Use of rock fall nets on Canadian National Railway – Design constraints and solutions

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ABSTRACT
Canadian National Railway (CN) is one of the largest Class I railways in North America, and many of CN's main line tracks traverse mountainous terrain and are exposed to rock fall hazards. As one component of rock fall risk management, CN has used rock fall nets to decrease derailment risk and reduce service disruption time and track damage cost from rock falls. This paper provides a review of the basic function of rock fall nets and discusses design constraints on rock fall nets in a railway environment. It utilizes two case histories to illustrate adaptation of conventional rock fall net installations to satisfy both railway and net function constraints on sites with difficult foundation conditions or site geometry. One of the rock fall net systems discussed is a 3000 kJ system, which at the time (2006) we believe was only the second installation of this largest available commercial rock fall net in North America. The second case history uses geosynthetic reinforced soil (GRS) for rock fall net post foundation support and deadman ground anchor restraint. The paper includes a check list of criteria to review when considering a rock fall net system for a railway application.

RÉSUMÉ
La compagnie des chemins de fer nationaux du Canada (le CN) est l'un des plus grands chemins de fer en Amérique du Nord et plusieurs lignes principales franchissent des régions montagneuses et sont ainsi exposées aux risques de chute de pierres. A même son système de gestion des risques liés au parois rocheuses le CN utilise différents types de mesures de contrôle afin de limiter l'ampleur des conséquences si des instabilités se produisent. Par exemple, des grillages de protection contre les chutes de pierres sont mis en place afin de réduire le risque de déraillement, diminuer le temps d'interruption de service et, enfin, de limiter les dommages a l'infrastructure ferroviaire Cet article offre un aperçu des fonctions des grillages de protection contre les chutes de pierres et discute des contraintes de conception de ces systèmes dans un environnement ferroviaire. Les auteurs utilisent deux exemples qui illustrent la façon dont l'installation de des grillages de protection a été adaptée en tenant comptes à la fois des conditions de terrain difficiles et aussi des contraintes ferroviaires Une des installations discutées est un système de 3,000 kJ, ce qui, en 2006, nous croyons être la deuxième plus importante installation grillage de protection contre les chutes de pierres en Amérique du Nord. Le deuxième cas décrit l'utilisation de murs de remblai renforcé de géosynthétique comme base de fondation pour les poteaux supportant les grillages ainsi que pour servir de butée pour les boulons d'ancrage retenant le système de protection. Les auteurs propose enfin une liste de des critères de conception pour les grillages de protection de chute de roc afin d'aider a l'élaboration de projets d'installation le long de voies ferrées.

1 INTRODUCTION

Canadian National Railway (CN) is one of the largest Class I railways in North America, and several of CN's main line tracks traverse mountainous terrain and are exposed to rock fall hazards. As one component of rock fall risk management, CN has used rock fall nets to decrease derailment risk and reduce service disruption time and track damage cost from rock falls. The first part of this paper reviews how rock fall nets function and their design constraints for arrangement on a slope. Typical system geometry constraints on anchor and post placement, and the typical ground forces generated by rock fall net systems are discussed. How these constraints interact with installation limitations typical of a railway environment are also discussed. A checklist of factors to review when considering a rock fall net installation in a railway environment is provided. In the second part of the paper, two case histories illustrate the interaction of rock fall net and railway constraints at two CN sites. These case histories discuss how the site geometry, typical rock fall net design, or both were modified to install a rock fall net system. One of the rock fall net systems discussed is a 3000 kJ system, which in 2006 was only the second installation of the largest available commercial rock fall net in North America. The second case history is for a 750 kJ rock fall net system that uses geosynthetic reinforced soil (GRS) for foundation and tie-back support.

The two rock fall net systems discussed in this paper were manufactured by GeoBrugg North America LLC. While much of the discussion in this paper is generic to other rock fall net systems with similar design arrangements, some specific comments on geometric design are based on experience with the GeoBrugg systems, and may not be applicable to other systems.

It is not the intent of this paper to review all elements of rock fall net design decisions, but rather to discuss features of rock fall net design that influence their use in a railway environment.

2 ROCK FALL NET DESIGN, FUNCTION AND FORCES

2.1 Basic Design and Function of Rock fall Nets

Rock fall nets are flexible barriers that are designed to intercept and arrest rock fall. They are typically fences of cable mesh or interlocking bundled wire rings (ring nets) raised off the ground by steel posts and suspension cables. Additional tie-back cables are also typically used. Figure 1 illustrates the basic components of most rock fall net systems.

When impacted, rock fall net systems absorb impact energy by transferring load from the net panels to the suspension cables, and from those cables to the suspension cable ground anchor points and the post tie-back cables and ground anchors. To dissipate the rock fall energy into the system over a longer period of time and reduce the forces in the system components, frictional breaking elements are typically included in the suspension cables and tie-back cables.

