Kicking Horse Cantilever Structure

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ABSTRACT

The largest cantilever roadway structure in B.C was completed in 2007 on the Trans-Canada Highway approximately 10 km east of Golden in the Kicking Horse Canyon. In September 2004, Emil Anderson Construction Inc. was awarded the $17 million contract to upgrade a section of Highway #1. The tender design included the construction of a pair of bridges crossing and returning over Kicking Horse River in order to facilitate the widening of a 2.1 km stretch of highway from two to four lanes. Klohn Crippen Berger was engaged by the contractor to develop a Value Engineering redesign for the project. The objective was to develop a more economical and constructible design within the extremely rugged and environmentally sensitive terrain of the Kicking Horse Canyon. The use of structural and geotechnical design innovations, along with highway alignment optimization, allowed the roadway to remain wholly on the south side of the river. A unique and simple design concept was used to cantilever a 155m long section of roadway off the south bank of the river. The major design aspects for the cast-in-place concrete structure included a 4.5m cantilever concrete deck over the Kicking Horse River, a counterweight concrete box structure containing compacted fill, a support retaining wall at the river edge founded on steel pipe piles drilled into bedrock, and scour protection using locally sourced rip-rap. The design of the cast-in-place walls made special provision for supporting the formwork for the cantilevered deck. Careful planning of the deck casting sequence, and design of a separately cast high-performance concrete overlay were incorporated to reduce cracking and associated risk of chloride contamination of the deck. By eliminating the need for the two new bridges, savings of $2.5 million were realized, as well as dramatic reductions in the environmental impact of the project. The major environmental benefits for the redesign were the elimination of bridge construction within the Kicking Horse River, and the prevention of the loss of 0.36 hectares of important riparian habitat on the north side of the river. The Kicking Horse Cantilever, with its simple design and clean aesthetics, provides an unobtrusive and attractive structure along the bank of the scenic Kicking Horse River.

1. INTRODUCTION

In September 2004, the Ministry of Transportation awarded Emil Anderson Construction Inc. a $17 million contract to upgrade a section of Highway #1 in the Kicking Horse Canyon. The section, known as Six Mile Hill to Rafters Pullout, is located approximately 12 km east of Golden, B.C., The tendered design had a split carriageway design, with the two eastbound lanes remaining on the south side of the Kicking Horse River, and the two westbound lanes crossing to the north side of the river and back to the south side again using two new bridges.

After the contract award Klohn Crippen Berger Ltd. was engaged by the Contractor to develop a Value Engineering redesign for the project. The objective was to develop a more economical and constructible design within the extremely rugged and environmentally sensitive terrain. The use of structural and geotechnical design innovations, along with highway alignment optimization, allowed the roadway to remain wholly on the south side of the river.

The elimination of the two new bridges and road construction on the north side of the river prevented the removal of nearly 4,300 m^2 of forest and riparian vegetation and resulted in savings of $2.5 million which were split between the Ministry and the Contractor. The Ministry then applied the savings to construction of additional rockfall protection structures to the west of the project limits, thereby providing an increased level of safety to the traveling public.

