
Needles Bridge Crossing: Managing Design Risk of a Long Term Infrastructure Investment

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Needles Bridge Crossing: Managing Design Risk of a Long Term Infrastructure Investment

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ABSTRACT: In 2003, the British Columbia Ministry of Transportation initiated a design competition for the detailed design of the Needles Bridge crossing over Arrow Lake. When constructed, this bridge will be the longest fixed link lake crossing in the province at a length of 1087 m. Arrow Lake was created in 1969 by the construction of the Hugh Kennleyside Dam; and in 1967 a previous crossing design project was initiated but ultimately was never advanced.

This paper describes the unique design methodology and risk management approach employed during the recent design competition project, and presents some of the significant challenges and constraints faced during alignment optimization. Geometric design played a key role in the overall design economy of this large structure. A bathymetric survey was combined with conventional survey data and used to optimize the subsurface and shoreline horizontal geometry. The survey amalgamation improved the overall economy through minimized pier heights and optimal positioning of the navigation span.

Geotechnical and structural requirements were integrated early into the design process in a true multi-disciplinary approach to design. Moreover, because the lake level is a function of the downstream dam, the reality of significant water level fluctuations introduced additional constructability constraints that required careful consideration by the design team.

The resulting final design of the structure contains one horizontal curve and three vertical curves and is a successful blend of geometric, geotechnical and structural expertise. The risk management strategies used throughout the course of the project significantly contributed to keeping the design project on schedule and on budget. As a result, an economical combination of superstructure, substructure, foundations and approaches was integrated together to provide a low life cycle cost alternative to the existing inland ferry service on Highway 6 at Arrow Lake.

1. INTRODUCTION

The Needles – Fauquier ferry crossing of Upper Arrow Lake is located approximately 59 km south of Nakusp on Highway 6, in the southern central interior of British Columbia. The crossing links the two small rural communities of Needles and Fauquier locally, but also connects the West Kootenays and the North Okanagan regionally.

In 2003, the British Columbia Ministry of Transportation initiated a design competition for the detailed design of a bridge crossing to replace the existing inland ferry service at this location. Figure 1 identifies the location of the proposed bridge crossing in relation to the major centres in western Canada.

