Construction of a composite barrier wall/rock shed structure at mile 109.43 of CNR's Ashcroft Subdivision

Tim Keegan, Bruce Willoughby
Klohn Crippen Berger Ltd., 301-2627 Elwood Drive, Edmonton, Alberta T6X 0P7, Canada
Tom Edwards
Canadian National Railway, Network Operation - System Engineering, Design and Construction, Western Region, 10229 - 127 Avenue, Edmonton, Alberta T5E 0B9, Canada
Matthias Busslinger, Matthieu Sturzenegger, Ann Wen
Klohn Crippen Berger Ltd., 500-2955 Virtual Way, Vancouver, British Columbia V5M 4X6, Canada

ABSTRACT
On November 25th, 2012 a 53,000 m^3 rockslide buried the Canadian National Railway (CNR) track at Mile 109.4, Ashcroft Subdivision, near Boston Bar, causing a 4-day service disruption on their main east-west railway connection. The rock landslide resulted in the collapse of a 21 m long concrete rock shed originally designed to protect the railway from debris raveling out of a gully above the track. The landslide rupture surface is composed of vertical release fractures and exposed day-lighting discontinuities. A number of rock and debris landslide hazard types are identified in the post-landslide slope. The magnitudes, frequencies, and seasonal occurrences estimated for these hazards posed a significant short and long term risk management challenge for construction of the track protection structure. This paper focuses on lessons learned during ground hazard assessment, design and construction of a new 80 m long track protection structure. The first construction challenge was the short term protection of the work site from raveling rocks. This was managed with a rock fall mesh attenuation curtain combined with safe work protocol. The permanent composite barrier wall/rock shed structure consists of a tied-back, gravel-filled barrier wall designed to absorb a large portion of the impact loads during a future rock landslide event, and a rock shed allowing the rock landslide to safely travel over the railway track. All components are modular, facilitating construction under railway traffic to meet the goal of reducing track service disruptions.

RÉSUMÉ
Le 25 novembre 2012, un éboulement avec un volume de 53,000 m^3 a recouvert la voie de la compagnie des chemins de fer nationaux du Canada (CN) au Mile 109.4 de la subdivision de Ashcroft, près de Boston Bar; il engendra une interruption de quatre jours le long de cet important tronçon de la ligne est-ouest. L' éboulement a détruit une gallerie de protection de 21 m, qui protégait les rails contre des debris rocheux provenant d'un couloir au-dessus de la voie. La surface de rupture de l'éboulement se compose de fractures verticales et de discontinuités orientées de manière défavorables. Plusieurs types d'instabiilités rocheuses et superficielles ont été identifiées le long de la pente rocheuse. Ces aléas se charactérisent par différentes tailles, fréquences et cycles saisoniers, et par conséquent, nécessitent une gestion du risque à court et long terme en ce qui concerne la construction de structures de protection. Cet article présente notre expérience acquise pendant l'évaluation du danger d'instabilité rocheuse, le design et la construction d'une nouvelle structure de protection le long de 80 m de la voie ferrée. Dans un premier temps, il a fallu assurer la protection du site de construction contre les chutes de pierres. Pour cela, nous avons installé un filet de protection et mis en place un protocole de sécurité. Une structure de protection permanente, formée d'un mur de soutènement combiné à une gallerie de protection, a ensuite été construite : le mur de soutènement est attaché à la pente par des tiges d'ancrage et remplie de gravier pour absorber une grande partie de l'impact d'un futur éboulement; la gallerie permet à l'éboulement de passer par-dessus de la voie ferrée. Les pièces de la structure sont modulaires pour faciliter la construction et pour réduire les interruptions du traffic ferroviaire.

1 INTRODUCTION

On November 25th, 2012 a 53,000 m^3 rockslide occurred along the Canadian National Railway (CNR) track, at Mile 109.4, between Lytton and Boston Bar, British Columbia (Figure 1). The slide covered 70 m of track with up to 10 metres of debris, destroyed a 21 m long concrete rock shed located at the base of a gully with raveling debris, and caused a 4-day service disruption (Figure 2a).

Klohn Crippen Berger (KCB) was contracted by CNR to characterize and assess rock landslide hazard at the site; recommend protection measures at the track level; and, design the selected protection structure.