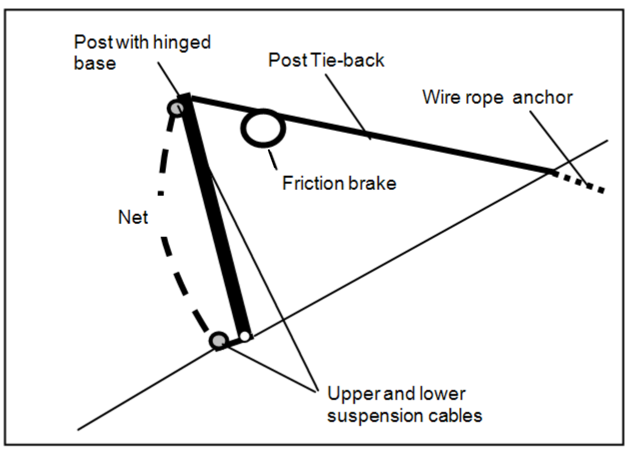

Figure 1. Schematic cross section of a rock fall net system

The posts are commonly spaced between 8 m and 12 m, and their primary functions are to raise the net off the ground and transfer axial post loads along the post into the ground. They are not intended to absorb rock fall energy. Posts typically have a hinge at the base that is mounted to a base plate, and the base plate is bolted to the ground. The hinged base reduces impact forces on the post by reducing moment and shear forces on the post base. Hinged posts also facilitate the extension of the net system down slope by allowing post rotation in a down slope direction.

The cable mesh or ring net usually ships in pieces about 5 m wide and the height of the rock fall net system. Pieces are joined together once installed on their suspension cables. The lengths of individual net pieces are independent of the post spacing, but the distance between the ground anchor points for either end of the net suspension cable is usually limited by the manufacturer and determines the overall rock fall net system length. This can be up to 60 m. When longer installations are required, independent rock fall net systems are installed with a shared end post.

2.2 Design Forces

Figure 2 illustrates the typical ground forces induced by a rock fall system when impacted. It is important for the designer to understand the ground forces produced by the system to check that there will be adequate bearing capacity and shear resistance of the post foundations, and adequate uplift restraint on lateral and tie-back anchors. The overall slope stability of the system under the applied forces also has to be considered. The design forces for the system should be provided by the manufacturer, and should be the result of measurements during full scale testing of the system.

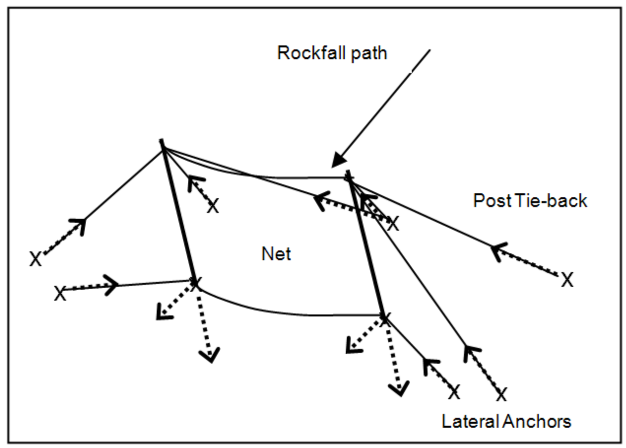

Figure 2. Isometric schematic of rock fall net ground forces. “X” denotes ground anchors, arrows are forces exerted on the ground by the rock fall net system.

3 CONSTRAINTS ON ROCK FALL NET USE ON RAILWAYS

Factors to be considered when determining if rock fall nets are suitable for a site can be grouped into five general categories: 1) the frequency of rock fall and their source volume size and particle size at the track, 2) installation constraints that are inherent in the mechanical design of the rock fall net system, 3) railway geometric and access constraints on the system installation and maintenance, 4) consideration of the suitability of the installation environment (topography, slope shape, foundation conditions), and 5) less tangible considerations that may involve assessment of human life, service disruption, and environmental risks.

Categories 2 to 5 are discussed in more detail in the following sections.

3.1 Rock fall Net System Design Limitations

Design geometry constraints and impact behaviour of net systems impose inherent limitations on net system installation geometry. The installation geometry of the system is limited by system installation tolerances such as post spacing constraints (typically 8 m to 12 m) and allowable differential elevation between posts. Differential elevation constraints between posts vary by system type but typical installations require less than a 15% gradient between posts. With pre-planning, custom design gradients between posts up to 100% can be accommodated. Post to post gradient requirements can constrain the plan view shape of a net system as it generally has to follow the contour of the slope. Or, if the slope is gullied, net geometry constraints can require overlapping net systems at different elevations on a slope to achieve the desired barrier.

Lateral anchors and post tie-back anchors also have placement tolerances based on their vertical and horizontal angles to the net system alignment and to the posts, respectively. Consideration of post locations has to simultaneously consider the adequacy of the post locations for both these sets of ground anchors. This constraint can be further compounded if steel bar ground anchors (rock bolts) are used, as their alignment should be limited to within about 10 degrees of the alignment of the design load to avoid excessive moment on the anchor head triggering anchor bar failure. If the slope geometry does not allow for this anchor to cable alignment while maintaining adequate anchor ground cover to avoid ground rupture when loaded, other ground anchor types should be considered. When the constraints on post spacing, anchor cable alignment, and ground anchor alignment are combined with irregular slope topography, finding a post and support cable arrangement that satisfies all constraints can be challenging.

To absorb impact, net systems extend down slope as net panels deform, braking elements are activated, and posts rotate down slope. In larger systems (up to 3,000 kJ) down slope extension at the end of the impact of up to 7 m are possible. This extension needs to be considered, including a factor of safety, when deciding the proximity of the system to facilities being protected.