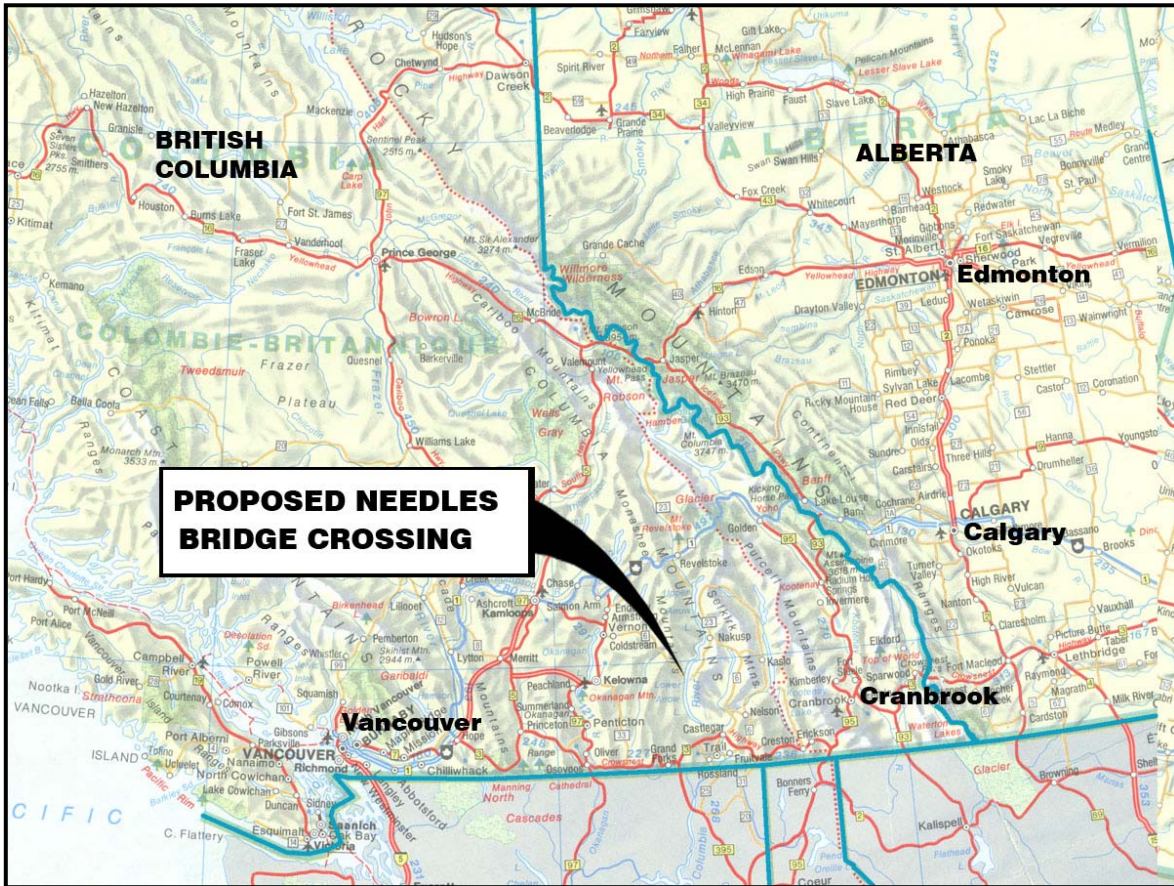


FIGURE 1 – LOCATION MAP OF NEEDLES CROSSING

This design competition presented several challenges and risks that required the design team to use a systematic approach in identifying, analyzing, responding to, and monitoring risk. These challenges were due in part to the aggressive design schedule and the fact that many bridge concepts were initially identified and evaluated by the design team. However, other external, regulatory, stakeholder and constructability risks also required consideration.

For the purpose of this paper, project risk is defined as an uncertain event or condition that could potentially have a negative effect on the project outcome or objective. Risk management is defined as the process used to maximize the probability of positive events and minimize the probability of negative ones.

The following discussion presents a pedantic review of the Needles Bridge design competition and identifies some of the geometric, structural and geotechnical issues associated with the project that required consideration by the design team. Some of the key technical challenges are presented as is a rudimentary colloquy on the techniques used to overcome them. Although managing design risk was a component of the project, the following is not intended as a set of edicts to be followed when performing similar assignments.

2. BACKGROUND

Provincial Highway 6 connects the City of Vernon to the central interior of British Columbia. Along this highway, an inland ferry crossing connects the two rural communities of Fauquier and Needles, both of which are located along the shores of Upper Arrow Lake. The Arrow Lake system was created in 1969 by the construction of the Hugh Kennleyside Dam located in Castlegar, British Columbia. The dam was constructed to provide power to both the local region and the United States.

In 1967 a fixed link crossing was investigated to connect the two communities that would find themselves separated once the dam was completed and the reservoir filled. This preliminary design study was never pursued further, as the costs were exorbitant. Over the subsequent years, public opinion encouraged the government to reconsider connecting these two communities.

The existing ferry is capable of accommodating 40 cars and up to 150 passengers, and is available on one-half hour intervals. The ferry operates from 5:00 a.m. to 10:00 p.m., with a shuttle service available outside these hours.

Projected traffic volumes along this corridor are expected to reach 700 AADT by 2025, indicating that during peak periods significant ferry line ups can be expected.

Late in 2003 the British Columbia Ministry of Transportation began to explore the possibility of providing the two rural communities of Fauquier and Needles with a fixed link. The need for this crossing can be justified in the following ways:

- Eliminate the disruption that was caused after the creation of the reservoir;
- Increase economic development, such as increased forestry activities; and
- Increase the potential for recreational development such as eco-tourism.

In May of 2004, the provincial government privatized the operation of all inland ferries throughout British Columbia. The Needles – Fauquier ferry was included in this privatization and many local citizens welcomed the on-going crossing design.

In order to maintain its position nationally, British Columbia must invest in its vast road network to provide access to resources, support industry, and increase foreign investment. British Columbia has a significant amount of natural resources located throughout its heartlands, and accessing and processing these resources is fundamental to the economy of the province. The British Columbia Heartland contains:

- 99% of the provincial land mass;
- 72% of the overall road network; and
- 40% of the total provincial population.