KCB's rock slope risk management approach follows the decision-making framework for risk management proposed by CSA (1997). Table 1 describes its six steps from risk management initiation to implementation of a mitigation plan. For the case study presented in this paper, due to the emergency related to the November 25th, 2012 rockslide event and the possibility for further instabilities, a rapid but thorough assessment and development of mitigation was required to provide safe rail operation, and consequently the program quickly progressed to steps 5 and 6.

Step 5 consisted of a detailed site investigation, including aerial imagery interpretation, combined terrestrial and airborne light detection and ranging (LiDAR), field mapping and numerical modeling. This formed the basis for the design of both a mesh curtain and a combined retaining wall/rock shed structure along the railway track.

Step 6 was concerned with the construction of these two rock fall and rockslide hazard mitigation structures in a complex topographic setting, with continuous raveling and railway traffic.

Table 1 KCB's rock slope risk management approach

Step No	Objective
1. Initiation	Recognition of ground hazards and their potential impact on elements at risk
2. Preliminary Analysis	Definition of the ground hazards and risk scenarios; identification of the extent of the study area(s)
3. Risk Estimation	Estimation of the risk
4. Risk Evaluation	Evaluation of the estimated risk (acceptable/unacceptable); prioritization of remediation work
5. Risk Control	Detailed analysis at a selected location, where the risk is considered unacceptable; development and selection of mitigation alternatives to reduce risk
6. Action/Monitoring	Implementation of a mitigation plan

2 HAZARD CHARACTERIZATION

The investigation of the November 25, 2012 rockslide event and the assessment for potential future events are reported in Sturzenegger et al. (2014). Site characterization was undertaken based on a combination of field mapping, airborne and terrestrial LiDAR (light detection and ranging). Rockslide modeling was achieved using limit equilibrium analysis and finite element modeling; a discrete fracture network was incorporated in the finite element analysis in order to provide a more realistic model.

2.1 Study of the November 25, 2012 rockslide

A study of weather data suggested that the November 25, 2012 event was triggered by a succession of freeze-thaw cycles and extreme rainfall periods. The rockslide occurred at the onset of a second series of freeze-thaw cycles. Prior to the events, tension cracks were observed along the back the rockslide area.

Geomorphological observations highlighted that the rockslide event occurred within the boundary of a paleo-landslide, the upper side of the rockslide corresponding to the prolongation of the paleo-landslide scar. Geological and structural mapping revealed the presence of both small scale folds and local faults (F1 and F2) in the sedimentary layers. In addition, the site is located in the vicinity of the major Fraser River Fault. One of the two local faults marks the northern part of the November 25, 2012 rockslide scar (Figure 2b).

Rock mass discontinuity characterization showed the presence of daylighting joints with an en-échelon configuration forming the basal surface of the rockslide. Two sets of sub-vertical joints formed lateral and rear release fractures. These observations suggest that the failure initiated as a rockslide with a complex failure surface.

Figure 1 Site location. The yellow line indicates the railway track.

