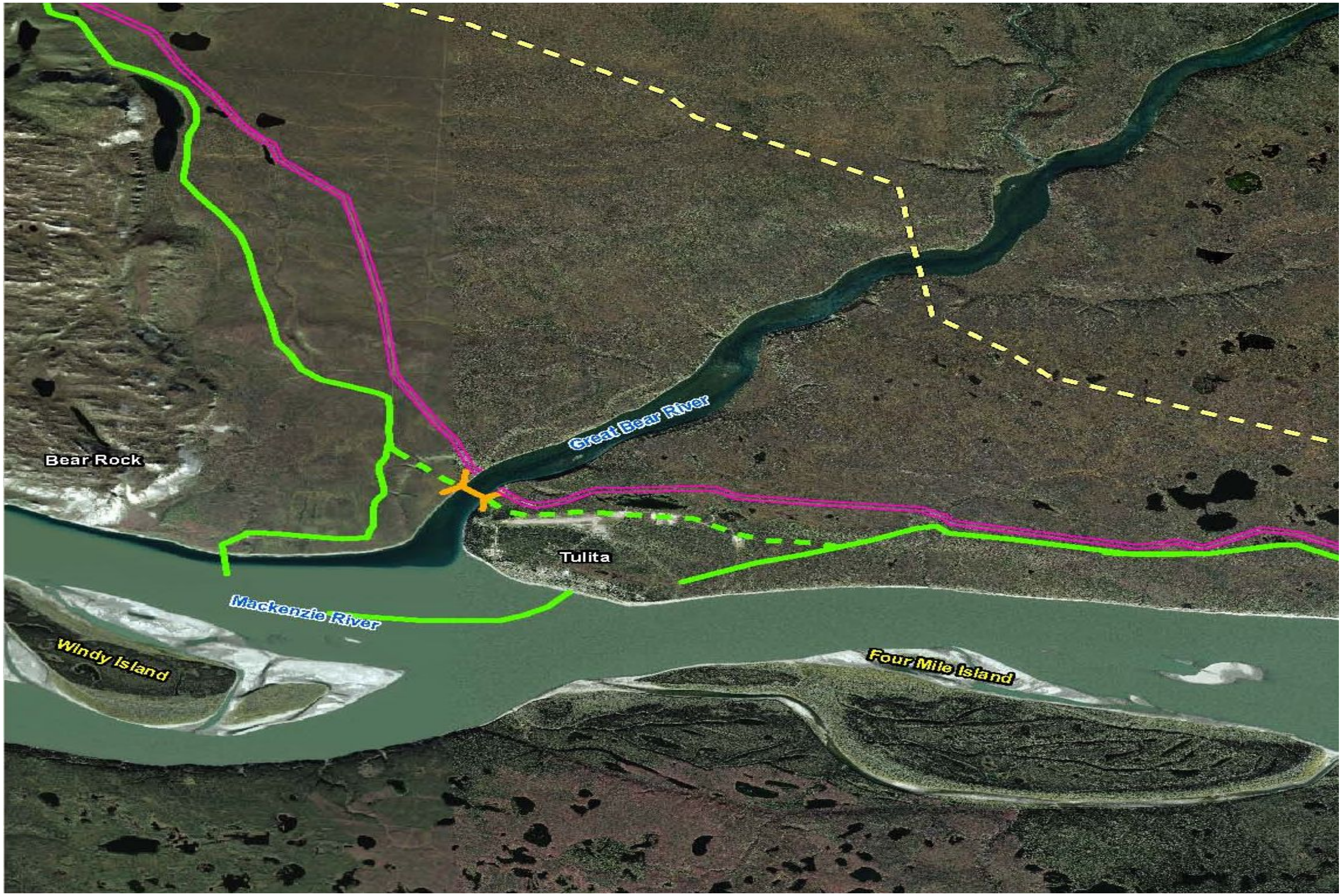

Figure 2: Current and proposed Winter Road in the GBRB Site

Figure 2

Figure 3: Great Bear River Channel Remains Open During Winter

Figure 3

Figure 4: Aerial Photo of Grant MacEwan Bridge over Athabasca River in Fort McMurray