Therefore, improving the transportation network in these areas will stimulate growth and improve the local economy; and, therefore, was considered paramount to the Province.

2.1 Existing Highway Operation

Provincial Highway 6 at its western limit begins in Vernon and generally traverses in an easterly direction through the communities of Needles, Fauquier and Nakusp until its junction with Provincial Highway 3A north of Castlegar.

The highway is a rural two-lane road of varying condition. The posted speed along the highway from Vernon is 80 km/hr; however, several speed reduction sections exist along its mountainous terrain, and improvements are required to re-establish the highway as a major connection between two major regions within the province. Design parameters were provided at the onset of the project that strived to meet the ultimate desired operating condition for the highway.

The general geometric requirements of the design were to provide full connection into the existing paved Provincial Highway 6. The alignment was required to stay within existing constraints that included a major power transmission line located south of the existing ferry crossing. Property issues and existing commercial operations also significantly impacted the selection of the preferred alignment, as did constructability since disruption to ferry service during construction was not permitted.

The western approach to the existing ferry site is located north of the Whatsam Creek valley. The existing highway approaches the ferry dock at a vertical grade of approximately 7%, which was identified as the maximum allowable vertical grade in the project design criteria, with a series of tight radii curves just prior to the ferry dock. Prior to the creation of the reservoir the western approach was the location for the community of Needles, which was virtually abandoned once the flooding of the reservoir was completed.

The town site of Fauquier, located on the eastern approach, is situated on a relatively flat area southeast of Highway 6. The terrain in the location of the proposed alignment is steep with grades at the lakeshore in excess of 15%. Two creeks are located on the upper slope of the eastern bank, flowing in a northerly direction intersecting the proposed approach alignment.

Both approaches bisect private properties. This required additional consideration during the alignment selection, as one property is leased by a forestry company that utilizes the western approach as a log sort area.

The highway is generally utilized by recreational travelers, commercial and industrial users, and residential users. Commercial and industrial users consist mainly of forestry operations and local deliveries. The majority of traffic occurs during summer months when the highway is subjected to increased tourist traffic. Although not the shortest route, the scenery makes this route a popular choice for many travelers. This route is not the busiest of British Columbia's provincial highways; however, ferry capacity and frequency limit traveler mobility.

2.2 Design Competition

The British Columbia Ministry of Transportation has explored many alternatives to capital infrastructure project delivery including:

- Conventional Design/Bid/Build,
- Design/Build,
- Design/Build/Develop¹, and
- Design Competitions.

The last process mentioned, Design Competitions, involves the process of selecting a minimum of three engineering consultant teams to compete in order to produce the most attractive / comprehensive design package.

The process begins by soliciting Expressions of Interest from interested teams, in which qualifications, experience and pertinent project team member information is submitted. The short-listing process is intended to produce a minimum of three qualified teams who are provided the Project Terms of Reference in order to produce the most economical, efficient and constructible design.

The main advantage to this process compared to other options is that the design is left in the hands of the professional design team, while the reporting is maintained directly with the owner. The owner is permitted to select a design that best fits the overall project objectives and that allows for minor revisions throughout the detailed design phase with little or no contractual impact.

The Needles – Fauquier Bridge project followed the design competition model and provided the government with the perfect opportunity to further explore this means of project delivery. As several non-engineering influences would play a role in the design, including first nations, environmental, archeological (dealing with flooded town sites) and political, which are extremely difficult to manage contractually with other delivery methods such as Design/Build, the design competition procurement method seemed appropriate.

In order to attract the most qualified design teams to the competition, the government elected to provide a lump sum payment to each of the teams. This transferred ownership of all submissions to the British Columbia government and allowed the integration of ideas to best meet the project objectives.

2.3 Factors Influencing the Selection of the Bridge Concept

The main factors that influenced the selection of the most economical bridge concept were the alignment, and superstructure and foundation costs. Table 1 summarizes these three factors, and the various options that were investigated.

¹ Process involves the transfer of provincially owned property to the successful bidder for subdividing to assist in financing the project.

