

Design and construction of a high energy rockfall embankment on the Trans-Canada Highway



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ABSTRACT

This paper will discuss the design and construction of a rockfall embankment built on BC Highway #1 (Trans-Canada Highway) near Boston Bar, British Columbia. The embankment consists of a free standing 8m high reinforced soil structure. The embankment was constructed in 2008. The 8m high rockfall embankment was built using a double sided, woven wire mesh gabion faced reinforced soil system designed to withstand a maximum rockfall impact energy of 10,000kJ.

RÉSUMÉ

Cette présentation est sur la conception et la construction d'un merlon contre chutes de pierres construit en sur le BC Highway #1 (Autoroute Transcanadienne), près de Boston Bar, en Colombie-Britannique. Le merlon est une structure autoportante de 8m de haut de sol renforcé. La construction à eu lieu en 2008. Le merlon de 8 m de haut a été construit avec un système à double face de gabions en treillis tissé, conçu pour résister à des chute de pierres d'énergie maximum d'impact de 10.000 kJ.

1 INTRODUCTION

The section of the Trans-Canada Highway, British Columbia Highway #1, from Hope, BC to Lytton, BC contains numerous areas that have been identified by the British Columbia Ministry of Transportation (BC MoT) as rockfall hazards. Many different methods to mitigate these hazards have been implemented over the years.

The section of Highway #1 from 53.3km to 53.6km east of Hope is one of these areas. The site, referred to as Slide 5, is located south of the Hells Gate Rapids. This section of highway was originally constructed in 1958. Indications of slope instability were observed and rockfall events were recorded shortly after the highway was opened. Between 1960 and 2008, over 60 rockfall events have been recorded where material reached the highway. Some of these events have resulted in damage to highway infrastructure, vehicle damage and personal injury.

Numerous attempts have been made to mitigate the rockfall hazard at this site. A concrete wall, known as the Ferrabee Wall, was built in 1961 along the east side (north bound lane) of the highway. It is 255m long and 2.4m high (Figure 1). A rockfall catchment area exists between the concrete wall and the toe of the rock slope. The catchment area varies between 8m and 22m in width. A diversion trench was excavated into the slope in 1975 in an attempt to re-direct rockfall away from the highway. In 1976, the highway was relocated westward 10m in an attempt to create additional catchment width. The catchment area is routinely filled with over 1000m³ of debris, resulting in rocks bouncing over or breaking through the concrete wall.



Figure 1. Highway #1 looking northward at Ferrabee Wall and rockfall slope

2 DEVELOPMENT OF DESIGN CRITERIA

BC MoT conducted numerous engineering studies during the 1970's and 80's to develop rockfall mitigation structures for the Slide 5 site. BC MoT conducted 350 rolling rock tests at the site in 1977 to determine the probable path and measured bounce heights of the rockfall. The use of steel cable net rockfall catch fences was investigated based upon these studies, but was ultimately rejected due to the required strength of the protection systems exceeding the strength and height of the catch fences available.

Rockfall embankments made from compacted soils, large rocks, gabions, or reinforced soil systems have been used throughout the world (Peckover and Kerr, 1977; Giani, 1992; Wyllie and Norrish, 1996; Oggeri and Peila, 2000; Nomura et al., 2002; Peila et al., 2007). Reinforced soil structures are most commonly used at this time.

Reinforced soil structures have been in active use in transportation related infrastructure for over 30 years. These structures allow for the construction of tall embankments that are capable of withstanding very high rockfall impacts in areas that are unsuitable for the use of traditional rockfall catch fences. These structures can be vertical/near-vertical berms, reinforced steep vegetated slopes, or a combination.

BC MoT began a review of the Slide 5 site in late 2005 in order to determine the suitability of a reinforced soil style structure for use as a rockfall embankment.

2.1 Design Concept

Computer simulations using the RocFall program from Rocscience were developed using detailed site topographic information and the results of the 1977 rolling rock tests. The 300m long section of the Slide 5 site encompassed different zones with varying degrees of rockfall hazard. The section of highest risk was selected for investigation into the use of the reinforced soil embankment.