Figure 4

Figure 5: Notta Creek Bridge at 982.3km

Figure 5

Figure 6: Ochre River Bridge at km 722.4

Figure 6

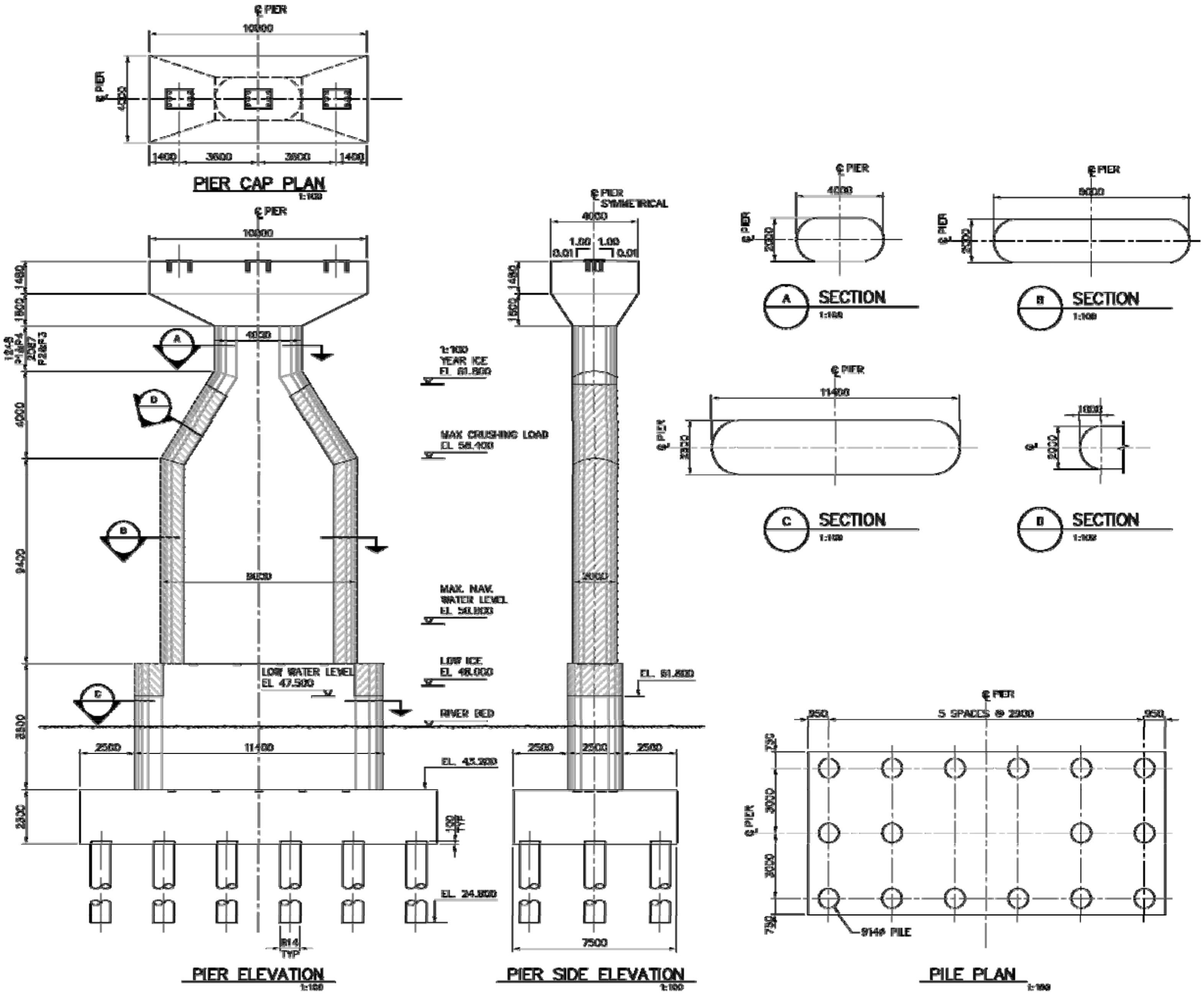