TABLE 1 – DESIGN OPTIONS CONSIDERED DURING COMPETITION

FACTOR	OPTION
Alignment	Straight “north alignment” near ferry crossing
	Straight “central alignment” near 1960’s proposed bridge crossing
	Curved alignment slightly south of 1960’s proposed bridge crossing
Superstructure	Steel truss
	Segmental concrete
	Steel plate girder with kingposts
	Steel plate girder (Vpiers to reduce mainspan)
	Steel plate girder (haunched at main pier)
Foundations	CIDH piles (cast in place drilled holes)
	Concrete filled steel pipe piles
	Spread footings on densified soil (by compaction)
	Spread footings on densified soil (by timber displacement piles)

The options shown above were considered throughout the preliminary design process. The team looked at two straight and one curved alignment, superstructure varieties that included steel trusses, segmental concrete and plate girders, and foundation options ranging from cast in place drilled piles, concrete filled steel pipe piles, and spread footings founded on densified soil using both timber displacement piles and conventional compaction.

The alignment is a key component to creating the most economical crossing, as it affects land acquisition issues, construction staging of the approaches, the amount of earthworks along the approaches, and the slope stability work near the abutments. It also dictates the depth of water along the crossing and where the piers are located (and thus the quality of soil that the piers are founded on).

Furthermore, if wisely selected, the alignment can also beneficially influence the structural behaviour of the bridge. The vertical profile of the alignment should be one that keeps the superstructure elevation as low as possible, thereby reducing foundation overturning demands due to lateral wind loads, while still maintaining the required navigational clearances.

Based on previous experience with similar assignments, the design team knew that creative solutions were required to address the challenging soil conditions. Coupled with a carefully selected bridge alignment, foundations that could be constructed economically and quickly would contribute to the project objectives. The competing geotechnical, structural and geometric objectives demanded the most significant portion of the risk management attention. The following section discussed the risk management strategy used by the design team.

3. DESIGN TEAM APPROACH TO RISK MANAGEMENT

The design team developed a unique risk management approach based largely on the Caltrans risk management process. The Caltrans process employs a six step approach that includes:

- i) Risk management planning;
- ii) Risk identification;
- iii) Qualitative risk analysis;
- iv) Quantitative risk analysis;
- v) Risk response planning; and
- vi) Risk monitoring and control.

Risk management planning was initiated very early during the competition phase of this assignment. Aside from professional reasoning, it was essential to identify key project characteristics that could significantly impact the budget or provide an advantage against competing teams. Consideration was given to material and contractor supply, alignment, approvals and safety.

The project was subject to a Value Analysis (VA) session so that the design team was cognizant of these implications and worked to predict the findings. This helped to mitigate potential design changes that could impact the project schedule or budget later in the process. Several recommended alignment modifications were identified by the VA Team, but ultimately none were advanced as the suggestions had a negative impact on operational safety with only a marginal cost savings.

The risk identification process was not cumbersome for this project. The team looked at what could go wrong, opportunities for better achieving the project objectives and triggers for identifying when risks are likely to occur. One of the key risks identified early pertained to foundation conditions. The design team was required to advance the competition design based on historic data, which could not be confirmed in a timely fashion.

The qualitative risk analysis step is intended to assess the importance of a risk and assign a probability to its occurrence. A subjective low, medium and high risk rating was assigned to each identified item. The ratings were reviewed as the project evolved and were reclassified or dismissed depending on their status at the time of review.

Quantitative risk analysis was not thoroughly conducted during the course of the Needles Project. The premise of this analysis is to numerically estimate the probability of risk qualitatively assessed during earlier steps. This work is somewhat subjective and without a statistically representative sample size upon which to base conclusions it is of limited value. Often in the case of very large projects (over \$500 M), specialists are assigned to perform this task as the cost implications of miscalculation or unexpected risk can exceed project contingencies.

PROJECT RISK MANAGEMENT PLAN

PROJECT: NEEDLES BRIDGE
 Date 4/15/2004
 JOB No.: 2111-02102-0

PROJECT RISK MANAGEMENT PLAN																																																												
Priority	Identification						Qualitative Analysis				OPTIONAL Quantitative Analysis				Response Strategy		Monitoring and Control																																											
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FIGURE 2 – SAMPLE OF NEEDLES RISK MANAGEMENT MATRIX

Risk response planning examines a strategy or action to address identified risk. There are four key actions that identified risks can be categorized into. These include avoidance, transference, mitigation and acceptance. These are for the most part self explanatory with perhaps transference as the exception. Transference pertains to shifting a known risk to another party more capable of taking steps to eliminate or reduce the consequences associated with the risk. For example, the uncertainties associated with the foundations were transferred to the geotechnical consultant, as they were best suited to minimize the associated risk of this uncertainty.