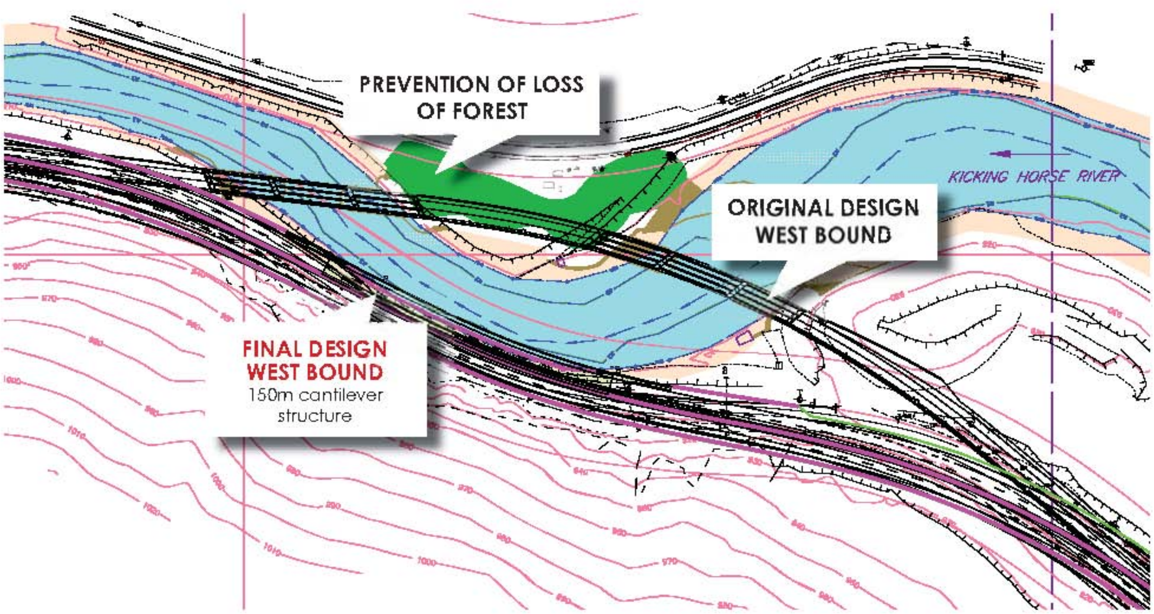

Figure 1 – Original and Value Engineered Road Alignment Plans

2. HIGHWAY REALIGNMENT

The roadway is cut into a steep slope on the mountainside adjacent to the Kicking Horse River and clearance from the rock face, as well as a ditch to capture rocks that might come down, were required for rockfall protection. A careful assessment of the rock face was undertaken and the highway alignment was optimized to move slightly towards the bank, and away from the river. Although this increased the amount of rock excavation required, it dramatically reduced the heights of retaining walls on the downhill side of the roadway, and reduced the overhang over the river for the cantilever structure.

The rock face at the west end of the section was composed of a material called “tufa”, a weak mineral-rich rock. Careful investigation of the properties and extents of the material concluded that the material was stable at a relatively steep angle and could be excavated easily. This allowed the highway alignment to be move away from the river into the bank.

3. ENVIRONMENTAL IMPACT REDUCTION

The original design required the removal of 4,300 m^2 of forest and riparian on the north side of the river, as well as the construction of four major bridge piers, and a temporary construction bridge within the Kicking Horse River. By redesigning to keep the roadway on the south side of the river where the existing highway was, the loss of vegetation was prevented, along with potential environmental damage due to construction of piers and a temporary bridge in the fast flowing river.

The Cantilever Structure is located directly south of “Rafters’ Pullout”, where whitewater rafters end their voyages. The simple design and clean lines provide an unobtrusive and attractive structure along the bank of the Kicking Horse River where many river users end their wilderness adventure.

4. STRUCTURE DESCRIPTION

The major design aspects for the cast-in-place concrete structure include:

- a 4.5m cantilever concrete deck over the Kicking Horse River,
- An interior counterweight concrete box structure containing compacted fill,
- a cast in place concrete exterior retaining wall constructed up to 5.8m high
- concrete-filled steel piles drilled into bedrock support the exterior wall
- scour protection using locally sourced rip-rap.

The structure is 155 m in total length with transitions at each end comprising 25 m and 30 m long cast-in-place retaining walls.

The exterior retaining wall is supported by 610 mm diameter piles that were drilled and rock socketed into sound bedrock. The base of the wall was also designed to act as a footing for the cantilever retaining wall to retain the backfill and provide stability during construction. The front wall was cast in two lifts to get the concrete above the river water level as work was taking place during the spring with the freshet approaching. The wall was then backfilled, so that the cantilever back span could be cast directly on the soil, thus avoiding formwork for the back span.

The cantilever deck has a maximum overhang distance of 4.5 m and tapers from a thickness of 550 mm at the exterior retaining wall to 225 mm at the outside edge. Along the back-span, the deck tapers from 550 mm at the back face of the exterior retaining wall to 300 mm at the face of the interior box structure.

The interior box structure acts both as a counterweight for the cantilever deck and as lateral restraint for the exterior wall. The inside of the interior box structure was filled with compacted soil. The back span of the cantilever deck is designed as a structural slab, and once cured, does not depend on the backfill for support.