A proposed embankment structure would be required to withstand a design impact of 10,000kJ from rocks that would vary in size from 0.6m to 3.0m in diameter. The structure was required to start at 6m in height, with a maximum height of 8m. The expected zone of impact would cover the entire height of the embankment on the slope side of the structure (Figure 2.).

The proposed rockfall embankment was required to fit into the existing roadway platform, consisting of a 10m wide shoulder on the north bound lane in front of the Ferrabee Wall. A 3m shoulder was required in front of the proposed embankment. The maximum design width of the structure at the base of the embankment was set at 7m. The minimum width of the embankment was 5m. The length of the proposed structure was set at 96m. The structure was required to have a maximum vertical batter of no more than 10 degrees.

The location of the embankment is on the outside edge of a slight horizontal curve in Highway #1. The layout of the new embankment was required to follow the curve of the existing Ferrabee Wall.

To reduce maintenance requirements on an exposed facing of the proposed embankment, BC MoT included a sacrificial barrier on the impact side of the proposed embankment.

In January 2006, BC MoT contacted Maccaferri Canada Ltd. regarding the feasibility of the embankment concept and to discuss the detailed design of the embankment using double twisted woven wire mesh materials. Double twisted woven wire mesh materials are used extensively in BC for rockfall drapery systems and soil retaining structures.

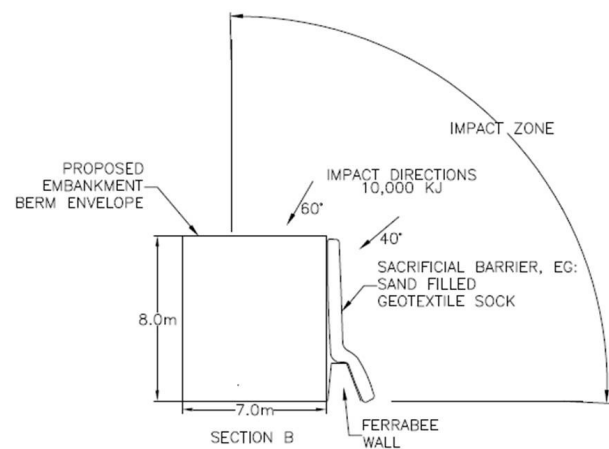


Figure 2. BC MoT Design Concept

3 DETAILED DESIGN OF REINFORCED SOIL EMBANKMENT

Detailed design of the rockfall embankment began in February 2006. In order to minimize the cost of the structure, it was decided to use a reinforced soil system in lieu of a conventional solid gabion gravity structure. The use of the reinforced soil system would allow for the construction of an engineered dense core of compacted sand and gravel material with a flexible gabion basket facing. Constructing the core of the structure with engineered fill was more economical than using rock filled gabion baskets. The Maccaferri Terramesh® System was proposed as an efficient combination of flexible facing and reinforced engineered backfill core.

3.1 Terramesh® System

The Terramesh® System is a modular system that is similar in concept to double twisted woven wire mesh gabion basket with an integral soil anchor. The mesh is manufactured from soft tensile, heavily galvanized and PVC coated double twisted steel wire mesh. The wire mesh used to manufacture the unit is manufactured in accordance with ASTM A975-97. The facing and the soil reinforcing tail element are made from the same mesh panel. This use of a single integral facing and reinforcing unit substantially reduces the potential risks associated with a facing connection failure as the connection has been engineered out of the system. The unit is formed by connecting the back panel and a diaphragm to the main unit, creating rectangular shaped cells. Gabion stone (100mm-200mm diameter, sound, durable rock) is placed into the gabion basket formed at the facing. Granular backfill is placed and compacted on the mesh tail, causing the woven wire mesh to act as soil reinforcement. Units are typically supplied as 2m wide units with a single layer of woven wire mesh reinforcement having a length determined for the individual structure design. These units are commonly used in conventional reinforced soil

applications.