The height of the net system is a design constraint. Current net systems are typically about 5 m maximum height, but have been built up to heights of about 9 m. Depending on the estimated rock fall trajectories and available slope installation locations, a rock fall net system may not be an effective rock fall barrier. This is discussed further in Section 3.3.

3.2 Railway Factors

Railways are a linear facility with some unique geometric and access constraints. As rail lines require low gradients (typically less than 2%), when crossing mountainous terrain they generally traverse the lower valley slopes of major river valleys. This places railways at the base of slopes and exposes them to uphill instabilities such as rock fall. As a result railways are often located in rock cuts with a narrow shoulder and steep slope to a river below. In this environment, space to work around rail lines is often limited. Limited working room around a track can influence rock fall mitigation decisions as room is usually needed at the site for material storage and equipment access during construction.

Sites along rail lines in mountainous terrain are typically not directly accessible by road, and travel along the railway from a location where road access to the railroad is available is usually required to reach a work site. In parallel with available materials and equipment (laydown) room at the site, this can affect the selection of rock fall mitigation designs. Difficult site access will also be a consideration when evaluating the necessary maintenance of any rock fall mitigation measures.

Frequency of rail traffic is also a consideration in the selection of rock fall mitigation measures. Where there are few trains a day, it is possible to close the track for periods of several hours to carry out rock fall mitigation work such as blasting and scaling. This type of work becomes more difficult with more frequent trains or with larger quantities of work. In extreme cases, train frequency can force consideration of rock fall mitigation measures that do not require track closure to complete.

The frequency of trains also influences the level of rock fall protection selected. Rock fall interruptions are not as tolerable where there is more train traffic because there is a higher probability of a train hitting a rock fall or a rock fall hitting a train. Rock fall protection requirements generally increase as train frequency increases.

The required clearance envelope for train passage, combined with the necessary extension room of a rock fall net system and often limited space around railways previously discussed, create a constraint on rock fall net design. The path of a train is fixed, as is the necessary clearance envelope to allow the train, and its rail cars, to safely pass. Unlike cars, trains have no potential to alter their path to avoid rock fall. In addition, long trains running on downhill grades can take distances exceeding one mile to stop. When this is combined with typical sight line distances in areas of high track curvature with rock fall potential, trains often cannot stop short of obstructions on the track unless they have advance warning of a problem. As a result, rock fall net installations have to be configured so that extension of the net system by a rock fall does not interfere with the railway clearance envelope. Otherwise, the retained rock fall poses a near-certain hazard to train traffic unless there is a system to warn trains of rock fall net activation.

3.3 Installation Environment Suitability

The suitability of the installation environment includes consideration of the site topography (gullies, benches, slope changes), near track slope geometry, and foundation conditions when deciding on the practicality and location on the slope of a rock fall net installation.

It can be difficult to arrange a rock fall net system on gullied rock slopes or slopes with irregular benches because of gradient and post spacing constraints along the rock fall net system alignment,. Rock fall net systems are simpler to install on sites with a uniform slope along topography.

For sites with convex changes in slope or benches, launching of rock fall at slope breaks can make effective barrier design difficult or prohibitively complex. Multiple rock fall net systems may be required to achieve adequate containment. Also, very steep slopes may not be practical for rock fall net installation because of access constraints or because of the high vertical clearance from the track required to have the activated system remain clear of the train envelope. Similarly, as discussed in Section 3.2, an apparently ideal rock fall net alignment near the rail elevation of the track may not be suitable because of activated rock fall net clearance limitations to the train envelope.

Foundation conditions are a key consideration when evaluating the suitability of a site for rock fall net installation, and may also limit the possible energy capacity of a system. Figure 2 illustrates typical rock fall net foundation forces. Design ground anchor force magnitudes vary with the rock fall net system capacity, but can be in excess of 500 kN for a 3,000 kJ system. Ground anchors need to have sufficient embedment to resist failure of the grout to anchor and grout to rock or soil bond, and sufficient ground restraint to not cause ground rupture when loaded. Multiple anchors attached to a plate at the surface can be used to distribute the load and reduce the capacity required on a single anchor and thereby reduce the required anchor size, borehole diameter and drill size. Site topography, such as gullies, can influence anchor placement as the designer seeks to maintain sufficient ground cover over the anchor bond zone to resist anchor breakout.

The diameter of ground anchors combined with the installation location (ground based or high slope work) can influence the practicality of the installation. In general, larger anchor diameters or the need to drill a cased borehole for anchor installation, require larger boreholes and drilling equipment limitations will require changes to larger and heavier equipment as borehole size increases. For high installations, large drilling equipment may be cost prohibitive or impractical to elevate. This is especially true around railways where the only working platform for cranes or other lifting devices at the base of the slope may be the track grade. Unlike a road where it is often possible to close a road lane for construction access, the railway grade cannot be closed for more than a few hours between trains and closure periods and start times cannot be guaranteed. To utilize short work blocks, construction equipment that occupies the railway clearance envelope has to be sufficiently mobile to quickly move on and off the grade. This usually precludes the use of cranes for daily slope access on busier rail lines.

If the preferred rock fall net location is in soil, ground anchors are typically either self-drilling grouted hollow core dowels, or threadbar rock anchors or cable anchors installed using cased borehole drilling. Except for some smaller equipment for shallow self-drilling dowels, the same constraints apply to these anchors as for rock anchors. In soil, additional concrete work for post foundations is also typically required to provide an adequate bearing surface for the posts.