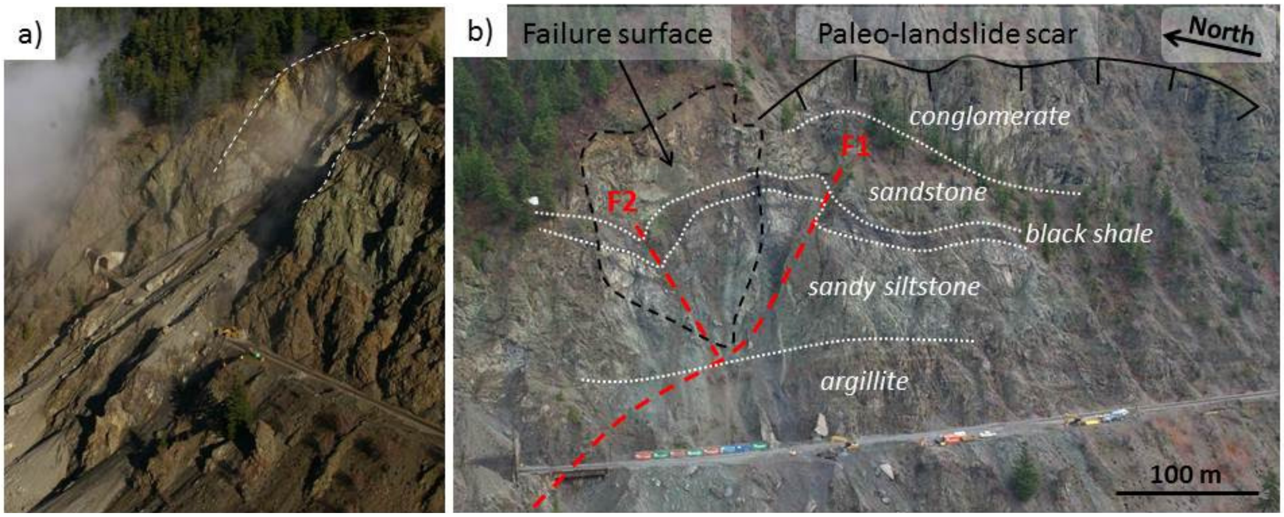


Figure 2 November 25, 2012 rockslide. (a) View just after the landslide; (b) post-slide view illustrating the geology of the site, the location of the failure surface, the paleo-landslide scar and faults F1 and F2.

The rockslide turned into a rock avalanche, according to Hungr et al. (2001) classification; i.e., the release of dry, fragmented rock mass (jointed but relatively intact at source), running out in flow-like motion at extremely rapid velocity (> 5 m/s). The landslide released an in-situ volume of 53,000 m^3, leaving a 70 m wide crest at EL. 295 m. At track level (EL. 186 m) the landslide deposit was 80 m wide, spreading to a total width of 140 m at Fraser River bank (EL. 113 m). Horizontal runout distance was approximately 190 m from crest to river bank, with some material travelling further into the river.

2.2 Residual Rock Landslide Hazard Assessment

The rock slope surrounding the November 25, 2012 rockslide was subdivided into domains, in which the rock landslide hazard was assessed. The likely failure mechanisms, locations and volumes of potential rock instabilities were evaluated. Limit equilibrium analysis and finite element modeling provided both factors of safety and probabilities of failure.

Some of the observed hazards were scattered over an entire domain, for example, planar failure in the presence of a daylighting joint set. Others were concerned with the presence of a specific block delimited by adversely oriented discontinuities.

It was found that the greatest threat to the railway track was a potentially retrogressive rockslide initiating from the recently exposed scar of the November 25, 2012 event. A discrete fracture network model was incorporated into the finite element analysis of this hazard in order to produce a complex failure surface, similar to the one back-analysed from the November 25, 2012 event.

3 REMEDIATION

Remediation includes both a mesh curtain and composite barrier wall/rock shed structure. The mesh curtain is a short term rock fall barrier to provide safe working conditions to the onsite construction personnel, while the composite structure is a long term structure to protect the track from rock falls and rock slides.

3.1 Mesh Curtain

Particularly hazardous conditions were experienced while scaling along the rockslide area: during the summer, a gully started to form under the action of wind in the dry overburden material, which generated constant raveling and unsafe working conditions in the rockslide area. The initial plan to install a dynamic rockfall barrier had to be modified, and a mesh curtain was used as an alternative.

The 60 m wide and 30 m high mesh curtain was installed across the rockslide area in order to protect the rock shed construction site from rock falls (Figures 3a and 3b). This system was intended to guide the rock fall trajectory under a tail drape, minimizing block bouncing movement and dissipating kinematic energy.

Compared to a dynamic rockfall barrier, the mesh curtain has the advantage that it does not require cleaning behind the net. Furthermore, its installation did not expose construction staff to constant raveling. Finally, it does not require barrier posts across the rockslide area, where the bedrock can be buried under several meters of debris.

The mesh curtain consists of a Geobrugg TECCO high tensile steel mesh connected to a 1” support cable with hooks. The mesh cable is attached to anchor systems on each side; the anchor systems are composed of two and three anchors at the east and west ends respectively, and of cable arrangements allowing even distribution of the load to each anchor (Figure 3c). Pulleys were also installed at locations where the mesh cable changes direction.

Installation of the mesh cable was achieved by lowering it from the east side, dragging and tensioning it through both the pulleys and west anchor system using an excavator and “come-along” winches. The mesh rolls with pre-attached hooks were then flown by helicopter to the east end, attached to the tensioned cable, and progressively moved along the cable.

The efficiency of the mesh curtain could be verified during the construction of the rock shed, when rock falls were redirected under the drape and rolled with low energy towards the base of the rockslide area.