Risk monitoring and control was conducted throughout the course of this project. As the design evolved and details emerged, the risk matrix was reviewed and reevaluated. Items which were adequately addressed were eliminated from the list while others were reviewed and alternately classified as appropriate. An example of reclassification occurred as property requirements for the Pope & Talbot log sorting yard were quantified in advance of the final submission.

Figure 2 shows a sample of the Risk Management Matrix used by the project team during the project. All of the key steps are accounted for in the matrix and since it was spreadsheet based, it was easy for the design team to revisit the contents periodically and make any adjustments that were necessary.

The subsequent sections examine some of the technical design characteristics of the project, focusing primarily on the geometry and structural considerations, to provide the reader with a better understanding of the coordination challenges faced during design. As documented, it becomes apparent that each discipline was faced with challenges that required an extenuatory approach in resolving. Often, the optimal solution for one constraint negatively impacted another. A balanced approach during design was required, as was close collaboration among design partners.

4. TECHNICAL DESIGN CONSIDERATIONS

The proposed crossing length is in excess of 1 km; therefore, the main factors that ultimately influenced the selection of the most economical bridge concept were the alignment, and superstructure and foundation costs. The lake crossing is complicated by the 21 m fluctuations in the lake level (due to the reservoir draw down), the generally poor soil conditions, and the necessity to provide a generous navigation envelope for the existing vessels utilizing the lake.

4.1 Geometric Design Treatments

As indicated earlier, the existing site conditions significantly constrained the options available in selecting the optimal horizontal and vertical alignments.

Geometric design criteria were provided to the project team by the owner at the onset of the project and, in general, were consistent with rural highways throughout the province. Generally, the selection of the preferred horizontal and vertical alignment was governed by the following criteria:

- Rural arterial undivided, 2 lane, 80km/h design speed;
- Minimum horizontal radius 250m;
- Maximum grade 7%;
- Property issues; and
- Constructability.

Using an expanded version of the aforementioned design criteria, the project team began to explore alignment options to satisfy a key objective of producing the most economical structure possible. Another major consideration in selecting the preferred alignment was to link to the existing alignment on each side as soon as practical to avoid additional reconstruction costs and disruption to the motoring public. Property acquisition issues were also a key factor on both approaches.

On the western approach, the proposed alignment joins the existing highway alignment in the general proximity of an existing emergency gravel arrestor bed entrance located on the south side of the road. The eastern approach is quite different as the existing highway traverses through the town site of Fauquier and is located north of the proposed bridge crossing. The design intent on the eastern side was to utilize the existing roadway that traverses in a southwesterly direction from the town site towards the proposed crossing location.

Developing the vertical profile presented several difficulties and was subjected to numerous iterations to develop a vertical alignment that met the following criteria:

- Project design criteria;
- Minimizing cut and fill;
- Avoiding areas of slope instability;
- Minimizing pier height; and
- Maintaining navigational clearances.

The vertical profile selected reduced pier height by minimizing the elevation on either side of the navigational span. This was accomplished through the introduction of vertical curves on the structure, while still respecting the 7% grade limit.

Figure 3 shows the vertical profile of the structure. Note the use of vertical curves to satisfy vertical constraints. Careful consideration was required to ensure the proposed design did not violate any sight distance requirements.

The design of the horizontal alignment considered the above criteria, but also focused on optimizing the structural components of the bridge by following areas where water depth was minimized, soil conditions were more favorable, and property issues could possibly be avoided. A bathometric survey was used to determine water depths and was blended with the topographic survey to provide designers with a more comprehensive picture of the project site.