Figure 7: Pier Configuration

Figure 7

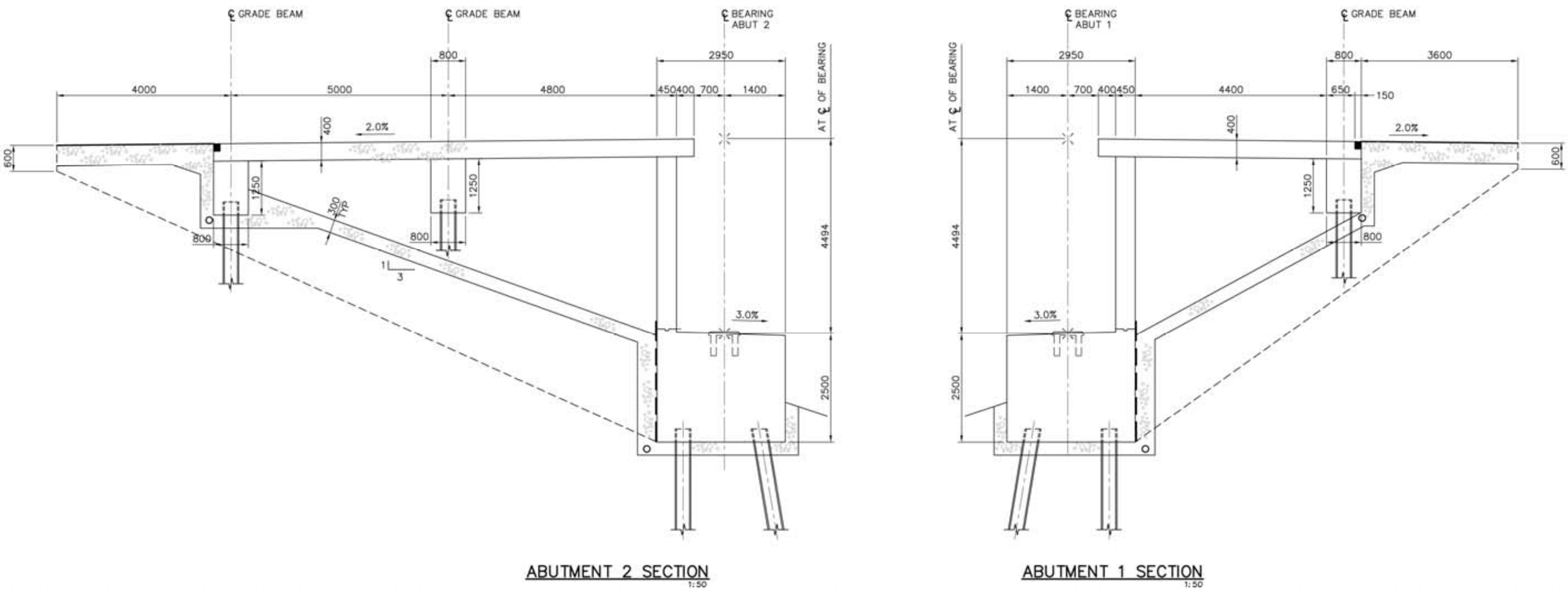

Figure 8: Abutments Configuration

Figure 8