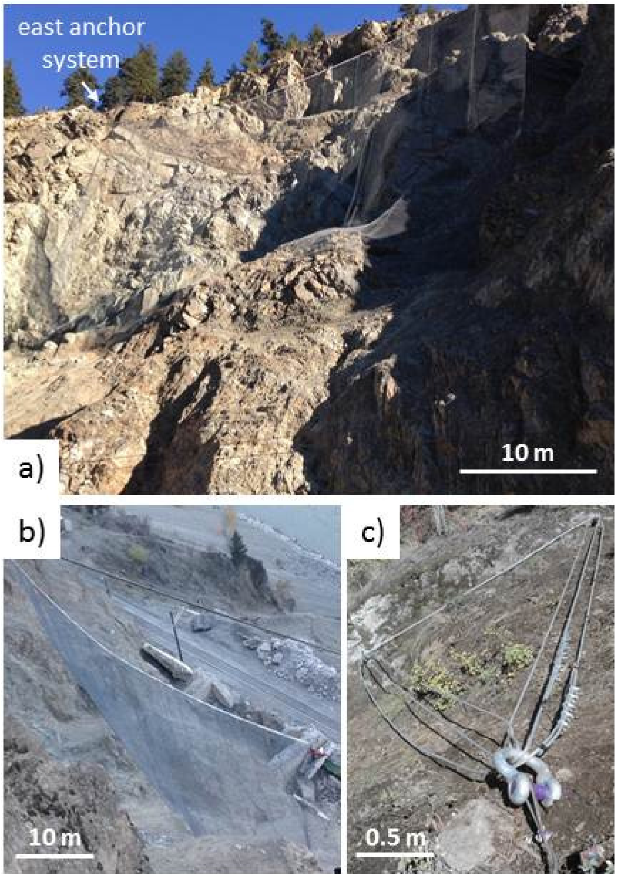
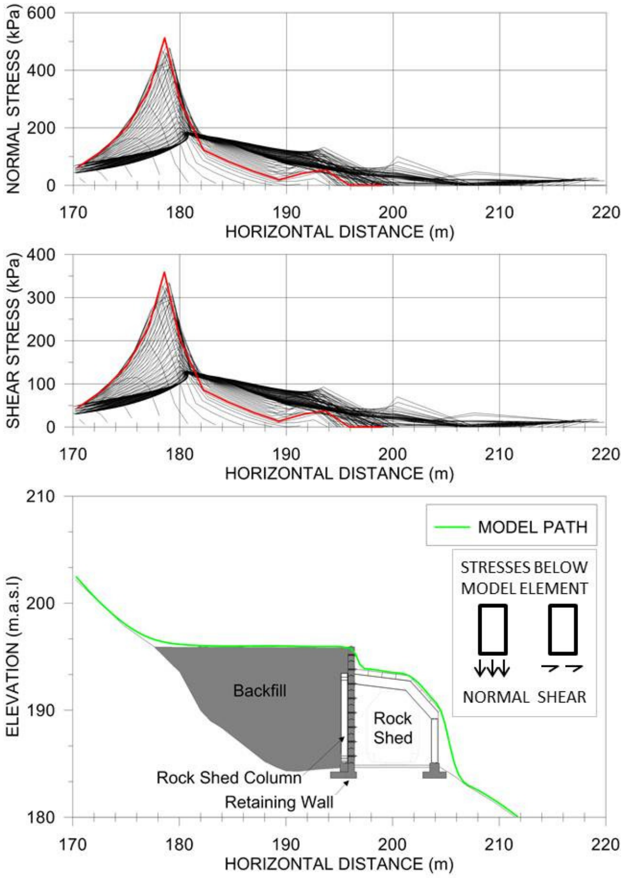


Figure 3 Mesh Curtain. (a) View of the curtain across the rockslide area; (b) View from the location of the east anchor system; (c) East anchor system composed of two rock anchors, the cables and the shackle connecting to the main mesh cable.

3.2 Composite Barrier Wall/Rock Shed Structure

Numerical analysis was carried out using DAN-W software to derive impact loads for design of the new track protection structure. The model was calibrated by finding best-fit frictional rheology for back-analysis of the November 25th, 2012 event. Forward analysis was carried out to estimate rock avalanche impact loads on the track protection structure. A modified version of the pseudo-three-dimensional runout analysis software DAN-W is used, allowing output of normal and shear stresses at the base of a sliding frictional mass (Busslinger et al., 2014).