The combination of galvanized wire and PVC coating allowed for the provision of a 75 year design life, in accordance with the Canadian Highway Bridge Design Code (CAN/CSA-S6-06).

A non-woven geotextile is placed at the back of the gabion basket facing. The geotextile functions as a separator to keep the granular backfill from migrating through the woven wire mesh openings and into the voids in the gabion facing units.

3.2 Reinforced Embankment Design

The design concept provided by BC MoT set the physical envelope into which the proposed structure must fit. A detailed analysis was required to determine that the structure would be: 1.) Sufficiently robust to survive the impact of the design rock fall event; 2.) structurally stable as a free-standing embankment; and 3.) Constructible.

In order to determine the structural dynamic response of the embankment to the design impact rockfall, it was necessary to determine the penetration depth of an impacting rock. There are currently various methods in Europe that are used for this determination (Kars 1978; Calvetti 1998; Peila 2004). The design rockfall event was determined to be a single boulder, approximately 5m³ in size and traveling at 30m/s. The depth of penetration of this boulder into the embankment was determined to range from 1.0 -1.5m. Based on the depth of penetration, the structure was required to be a minimum width from outside face of embankment to outside face of embankment of 2 times the maximum penetration depth.

The base of the embankment was set at 7m (face to face of embankment). Using this initial base width and a maximum vertical batter of 10 degrees, a model was created using the program MacSTARS 2000 in order to check the static stability of the proposed embankment structure. MacSTARS 2000 is a program developed for Maccaferri that is used to perform slope stability analysis using different types of reinforcement and complex design scenarios. Stability checks are performed using conventional Limit Equilibrium Method methods (Bishop or Jambu); either with or without the presence of a reinforcement configuration.

Figure 3 shows the overall configuration of the 8m high section of the embankment. The reinforced soil core of the embankment was 5m at the base plus 2 -1m wide woven wire gabion baskets facing elements (7m total width). The structure was segmented into 4 - 2m high vertical blocks. Each block was set back 0.25m at the face from the underlying block. At the highest part of the embankment, the reinforced core was 3.5m plus 2 -1m gabion units (5.5m total width).

The narrow configuration of the reinforced embankment allowed for the custom manufacture of single, double faced woven wire mesh units that would have a series of variable lengths (distance from unit face to unit face) with a standard unit width of 2m and heights of either 0.5m or 1.0m (Figure 4). Each unit was individually identified in order that it would be assembled and positioned correctly within the embankment.

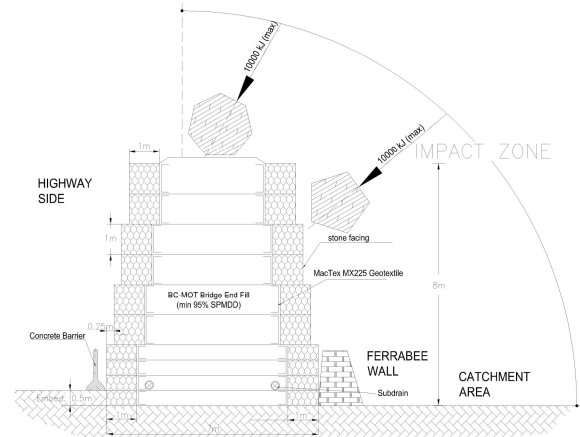


Figure 3. Reinforced Soil Embankment.

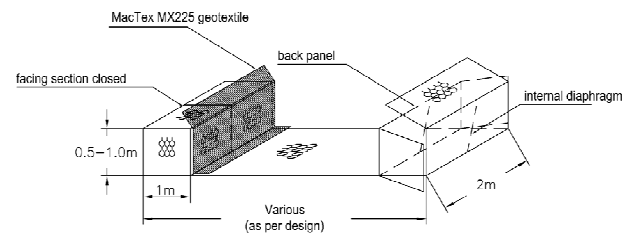


Figure 4. Double sided wire mesh unit.

