Avalanche deflection berm and stopping wall at a hydroelectric facility in British Columbia, Canada

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ABSTRACT

Avalanches pose significant risk to an ongoing construction project at Rio Tinto's Kemano hydroelectric facility in the Coast Mountains near Kitimat, British Columbia, Canada. Horetzky Landing is host to a workers' camp, offices, equipment laydown areas, and the primary adit for current tunnelling operations that will twin existing water supply to Kemano by 2020. Two reinforced-earth avalanche defence structures have been designed and constructed at Horetzky Landing to protect infrastructure and equipment in the runout zone of a large avalanche path. The structures consist of a 10 m tall, 150-m long deflection berm in the upper runout zone, and an 8 m tall, 120 m long, reinforced Gabion-faced stopping wall immediately above the tunnel adit in the lower runout zone. The deflection berm was designed to divert the dense flow of a 10-year return period avalanche, and the stopping wall to resist a 30-year return period design avalanche. Geotechnical design considerations included a constrained footprint on the congested Landing, variable-quality subgrade conditions as a result of past site work, sources of suitable fill for construction, and a short design life. Construction was completed in fall 2018.

Keyword: *avalanche defence structure; avalanche engineering; stopping wall; deflection berm*

1. INTRODUCTION

Multiple large avalanche paths threaten infrastructure and ongoing construction works at the Kemano hydroelectric facility in the Coast Mountains near Kitimat, British Columbia, Canada. The facility is operated by Rio Tinto Alcan (RTA) and has been providing electricity to the aluminium smelter at Kitimat as well as neighbouring communities since the 1950's. Construction of a second water-intake tunnel (T2) for the Kemano generating plant has recently resumed after initial construction was halted in the early 1990's. Current construction works began in spring 2018 and are scheduled to be completed within three years.

Construction of the T2 tunnel and supporting operations are staged from Horetzky Landing (Fig. 1), situated at the head of a steep mountain valley northeast of Kemano. The Landing is accessible via an 11 km long access road ascending the valley. Horetzky Landing supports the primary adit (access portal) for the Tunnel Boring Machine (TBM) and is host to a workers' camp, offices, concrete batch plant, TBM maintenance shed, wastewater treatment facility, and multiple equipment laydown areas.

Numerous avalanche paths threaten Horetzky Landing and the access road. A path known as 28.0N directly affects Horetzky Landing and is capable of producing large avalanches that have the potential to impact infrastructure across the Landing and fill the T2 adit with debris. To maintain the current T2 construction schedule, project specifications stipulated that avalanche closure times at the Landing were to be minimized, and the T2 adit should remain operational throughout the winter even if the Landing was impacted by a large avalanche.

Mitigating avalanche risk to Horetzky Landing involves a combination of an active forecasting and control program, Remote Avalanche Control Systems (RACS) in the start zones of 28.0N, and passive defence structures at Horetzky Landing. The structures consist of an avalanche deflection berm and stopping wall designed and constructed in 2018, and described herein.

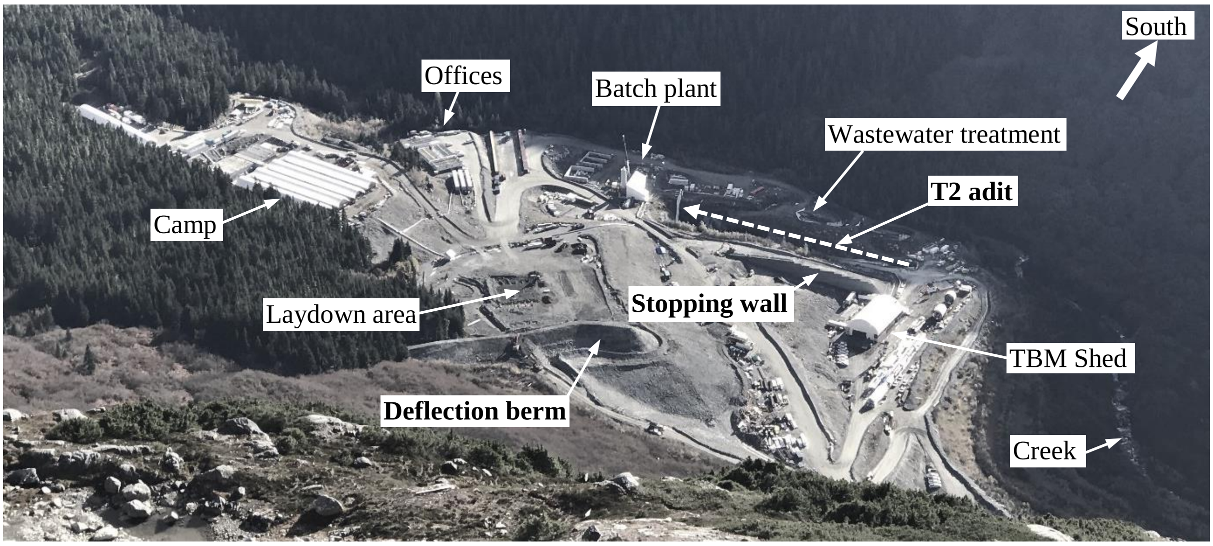

Figure 1 Horetzky Landing, viewed from the start zone of avalanche path 28.0N during late-stage construction of the deflection berm and stopping wall (Photo: October, 2018).