3.4 Intangible Factors

Railways have some unique environmental, operator safety, and economic rock fall risk factors that affect the cost versus benefit assessment of rock fall mitigation options for a site. These can influence the choice of a rock fall net system over other rock fall mitigation or detection methods, or the decision to use a rock fall net system in conjunction with other rock fall mitigation methods.

Environmental and operator safety factors that influence the cost versus benefit assessment for rock fall protection against derailment include the proximity of tracks to rivers, the potential for large quantities of potentially environmentally damaging cargo, and also the difficulty in accessing a site to mitigate derailment consequences.

Safety is also a concern for the work crews carrying out rock fall mitigation work. At most sites, it may not be safe for workers to install a rock fall net without other, sometimes extensive, rock fall mitigation prior to the net construction. This may negate the cost versus benefit or alter the practicality of a rock fall net system.

In Western Canada, there are only three railway alignments connecting Vancouver to eastern Canadian provinces. CN through Western Canada experiences up to 40 trains a day with lengths up to 3.6 km (12,000 feet). Interruption to this service corridor attracts economic losses that grow exponentially with the length of the outage. Disruption causes a ripple effect that first influences trains in the system and “just in time” delivery of merchandise, then shippers as product transfer points reach storage capacity. Ultimately, worldwide shipping is affected as ships wait for deliveries and loading, or wait for room in the unloading facility to unload cargo.

4 ASSESSMENT OF ROCK FALL NET MITIGATION POTENTIAL FOR RAILWAY SITES

Section 3 provides a general discussion of factors to consider when contemplating the use of rock fall nets in a railway environment. Table 1 summarizes and combines those factors in a sequential checklist format with initial assessment of the rock fall characteristics.

5 CN ALBREDA SUB. MILE 53.2 CASE HISTORY

5.1 Setting and Rock fall Characteristics

The CN Albreda Subdivision begins at Jasper, Alberta and extends west through the Rocky Mountains to Blue River, British Columbia. Between about Mile 52.5 and Mile 55 of the subdivision the rail line traverses talus slopes near the base of the northern slope of Mt Klapperhorn. Through this area, the CN Robson Subdivision is parallel to the Albreda Subdivision, but about 30 m lower in elevation on the slope. Figure 3 illustrates this general arrangement.

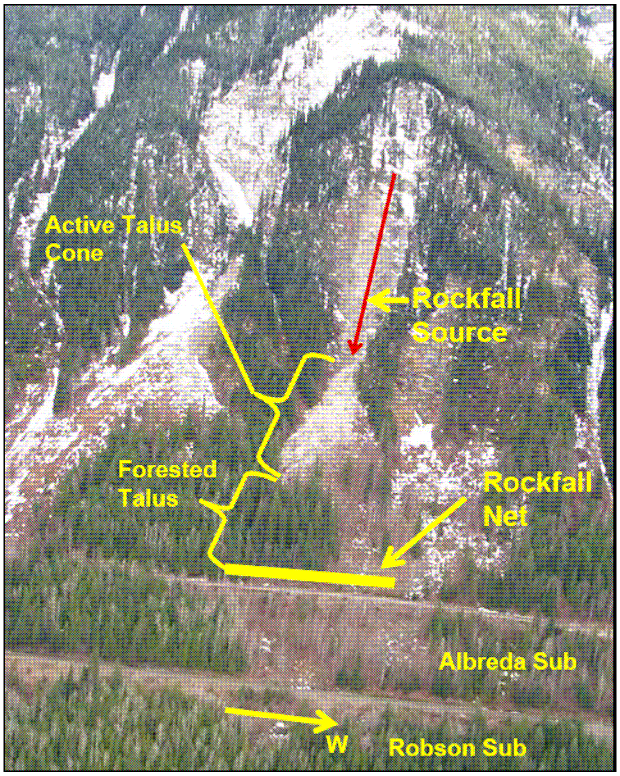

Figure 3. CN Albreda Sub. Mile 53.2. Aerial view looking south at the north slope of Mt. Klapperhorn showing the rock fall source, slope geometry and track locations. Photo: T.Keegan.

Mt. Klapperhorn produces rock fall, and at Albreda Subdivision Mile 53.2, rock falls are funnelled into a rock spur bounded talus chute that opens onto a talus fan and apron at the base of the mountain. The channelling effect of the rock chute has created a defined talus cone and rock fall path. Figure 3 provides an overview of the site, while Figure 4 illustrates the near track conditions prior to work.

While most rock fall are retained on the active talus cone, the largest rock particles (typically 2 m^3 to 6 m^3) can run out past the toe of the active talus onto the forested talus slope. Some of these larger rocks roll over the talus slope to the track where they often come to rest in the ditch or on the track. Occasionally, they have sufficient energy to roll over the Albreda Subdivision, and continue down the approximately 50 m slope to the Robson Subdivision.

While both subdivisions are protected by slide detector fences, CN wished to reduce the service disruption as rock fall reaching the track usually cause track damage (often to both subdivisions) or train delays while the rock fall are removed from the track.