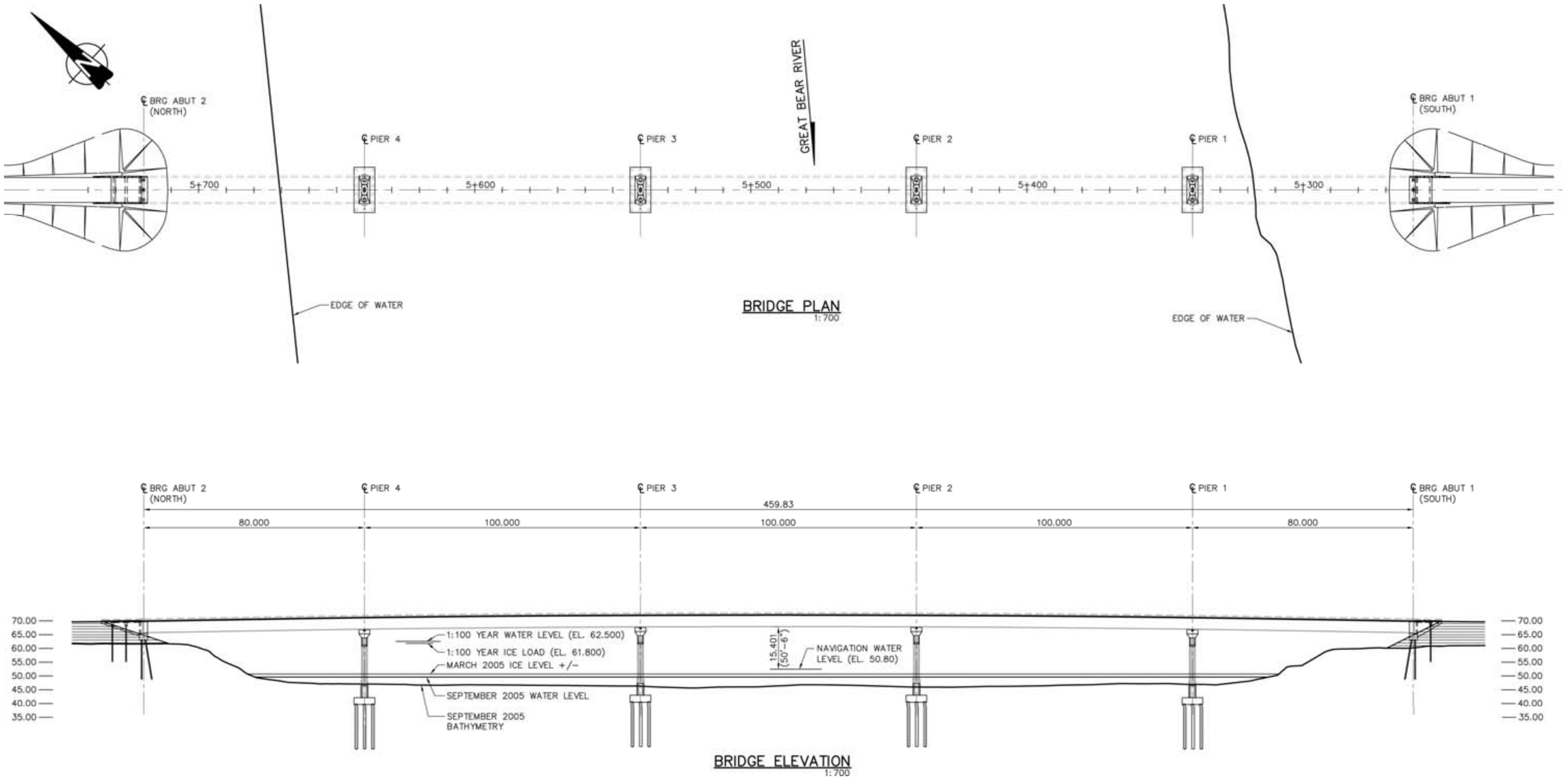

Figure 9: GBRB General Arrangement

Figure 9

Figure 10: Artistic Rendering of GBRB

Figure 10