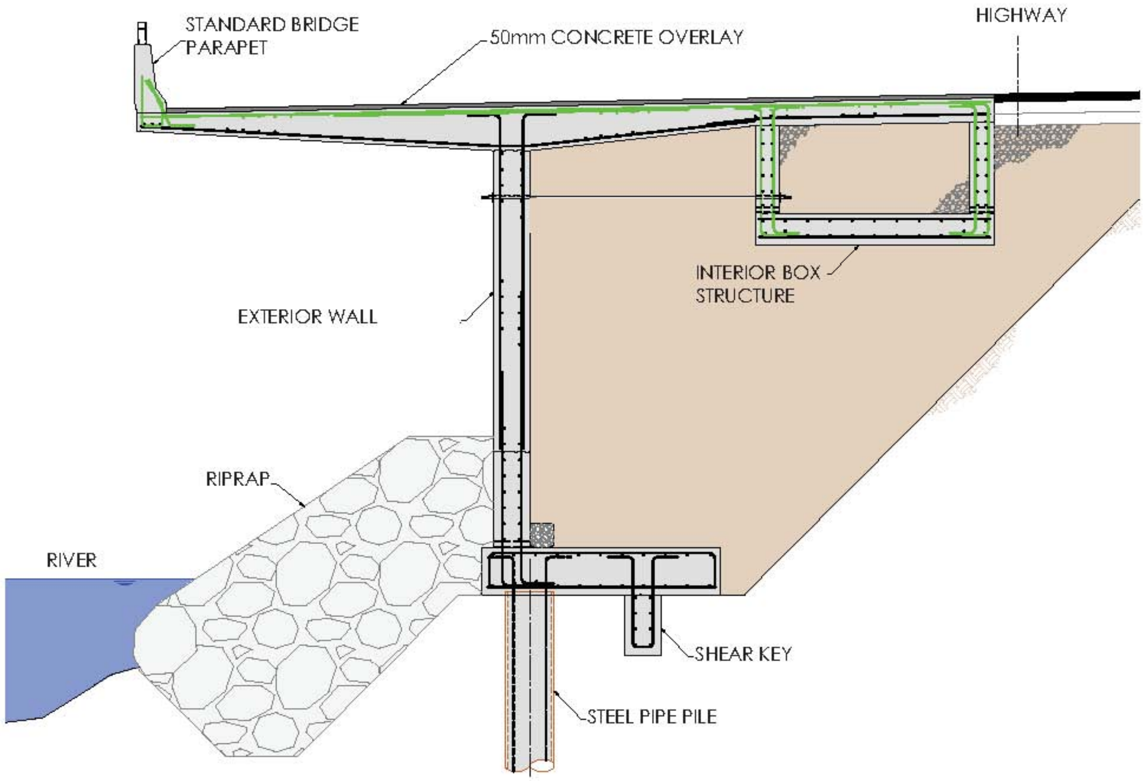

Figure 2 – Structure Cross-section

Picture 1 – Cantilever Structure

5. FOUNDATION DESIGN

The soil at the site of the cantilever structure consists of a dense to very dense sandy gravel with cobbles and boulders underlain by bedrock. A seismic refraction survey was performed to estimate the projected bedrock elevations at the pile locations. Along the length of the structure the depth to bedrock varied from 14 m to 28 m below the footing/pile cap.

The piles were drilled in using a Barber rig. A minimum rock socket length of 7.1 m was required to achieve a vertical factored pile resistance of 9700 kN (See Picture 2). Pile capacity was assumed to be provided only by the shaft friction capacity of the rock socket. Shaft capacity in the granular soils above bedrock was ignored due to potential variations in the depth to rock. End bearing capacity of the rock socket was also ignored, as recommended by the Canadian Foundation Engineering Manual, 3rd Edition (1990), as the piles are of too small in diameter to visually inspect the base of the socket and clean out drill cuttings If the bottom of the socket were not sufficiently clean then settlement might be required to mobilize the end bearing capacity.

Picture 2 – Pile Installation

6. DECK DESIGN

The design of the cantilever deck was based primarily on CL-625 truck and lane loads in accordance with the Canadian Highway Bridge Design Code, CAN/CSA-S6-00.