5.2 Mitigation Assessment and Rock fall Net Selection

Two dimensional rock fall runout analyses were carried out and calibrated to rock fall path strike marks and block sizes documented on site. Assessment confirmed that, the 1 m to 2 m largest dimension rock fall fragments were rolling with low trajectory and energy typically less than 750 kJ by the time they reached the Albreda Subdivision. Various barrier options were considered because assessment of mitigation options concluded that it was not practical or cost effective to undertake stabilization of the rock fall source area. Part of the slope immediately above the track is loose, large angular talus at its angle of repose, and part is a forested talus slope. As a result, it was not considered practical, or aesthetically acceptable adjacent to Mt. Robson Provincial Park, to disturb vegetation and construct barrier ditches across the slope. At the track, there was insufficient ditch width to construct a barrier wall. Review indicated that a rock fall net system could provide a reduction in rock fall reaching the track; but establishing a location where the activated rock fall net would remain clear of the track and have adequate foundations would be difficult.

Figure 4. View looking west along lower talus slope above CN Albreda Subdivision Mile 53.2 showing large talus, minimal ditch, and slide detector fence. Photo: M. Pritchard

Rock fall net sizing was discussed with CN. Keeping in mind that the site was already protected by a slide detector fence that would be maintained, the focus of the net system was on cost-effective reduction of service disruption risk rather than complete containment of rock fall. Selection was made considering this purpose, and by comparing the rock fall energies to the cost versus energy capacity of different rock fall net systems. A 750 kJ energy system was selected, subject to resolution of the alignment and foundation design issues.

5.3 Foundation Conditions and Railway Constraints

The talus slope at the site encroaches on the track, and the rock fall net alignment had to be on the talus slope to have sufficient horizontal clearance to the track with the net activated without affecting the train clearance envelope. Placement of the net up the talus slopes was not considered practical for site disturbance reasons and constructability of working in the loose, large angular talus. Also, installing conventional ground anchors for posts and support cables by drilling in the loose talus was considered to have high construction cost risk. Alternative solutions for suitable foundations were needed.

In addition to the up slope space and foundation constraints, work at the site was constrained by being

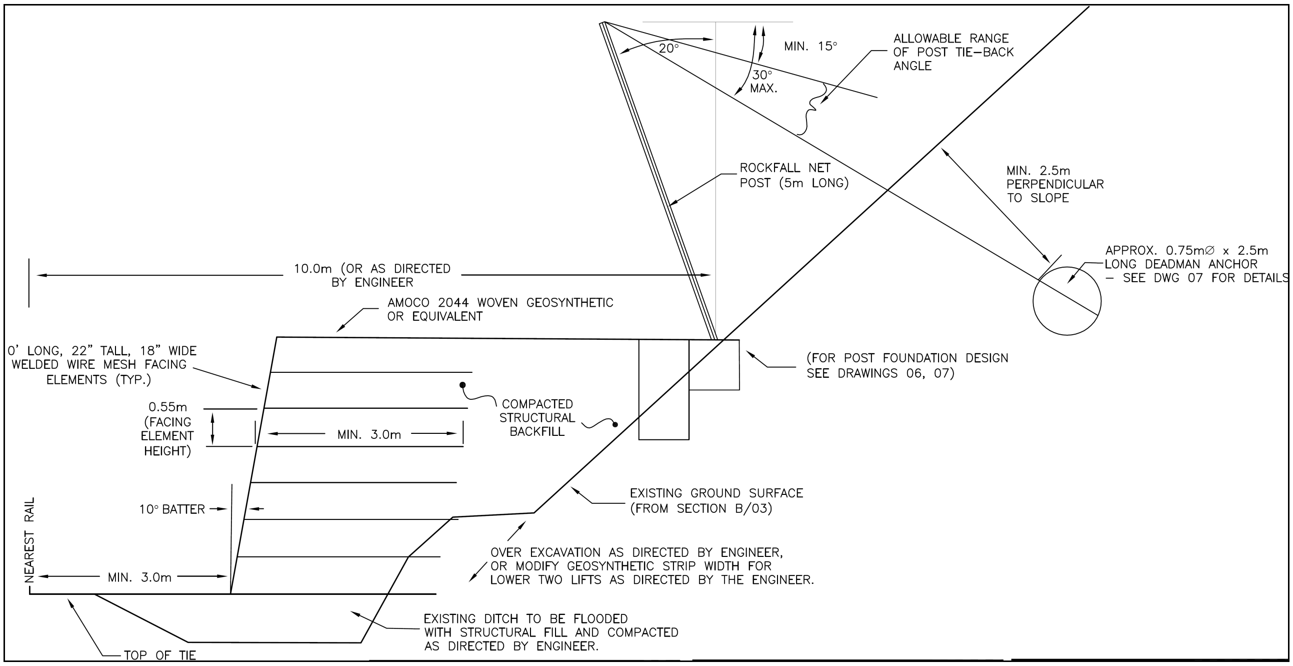

Figure 5. CN Albreda Sub. Mile 53.2. Typical section illustrating GRS wall, post foundation, and post tie-back arrangement

railway access only, a lack of track shoulder for laydown, and the presence of a second rail line down slope. Earthworks were also constrained by a fibre optic cable buried in the up-slope ditch, and the existing slide detector fence in the ditch.

5.4 Design Solutions

The solution adopted for the location of the rock fall net system was to construct a geosynthetic reinforced soil (GRS) wall founded at the up slope side of the ditch as a platform for the post foundations. The wall height was varied as dictated by the up slope topography to maintain a constant bench width on the top of the GRS wall. The desired bench width was dictated by the need to provide post foundation locations in the wall fill, and having the post foundations at least 7 m from the track that the activated fence would not affect the train clearance envelope. Figure 5 illustrates this concept.