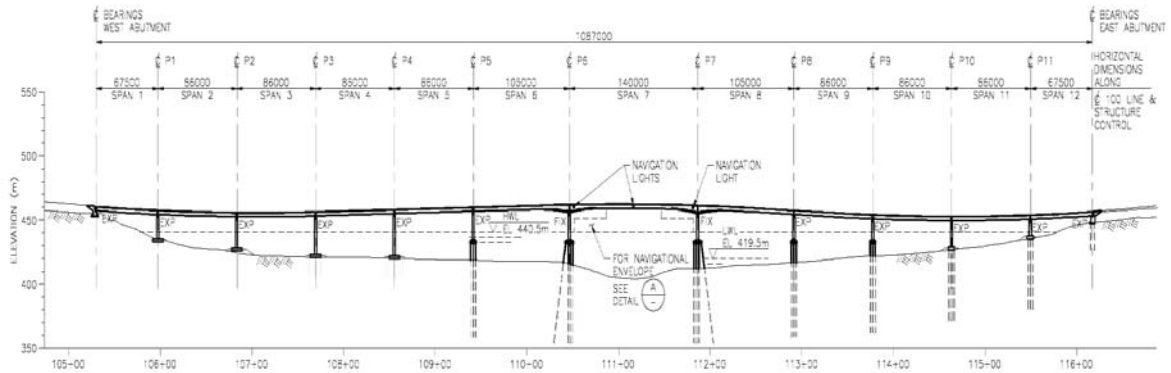


FIGURE 3 – VERTICAL PROFILE OF CROSSING

4.2 Structural Considerations

During the conceptual design, the curved alignment was recognized as not only a geometric feature, but a structural feature as well. The curved alignment was seen as potentially allowing the bridge to carry lateral wind loads in an arching action. These loads are resisted to a large extent by thrust at the abutments. The arching action, combined with the fact that the curved alignment follows the minimum water depth, resulted in reduced foundation demands at the piers.

Multispan bridges typically rely on each foundation to carry lateral loads through bending in the piles, so the concept of utilizing the curved alignment to act as an arch was unique and potentially would provide cost savings by attracting loads away from these expensive foundations. Arching action (in plan) of the bridge requires that the abutments sustain horizontal thrusts without displacement. However, girders fixed against longitudinal movements at the abutments were not found to be feasible as the piers would experience excessive loads due to thermal movements, while girders free to move longitudinally at the abutments would eliminate the beneficial arching action that is desired. Figure 4 shows a plan view of the proposed structure.

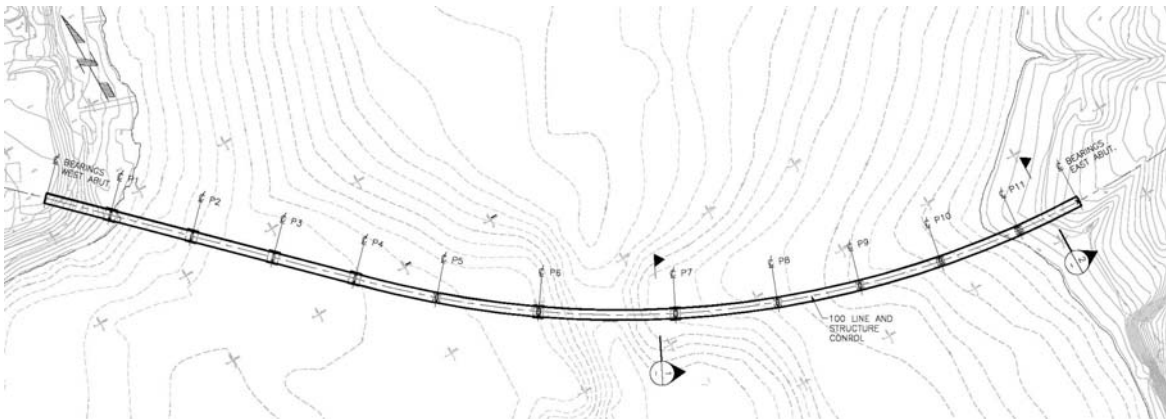


FIGURE 4 – PLAN VIEW OF PROPOSED STRUCTURE



FIGURE 5 – TYPICAL LOCK UP DEVICES

Lock up devices (LUDs) connected between the abutment and girders are suited to such situations because they resist rapidly applied loads, such as buffeting wind, while permitting slow displacements due to loads such as temperature. Compressive thrusts on the abutment would be resisted by the passive pressure of the backfill soil, while tensile loads would be resisted by corrosion protected high strength post tensioning bars connected to a concrete deadman. Figure 5 shows typical lock up devices suited to this type of application.