NOTES:
1) PLOTS SHOW TIME STEPS AT 0.1s INTERVAL UP TO 20s MODEL TIME.
2) RED LINE INDICATES TIME STEP WITH PEAK NORMAL STRESS.

Figure 4 DAN-W analyses. The top two figures are DAN-W results for normal stress and shear stress. The bottom figure shows the proposed composite barrier wall/rock shed structure.

The software allowed computation of centrifugal acceleration for each sliding mass element (i.e. element velocity squared/ vertical curvature radius of path). Results showed that peak normal and shear stresses are sensitive to sharp terrain breaks (i.e. changes of the slope of the terrain), due to centrifugal forces generated by the moving mass (Figure 4). Peak stresses occurred in the frontal part of the rock avalanche. Stress magnitudes were sensitive to radius of terrain break and incoming velocity. These findings were used to optimize the design of the new composite barrier wall/rock shed structure to the loading from a rock avalanche hazard.

One of the challenges of the construction of this composite structure along the railway track is to deal with the ongoing train traffic. Our design solution was to use modular components, such as barrier wall concrete panels and rock shed footings, which could be pre-cast and transported to the site (Figure 5).

Figure 5 Installing one piece of pre-cast concrete footing along the upstream side of the rock shed.

The modular concrete components of the barrier wall were assembled and tied back to the bedrock outcrops using rock anchors (Figure 6). Gravel fill was used for backfill of the wall to absorb a large portion of the impact loads during a future rock avalanche.

Once the impact energy of a future failure is reduced, the rock shed structure is designed to allow the travel of the debris over its roof, down towards the river. It consists of pre-cast concrete footings, steel frames and concrete roof panels (Figure 6). On the downstream side of the structure, the concrete footings were tied with micropiles through the talus and heavily fractured bedrock.

4 CONCLUSIONS

This paper presents an engineering project related to the November 25, 2012 rock slope failure at Mile 109.43 along the CNR railway track in the Ashcroft Subdivision. The project started with the geological site investigation and the description of the rockslide event. A hazard assessment was undertaken to identify potential future instabilities. The assessment led to the design and construction of protection structures, including a mesh curtain and a composite barrier wall/rock shed structure.

During this project, KCB integrated recently developed analysis and design techniques, which were verified using traditional methods. The innovative analysis techniques include terrestrial LiDAR for rock slope characterization and hazard identification; this technique proved to be particularly advantageous at this site characterized by steep and hazardous terrain.

The discrete fracture network modeling approach used for stability assessment allowed analysis of a complex failure mechanism characterized by sliding along a stepped failure surface. Finally, the dynamic run-out analysis for the design of the protection structure allowed estimation of both the normal and shear stresses acting on the proposed composite barrier wall/rock shed structure; these parameters were used for the design of the structure.

The modular concrete and steel components of the barrier wall/rock shed structure provides ease of construction/repairs and minimal train service disruption. This innovative design is also transferrable to railway rock landslide hazards having similar design constraints and criteria.

This project illustrates the benefits of integrating innovative approaches in the rock slope risk management process.

Figure 6 First row of modular pre-cast concrete panels tied back to the bedrock with rock anchors. Installing the bracing between steel columns.

ACKNOWLEDGEMENTS

We would like to thank Canadian National Railways (CNR) for their encouragement and input in seeking innovative design at every step of this challenging project and for allowing the use of project material in this paper.

REFERENCES

Busslinger, M., Hungr, O., Keegan, T., Wu, W. and Edwards, T. 2014. Rock mass fall – rock avalanche design load for railway track protection structure. *Geohazards 6*, Kingston, Canada, June 15-18.

Canadian Standards Association (CSA), 1997. Risk management : guidelines for decision-makers.CAN/CSA-Q850-97, Etobicoke, Ontario.

Hungr, O., Evans, S. G., Bovis, M. J., and Hutchinson, J. N., 2001. A review of the classification of landslides of the flow type. Environmental & Engineering Geoscience, Vol. VII, No. 3, Aug. 2001, pp.221-238.

Sturzenegger, M., Keegan, T., Wen, A., Willms, D., Stead, D. and Edwards, T. 2014. LiDAR and discrete fracture network modeling for rockslide characterization and analysis, *IAEG XII Congress,* Torino, Italy, September 15-19.