Ground anchorage and down slope shear resistance for the post foundations was achieved by mounting the base plate for each post on a concrete lock-block (dimensions 1.5 m x 0.6 m x 0.6 m), and setting each block behind two other lock-blocks that had been bolted together and set into the GRS structure to form an in-ground wall 1.5 m tall, 1.2 m wide and 0.6 m thick. This arrangement provides passive earth resistance against horizontal shear of the post base in a down slope direction. It also provides uplift resistance equal to the weight of a lock-block, although the latter was not part of the design loading criteria for the posts. Formed concrete was not used for the post foundations because of the complexity of mobilizing batched concrete to the site with uncertain and unpredictable track time combined with highway travel time from the nearest concrete plant.

Rock fall net suspension cables (upper and lower) required lateral anchors, and posts required tie-back ground anchors. Lateral anchors were achieved by burying deadman anchors in the GRS wall. The post tie-back ground anchors used the same deadman anchor, but installed in the talus slope uphill. Figure 5 illustrates the post tie-back arrangement. For deadman anchors, scrap concrete railway ties, which are heavily steel reinforced, were bundled to make an anchor with approximate dimensions of 0.6 m diameter and 2.4 m long.

The GRS system used consists of an "L" shaped weldmesh facing element with Amoco 2044 woven geosynthetic at 0.28 m vertical spacing. Fill was locally available well graded sand and gravel, well compacted. Design of the GRS wall was provided by Terratech Consultants Ltd.

5.5 Summary

Figure 6 illustrates the completed system. Innovations with a GRS wall provided a platform that allowed the rock fall net system to be placed clear of the train envelope, and the use of deadman ground anchors and modular concrete post foundations were successful in overcoming the combined constraints of the rock fall net system design requirements and the site characteristics. A successful rock fall net installation was achieved that otherwise would have been very difficult to construct and resulted in much more extensive site disturbance.

Figure 6. View looking east from the west end of the completed GRS wall and rock fall net system, CN Albreda Subdivision Mile 53.2. Photo: C. VanBuskirk

6 CN YALE SUB. MILE 5.3 CASE HISTORY

6.1 Setting and Rock Fall Characteristics

Approximately 8.5 km (5.3 Miles) south of Boston Bar, BC on the east side of the Fraser River Canyon, CN's Yale Subdivision traverses the toe of an ancient rock slide that is locally known as the China Bar Slide. Figure 7 illustrates the site. The head scarp of the ancient slide is 260 m in elevation above the Fraser River, and 230 m in Elevation above the CN track. The width of the slide scar is about 125 m at the track elevation and about 50 to 75 m at the head scarp. At 80 m in elevation above the track, the TransCanada Highway 1 occupies a tunnel beneath the ancient slide, and the precursor of that highway, the now abandoned Caribou Highway, traverses the ancient slide. BC Hydro operates power transmission lines that utilize the old highway road bed for pole foundations on either side of the slide scar with a large span over the slide scar. The power lines service the community of Lytton upstream to the north.

The rock slide scar regularly produces rock fall and the site has been protected for decades by a generally wide and deep ditch at the track and a slide detector fence at the track.

On December 23, 2005, an approximately 700 m^3 rock slide occurred from the head scarp of the ancient rock slide, burying the track as illustrated in Figure 8. Residual smaller rock fall occurred for several days. For the safety of personnel, track clearing and repair was not attempted during this period. The track was closed for five days while residual rock fall risk was assessed and minor scaling at the slide head scarp was undertaken. Once the track was cleared by rock guarded equipment, it was still considered too dangerous for unprotected personnel to repair the slide detector fence. The fence was not repaired, but the track was in service for freight traffic only and under protection of a 24 hour watchman and with trains travelling at restricted speed (able to stop short of an obstruction).

Figure 7. View looking east across the Fraser Canyon at CN Yale Subdivision Mile 5.3 and the China Bar Slide. Photo: T. Keegan

Figure 8. CN Yale Sub. Mile 5.3. View looking south at December 23, 2005 rock slide debris. Photo: D. Allen

Scaling continued at the slide head scarp, but in early January, two additional smaller rock slides occurred. These were separated by several days, and each closed the track for approximately a day. At this point the issues were: 1) safety of scaling personnel, 2) the effectiveness of trying to reduce rock fall or rock slide likelihood solely by scaling the slide head scarp, 3) restoring the track to normal running speed, 4) reducing the frequency of future track service disruptions and 5) future risk to CN personnel from rock fall or slides at the site. Returning the track to normal running speed required restoration of the slide detector fence. In mid-January 2006, restoration of the slide detector fence was still considered to pose an unacceptable risk to unprotected personnel who would be immobile and exposed up slide fence poles should a rock fall initiate. It was also not practical to restore the fence while scaling was continuing. Reducing future track service disruption and personnel risk from rock fall required a solution to either reduce the likelihood of rock slides or falls, or reduce their potential to reach the track.