The two areas where LUDs are commonly used in bridge structures are in seismic retrofit applications, where large bearing movements are restricted by the locking mechanism, and in long-span cable-stayed bridges where the wind and seismic movements can be excessive and must be restricted. In both of these cases, slowly applied loads such as thermal loads, creep and shrinkage are still permitted by the LUD.

In the case of the Needles Bridge, longitudinal movements at the end of the bridge due to wind loads are expected to be quite small. Furthermore, the east abutment is expected to be backfilled with lightweight fill, which is more compressible than conventional fill. This led to the conclusion that if the abutment was to have even the slightest flexibility, its movement could be a large percentage of the wind movement that was intended to be restricted. The effectiveness of the arching action would then be compromised and that was deemed unacceptable to the design team. Therefore, the LUD concept was not carried through to final design.

5. OPTIMIZED CROSSING DESIGN

The bridge structure included the following main components:

- A multispan, continuous weathering, steel plate girder bridge, consisting of two plate girders, made composite with a cast-in-place concrete deck;
- Concrete piers that are hollow and rectangular in cross section;
- Concrete abutments with wing walls parallel to the direction of traffic; and
- Foundations consisting of spread footings at four piers and one abutment, and piled foundations at the remaining seven piers and one abutment.

Steel plate girders with a concrete deck were selected as being the most advantageous after considering a variety of superstructure types. Fortunately, the 130 m navigational

clearance (and thus 140 centre to centre of main piers) is still manageable for a steel plate girder, although it is pushing the limits of applicability. The bridge structure has been designed to accommodate the future addition of a lightweight steel grating sidewalk to one side of the deck, if pedestrian volumes increase. Currently, there is very little pedestrian usage, as the area is sparsely populated, particularly on the west side.

Two cross section sizes were selected for the concrete piers. The two main piers bordering the navigation channel were designed with a larger cross section, while the nine other piers had a smaller cross section. Given the remoteness of the site and the need to quickly construct the piers to avoid the influence of fluctuating water levels, repetitive construction was deemed to be advantageous.

The spread footing foundations were founded on densified soil. The densification method ranged from using a vibratory roller at the abutment to driving timber piles at 1.2 m centers at two of the piers. Piled foundations consisted of a cast-in-place pilecap supported by 910 mm diameter piles driven to approximately 60 m embedment. The selection of a pilecap elevation was one of the key design decisions during the foundation design. A pilecap set at a low elevation would be structurally the most efficient, but would have a very limited construction window as the lake low water level occurs for less than a month in the spring. A pilecap set at a high elevation would be structurally inefficient, as bending in the piles caused by lateral loads would be large. However, the construction window would prove to be much longer.

Another disadvantage of high pilecaps is the lack of aesthetic appeal due to the length of exposed piles. The design was eventually based on a pilecap elevation between the two extremes, thereby providing a reasonable construction window, and at the same time avoiding excessive bending demands in longer piles. The aesthetic appeal would be preserved as the piles would be exposed only during a limited time in the spring.

6. SUMMARY

The Needles Bridge design competition resulted in the design of a 1087 m fixed link crossing over Arrow Lake. When constructed, the structure will be the longest fixed link lake crossing in the province. Geometric design played a key role in the overall economy of this large structure and numerous iterations were required to satisfy the sometimes competing objectives of design criteria and economy.

The preferred bridge concept included steel girders and concrete deck. The foundation design proved to be challenging due to large fluctuations in the lake level. Design optimization for this component of the structure balanced the need to provide an adequate construction window, while recognizing the sensitivity of pile demands due to elevated pilecaps.

The Needles Bridge will provide a low life cycle cost alternative to the inland ferry service on Highway 6. This link is vital to the economic health of the region and will encourage development and growth in the surrounding communities.

The design competition procurement approach used by the British Columbia government presented the design team with several challenges and risks that required careful consideration. A modified risk management approach was adopted from Caltrans for this project and was found to be efficient and easy to work with. The team was able to re-

evaluate project risk periodically and identify issues or constraints that warranted further or more concentrated attention.

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