2. AVALANCHE RISK AT HORETZKY LANDING

2.1 Snow Avalanche Geoclimate

The T2 Project area is located in the Maritime snow climate of the Northern Coast Range of British Columbia, which is generally characterized by heavy snowfall and relatively mild winter temperatures. Local winter weather patterns are historically severe due to latitude and the amplifying effects of local mountain topography that ascends abruptly from sea level to over 2000 m causing rapid orographic lift of inbound Pacific coastal weather systems. The region receives some of the heaviest snowfalls in North America, with settled seasonal snowpack depths ranging from 3–8 m.

2.2 Avalanche Risk Assessment

Avalanche risk to Horetzky Landing was assessed using a combination of field studies, historical avalanche observations from previous phases of construction (Alcan, 1991), dynamic and statistical avalanche models, and expert judgement. Avalanche runout distance, velocities, flow depths and widths were estimated using multiple dynamic runout models, including PCM Model (Perla et al., 1982), PLK Model (Perla et al., 1984), and RAMMS (Christen et al., 2010).

Path 28.0N has multiple alpine start zones ranging in elevation between 2000 m and 1300 m with east, south and west aspects. The runout is below treeline, much of which covers Horetzky Landing at an elevation of roughly 760 to 820 m. The path is capable of producing avalanches up to size 3.0 (destructive scale) annually and larger size 3.5 to 4.0 avalanches are expected with 10 and 30-year return-periods.

Without defence structures at Horetzky Landing, the runout of a 10-year return-period avalanche would reach the upper Landing, impacting a large equipment laydown area. The runout of a 30-year event was expected to reach 40–50 m beyond the T2 adit on the lower Landing, filling the adit with debris and impacting the TBM maintenance shed, wastewater treatment facility and additional equipment laydown areas. Larger avalanches would completely cross the Landing, with the largest events crossing Horetzky Creek and running up the opposite side of the valley. The workers' camp and offices are situated east of the avalanche runout, sheltered behind mature forest.

Construction and tunnelling works staged from Horetzky Landing are expected to take 2–3 years to complete. The encounter probability of a 10-year-return-period event occurring in that time is 27% and the encounter probability of a 30-year event is nearly 10%.

3. DEFLECTION BERM AND STOPPING WALL DESIGN

3.1 Design Criteria

The objective of the avalanche deflection berm and stopping wall were to reduce the exposure of critical infrastructure and minimize closure times at Horetzky Landing during the 3-year construction period. The deflection berm was designed to deflect the dense flow component of size 3.5 avalanches with 10-year return periods, and partially deflect but be overtopped by 30-year and larger avalanches. The stopping wall was designed to stop the dense flow of the 30-year return-period size 4 avalanche about 40 m short of its estimated runout distance. The powder component of the design avalanche will overtop the stopping wall and impact structures beyond the T2 adit. Additional design criteria included:

- Locating the structures where they would be most effective against avalanches;
- Minimizing land-use (footprint) on the crowded Landing;
- Minimizing environmental impact and disruption of natural drainage courses;
- Using on-site stockpiles of TBM muck or drill/blast waste-rock for construction fill;
- Satisfying established geotechnical stability Factors of Safety (FOS).

3.2 Geotechnical Parameters

Much of Horetzky Landing is constructed on stockpiled drill/blast waste-rock and TBM muck fills from previous T1 and T2 tunneling operations in the 1950's and early 1990's, respectively. These materials were used for construction of the structures and also formed the underlying foundation soils. Available geotechnical information was sparse and outdated in the areas of the stopping wall and deflection berm, since relevant reports predated the early 90's T2 construction works in which large volumes of waste rock and TBM muck were disposed across the site.

From available reports and drawings, it was understood that most of the deflection berm would be situated atop the existing 1950's drill/blast waste-rock stockpile that formed the upper Landing and large equipment laydown area (Fig. 1). This material consisted of gravel, sand, angular cobbles and boulders with old wood waste and project materials encountered sporadically amongst the fill. The stockpile slopes south of the berm location were up to 20 m tall with 2.5 horizontal to 1 vertical (2.5H:1V) grades.