6.2 Mitigation Assessment and Rock Fall Net Selection

Rock slope stabilization or rock fall prevention options were evaluated. The potential rock fall source area in the slide head scarp was considered too large for cost-effective stabilization. The slope shape below the old highway is benched and scatter of rock fall increases in this area. The benched topography and rock fall scatter meant that longer barriers would be required if placed at the base of the slope, while their efficiency would be less than desired. In places, there was also not sufficient space for a barrier near the track. The portion of the rock slide above the old highway has a bowl shaped topography that funnels the majority of rock fall to a single path across the old highway. Rock fall modelling trials indicated potential rock fall energies at the old highway, could potentially exceed 3,000 kJ.

The most effective rock fall reduction measure appeared to be a barrier installed on the old highway. However, the positioning of a barrier part way up the slope meant that the frequency of rock fall originating from below the old highway and reaching the track would not be reduced. The old highway was between 4 m and 7 m wide, which was not considered sufficient width for an earth or rock fill barrier. Rock fall nets were considered, but the potentially high rock fall energies meant that there was some potential for damage, even for the largest commercially available rock fall net (3,000 kJ).

CN considered the alternatives and elected to reduce service disruption and improve employee safety by installing the 3,000 kJ rock fall net along the old highway. It was recognized that this solution would not improve rock fall protection for rock fall that originate from below the old highway, and that the net system could be damaged by a rock fall that exceeds its design capacity. It was also recognized that additional reduction of rock fall risk from the slide head scarp would be required to make construction work safe, but that work could be much less extensive than would otherwise be required to effect a similar longer term rock fall risk reduction without the solution of a rock fall net.

While waiting for delivery of the rock fall net system, trim blasting and scaling of the slide head scarp were completed to remove loose rock. To facilitate this work, CN was able to establish regular 2 to 4 hour work blocks during the day. This provided sufficient time to place the substantial waste rock pad needed to protect the track, carry out trim blasting, scale the resulting trim area, and remove the protective waste rock pad.

6.3 Rock fall Net Design Issues and Railway Constraints

Figure 9 illustrates the condition of the old highway in early January, 2006. While the old highway provided a convenient bench with easy access from Highway 1, laydown areas, and a level installation surface accessible to machines, some characteristics of the site were problematic. Rather than a uniform rock ledge, the old highway was a gullied bench with old timber crib retaining walls placed as fill in gullies. Restoration of one wall was required for access and installation of the rock fall net. Design required spacing the posts along the road edge to avoid gullies while meeting the 8 m to 12 m post spacing constraint. The BC Hydro power pole at the north end of the installation was down slope of the last net panel, and extension of the net system during an impact would have knocked this pole over. This pole was replaced with one further north. With the rock fall net installed, the clearance of the system to the power lines would not meet BC Hydro guidelines. This was addressed by installing taller power poles at either end of the system.

The rock mass in most of the rock fall net installation area was generally dilated along joints and not expected to hold an open borehole for anchor installation. As a result larger cased boreholes were required. This meant larger equipment, and careful consideration of equipment sizing given the limited working room on the narrow road bench. To meet requirements for plan view angle to the net alignment, some of the lateral support rope anchors needed to be installed down slope from the road bench. This required the drill equipment to be capable of reaching down over the road edge and drilling back into the slope. The dilated nature of the slope was expected to cause excessive anchor grout loss, and methods to limit this loss were required. Lastly, the dilated rock mass, particularly at the outside edge of the old highway, raised the possibility of inadequate rock foundations for the posts in this area.

Figure 9. CN Yale Sub. Mile 5.3. View looking north along old highway prior to construction. Photo: T. Keegan

6.4 Design Solutions

An arrangement was found that met the system post spacing, provided locations for the lateral suspension cable ground anchors, and avoided posts in gullies.

Track mounted down-the-hole hammer drills were used for anchor drilling that were capable of the orientations required and cased boreholes. A grout gelling agent was used in cement grout to limit grout loss when grouting anchors. Cable ground anchors were assembled on site to match borehole lengths that were determined by drilling conditions encountered in each borehole.

Post foundations were designed to be two 43 mm diameter 517/690 MPa, five metre deep threadbar anchors in rock with a nominally 0.30 m thick seating pad of reinforced concrete for the base plate. For several of the post foundations, the rock mass was too dilated to successfully drill or grout in the threadbar anchors or the rock mass on the highway shoulder was not considered strong enough to resist the design down slope horizontal load. In these cases, the design was modified to deepen and further reinforce the concrete base for the pad, and tie back the post pad to the old highway cut slope. The post tie back was accomplished by including a horizontal threadbar into the concrete pour that projected from the up slope side of the foundation, installing a cable anchor into the toe of the highway cut slope, and extending that cable anchor to connect to an eye on the threadbar. Figure 10 illustrates this arrangement. Figure 11 illustrates the site during rock fall net foundation construction.

Rock fall protection during construction was managed by a combination of the precursor trim blasting and scaling, a rainfall shutdown criteria, and a full time rock fall watchman with headset radio communication with workers. The work was also carried out in late spring when rock fall triggering conditions were less likely.