4 CONSTRUCTION

Construction was originally scheduled for fall 2007 but postponed until 2008 due to emergency road works projects elsewhere in the province.

The material used for the gabion stone fill and for the reinforced soil backfill (BC MoT Bridge End Fill) was to be provided to the General Contractor by BC MoT from a roadside borrow pit located approximately 10km south of the project site.

The contract to construct the reinforced soil berm and associated road works was awarded in the spring of 2008. BC MoT chose to arrange for the supply of the reinforced soil system units to their facilities and supplied the units to the contractor for installation only.

Highway #1 is a two lane highway through the project site. To maintain access on this section of highway during clean up operations from past rock fall events, traffic diversion lanes had been previously constructed in the work area. The diversion was configured to carry a single lane of southbound traffic. Northbound traffic was directed into the old southbound lane, freeing up the original northbound lane for construction operations related to the installation of the rockfall embankment.



Figure 5. Reinforced soil units prior to placing structural backfill. Looking north.

The Contractor decided to build the embankment by constructing access ramps at the both ends of the structure and using one-way equipment travel in order to construct the gabion basket facing units and to place and compact the engineered fill. At the uppermost layer, the back of gabion to back of gabion clearance was only 3.5m.



Figure 7. South access ramp and rockfall catchment area

Access to the centre portion of embankment was achieved via the ramps at the north and south ends of the structure. Once the centre portion of the embankment exceeded 6m in height, work began to complete the north end of the structure. Access to the upper portions of the embankment was then restricted to the southern ramp only, limiting equipment mobility. The final step was to remove the southern ramp and complete the embankment.

The sacrificial barrier on the impact side of the embankment was originally conceived as a geotextile sock or similar type of system. Recycled 16mm thick fibre reinforced rubber conveyer belting was installed as the sacrificial barrier. A single layer of double twisted woven wire mesh was draped over the conveyer belting as an additional layer of sacrificial protection.



Figure 6. North end of embankment after ramp removal.

The combined drapery system was secured to the upper portions of the reinforced soil berm by threaded soil anchors that were installed during placement of the backfill. The drapery was placed over the anchors and secured to the structure by steel plates and nuts.



Figure 8. Completed Structure September 2008. South end is in foreground

The total value of the project, including contractor mobilization/demobilization, supply of reinforced soil system and granular materials was approximately \$879,000 (CDN). Construction began in July 2008 and the installation of 1,374m² of total wall surface was completed by the end of August 2008.



Figure 9. Completed embankment with protective facing



Figure 10. Rockfall debris on structure November 2009

5 DISCUSSION

Double sided or back-to-back reinforced soil structures have been used successfully through the world for rockfall embankments. This is the first use of a double sided reinforced soil structure along a highway in British Columbia as a rockfall embankment. This concept has allowed for the construction of a robust, high impact strength structure within very limited physical constraints in a cost effective manner.

Less than one month after completion of the embankment, the structure started to receive rockfall impacts. The embankment performance during the first year of operation satisfied the Owner, from both an operational perspective and from a cost perspective.

An unintended benefit of using the layer of double twisted wire mesh is that any rockfall impacting on the structure creates an impact record, thus providing an empirical method of tracking the actual number of rockfall events between inspection visits.

As it is now possible to quantify in greater detail the number of rockfall events at the site, a greater understanding of the nature of the rockfall hazard at this site is being developed. Some of the rockfall events that may have previously cleared the concrete wall and

traveled over Highway #1 are now being intercepted by the reinforced soil embankment. Some of these events have been close to the top of the embankment.

During the fall of 2009 and spring of 2010, a series of rockfall events impacted on the upper portions of structure and have required a re-evaluation of the configuration of the embankment. An investigation into additional rockfall protection measures that can be incorporated onto the Slide 5 Reinforced Soils Embankment has been started by BC MoT.

6 ACKNOWLEDGEMENTS

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