Avalanche loads originating from steep slopes on the south side of the highway were also an important design consideration. A specialist consultant, Chris Stethem and Associates Ltd., provided avalanche design loads equivalent to a 3 m deep layer of snow covering all four lanes of the highway. The avalanche load included a vertical dynamic component, the friction load from the snow flowing across the deck, and an impact load against the bridge parapet located along the north edge of the cantilever deck.

The construction of the cantilever deck section presented a major challenge as the sloped rip-rap below precluded the use of scaffolding to support formwork. An innovative solution was developed using proprietary construction formwork from EFCO Systems (see Photo #3). The exterior retaining wall was used to support EFCO “super stud” columns and beams spaced along the entire length of the cantilever deck section. The additional weight from the falsework acting on the exterior retaining wall was countered by a tie-back system of Dywidag rods running through the exterior wall to the interior box structure. The resistance due to friction between the soil and the box structure was sufficient to counteract the weight of the falsework.

Careful monitoring of deflections during construction was required as construction sequencing was extremely important. Dywidag rods for horizontal support at the top of the formwork were installed first, and then the backfill was placed and compacted up to the deck level before the EFCO deck formwork system was installed and the deck was poured.

Picture 3 – Cantilever Formwork

Durability of the cantilever deck which will be subjected to rain, snow and freeze-thaw cycles in the Kicking Horse Canyon was a major concern for the Ministry. A deck-pour sequence was carefully planned to reduce shrinkage cracks along with the use of epoxy coated reinforcing (top bars).

In addition, a 50 mm thick high-performance concrete overlay was cast to reduce the risk of chloride contamination. Before the overlay was placed, traffic was allowed on the deck for one winter. The deck was then cleaned with a high pressure wash before application of the overlay.

Picture 4 – Deck Construction

7. STABILITY DESIGN

Stability influenced several key elements of the cantilever structure, including the interior box structure and the footing/pile cap below the exterior retaining wall (see Figure 2)

Global demands on the exterior retaining wall include lateral earth pressure, live load surcharge from the roadway, live load on the cantilevered deck and the dead weight of the deck itself. No hydrostatic loads were considered as drainage measures were provided on the backside of the exterior retaining wall. These included 76 mm diameter weep holes and filter fabric wrapped drain rock along the full length of the wall. As constructed, the interior box structure containing compacted fill acts both as a counterweight for the cantilever deck and a lateral support for the exterior retaining wall.

The exterior wall was designed with a wide enough footing above the piles to perform as a cantilever retaining wall to support the backfill and provide stability during construction. Horizontal forces at the base of the wall were primarily resisted by the concrete shear key located below the exterior wall footing. Once the deck was poured, the exterior wall was considered supported horizontally at both the bottom and top, and horizontal forces at the top of the box were resisted through friction between the interior box structure and the underlying soil. This is the primary mechanism for resisting lateral loads at the deck level including impact loads on the parapet from traffic accidents or avalanches.

If the rip-rap were to be lost in an extreme event, the resistance to horizontal forces at the bottom of the wall are through shear and flexure in the piles. The piles are designed for the horizontal loads from this scenario, which considers reduced horizontal loads in recognition that the backfill will have been partially removed from the wall by the undercutting.

8. SCOUR PROTECTION

Protection against scour was a major concern for the Ministry given the importance of the structure, and the high river velocities in the area. Closure of the Highway for extended periods of time would be unacceptable. In accordance with CSA-S6, the design does not rely on the rip-rap to prevent collapse of the structure, and redundant defences against scour were designed into the structure (see Figure 2).

At the front of the exterior retaining wall, a layer of 1000 kg class rip-rap was placed at a slope of 1.5H:1.0V.

Should the 1000 kg class rip-rap fail, the exterior cantilever wall is supported by rock-socketed piles in sound bedrock, preventing settlement of the cantilever structure.

If scour were to undercut the foundation of the exterior cantilever wall, a layer of 100 kg class rip-rap lines the interior face of compacted bridge end fill material underneath the interior box structure. This layer of rip-rap is designed to limit the extent of scour under the structure along its length. For this extreme event, the interior box structure has been designed to span a minimum of 35m without support.

Repairs under the cantilever roadway structure from extreme scour events would be similar to that of an undermined bridge abutment. Traffic can be diverted onto the cantilever structure while excavation of the eastbound lanes can provide accessibility below the structure to fill any voids.