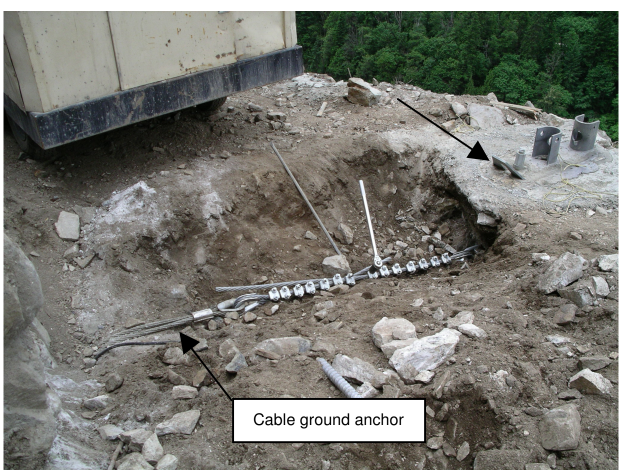

Figure 10. CN Yale Sub. Mile 5.3. Photograph of post foundation utilizing tie-back to ground anchor in old highway cut slope. Photo: A. Benson

Figure 11. – CN Yale Sub. Mile 5.3. View looking north along old highway during rock fall net foundation construction. Photo: M. Pritchard

6.5 Summary

Figure 12 illustrates the completed rock fall net system. The system is an example of the use of a rock fall net to augment other protection systems, with the understanding that the rock fall net is not designed to intercept all rock fall, and may be overwhelmed by the largest potential rock fall. In this case, the reduction in service disruption potential and the improvement in worker safety were considered worthwhile.

Figure 12. CN Yale Sub. Mile 5.3. View looking south along old highway from middle of completed rock fall net system. Photo: C. Laughlin

The installation is also an example of near ideal installation access conditions in a railway environment. The old highway provided road access for equipment with all work being clear of the track and with adequate laydown and vehicle access. Without the old highway bench, installation of the system on the slope would likely have been considered impractical.

The installation also illustrates adaptation of system layout and foundations to the site conditions while remaining within the design constraints of the system.

7 CONCLUSIONS

The overview of rock fall net system design constraints and considerations provided in this paper and illustrated by case histories provides a guideline for rock fall net design in a railway environment. With an understanding of rock fall net mechanical design and railway constraints, the designer is better prepared to assess the merits and difficulties of a rock fall net installation, and compare a rock fall net solution to other rock fall risk reduction measures. The designer is also better prepared to consider modifications to the site or the net system to achieve a cost effective installation and minimize environmental disturbance.

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Table 1. Checklist for Rock fall Net Selection and Design in a Railway Environment

Questions or Considerations	Comments
What are the estimated rock fall energies, particle sizes and trajectories?	A site that produces scattered small rock fall particles of weak rock will have a different design approach than a site that produces large rock fall fragments of strong rock as the consequences for train traffic are different. The former poses a low risk to trains and is more of a maintenance issue, while the latter poses a greater derailment or service disruption risk. Assessment of rock fall mitigation approach and if selected, rock fall net system sizing, depends on these factors.
Are other approaches to rock fall risk management more suitable? For example: • Stabilization – extent, cost, practicality, longevity • Methods to prevent rock fall from reaching the track (e.g. ditching, barrier walls, slope mesh, avoidance by track realignment such as moving the track away from the hazardous slope or tunneling. • Warning devices (e.g. slide detector fences)	Assessment of other approaches to manage the rock fall risk should include: • the potential of the rock fall to cause derailment (e.g. particle size at track, intact rock strength and frequency of larger rock particles reaching the track) • the potential service disruption costs (track damage, out of service time, economic losses) • the cost and effectiveness of different management methods. This should include preliminary assessment of rock fall net sizing • train frequency and its affect on the practicality of stabilization methods that require track closure • train crew safety, environmental, and service disruption consequences • the longevity and maintenance costs of other rock fall risk management methods compared to rock fall nets • Signal fence maintenance and exposure of signal fence maintainers, Slow orders associated with frequent signal fence activation.
How often would a rock fall net system need cleaning or maintenance?	Very high rock fall frequency sites may not be suitable for rock fall nets because of the high cost of access in a railway environment to clean out and maintain the systems
Does the site topography facilitate rock fall nets?	This considers: • slope benches and gullies and their affect on rock fall trajectories and ultimately on appropriate rock fall net alignments. For sites with changes in slope and high rock fall trajectories, rock fall nets may not be appropriate, or multiple rock fall nets may be required. • whether the post spacing, post to post elevation change, and ground anchor alignment design requirements can be made to fit the appropriate rock fall net alignment. • For the preferred system alignment, is there room for the system to activate and be clear of the train envelope?
What are the anticipated foundation conditions, what anchorage will be necessary (forces), and is it practical and cost effective to access the preferred system alignment with the necessary construction equipment?	This requires: • determination of post, post tie-back, and suspension cable anchor forces • ground anchor design and post bearing and shear resistance design • check on slope stability under net system design load • assessment of necessary construction equipment and access to the site.
What are the design parameters for the system for probability of rock fall interception and retention?	The acceptability of a design will depend on assessment of the probability of rock fall interception, on the system energy capacity weighed against the likelihood of different rock fall energies from the slope, and on the consequences of rock fall bypassing the system. For example, if a site is already protected by a rock fall warning device, a lower net performance may be acceptable than without a warning device. In this case, compromise solutions between cost and rock fall interception effectiveness may be considered such as a lower design capacity, or lower net height.
How easy and safe will it be to access, construct and maintain the rock fall net system?	Is there ground access or does the installation require rope work or basket lift work? Is there road access or is access only by rail? What is the rail distance from the nearest railway access point? Is it safe to put personnel in the installation area? What are the costs to make the site safe for work?