At the stopping wall location, the depth of existing fills and native colluvium overlying bedrock was unknown but assumed to be 1 to 5 m thick. A series of 3 m test pits along the length of the wall conducted in Spring 2018 revealed free-draining granular fill soils mixed with significant organics, wood waste and metal. Shallow bedrock was encountered at the east end of the wall.

Expected gradations of the 1990's TBM muck and drill/blast waste rock materials were provided by RTA and formed the basis of shear strength calculations in the design of the structures. The TBM muck was expected to be well-graded with a maximum particle size of 100 mm and less than 8% fine silts and clay. Drill/blast waste-rock was reported to be up to 450 mm in particle size with roughly 5–10% oversize and negligible fines content.

Geotechnical Factors of Safety (FOS) against deep-seated global instability of the structures were based on project specifications provided by the RTA. The near-vertical Gabion-face of the stopping wall was designed to a FOS of 1.5 under static conditions, while the backslope of the wall and the side-slopes of the deflection berm were designed to a FOS of 1.3. A minimum FOS of 1.1 for both structures under avalanche impact loading or pseudostatic seismic loading was also specified.

3.3 Deflection Berm Design

The deflection berm (Fig. 2) is located in the upper runout zone of Path 28.0N on the upper edge of Horetzky Landing and is oriented at 33 degrees to the primary avalanche flow direction. The berm is a 150 m long and 10 m high with a 3 m crest and steep side-slopes shaped at 1.3H:1V to minimize the footprint and fill requirement, and to prevent avalanche run-up. The berm required roughly 23,400 m^3 of fill to construct. It has a gentle dog-leg to the west at the downhill end. At the uphill end, the berm ties into a steep natural bank of mature forest that helps channel the dense flow of the design avalanche toward the berm. The toe of the berm was set back a minimum of 10 m from the crest of the tall fill slopes of the 1950's waste-rock stockpile on which it was situated.

Figure 2 Construction of the deflection berm with temporary access ramp (October, 2018).

The steep side-slopes of the berm necessitated geogrid reinforcement within the structure in order to satisfy the 1.3 FOS requirement. Primary layers of uniaxial geogrid were placed at 2 m vertical spacing with each layer spanning the entire width of the berm and continuously along the length. Shorter, 3 m lengths of the same geogrid were spaced between the primary grid for added facing stability.

3.4 Stopping Wall Design

The stopping wall (Fig. 3) is located lower in the runout, immediately above the T2 adit. The wall is 8 m high with a near-vertical Gabion-basket face, a 3 m crest, and a 1.3H:1V backslope to minimize the footprint next to the adit. It is 120 m long and required nearly 10,000 m^3 of fill and roughly 490 Gabion baskets to construct. The length of the wall followed the naturally sloping terrain parallel to the T2 adit at an average grade of 19% which required stepping the Gabion layers at every third or fourth basket along the wall. Continuous layers of uniaxial geogrid reinforcement with were placed between each Gabion layer and extended back through the structure to stabilize both the Gabion face and 1.3H:1V backslope. The short design life of the structure and the potential for damage to the geogrid in the coarse fill were considered when factoring the tensile strength of the geogrid.

Deleterious subgrade soils beneath the Gabion face were over-excavated to 2 m (or shallow bedrock) and replaced with crushed gravel interbedded with two layers of biaxial geogrid to strengthen and stiffen the foundation of the wall.

The wall was evaluated for global stability and sliding under the design avalanche impact load. The avalanche impact was conservatively modelled as a static load with an even distribution of 32 kPa representing the dense flow from 0 to 3 m height, and a triangular distribution of 32 to 5 kPa from 3 to 8 m height representing the transitional saltation and powder flow layers. A static design snow load of 13.9 kPa was also applied as a surcharge to the crest and backslope of the stopping wall structure under some conditions. In addition to satisfying global stability, the FOS against sliding and bearing failure were calculated, and internal factors of safety against geogrid rupture and pullout were also verified.

Figure 3 Final construction of the avalanche stopping wall (November, 2018).

4. CONSTRUCTION

Construction of the deflection berm and stopping wall took place simultaneously in the fall of 2018. Weather during the construction period (September to early November) was favourable, with unseasonably mild temperatures and relatively low rainfall for the region and time of year. Snow and freezing temperatures were not a factor during construction.

Material gradation and developing a consistent source of suitable quality fill was a challenge at the start of construction. The 1990's TBM muck, for which the structures had been designed to use as fill, turned out to have a much higher fines content than the gradation curves provided by RTA during the design stage. Although suitable compaction could be achieved in dry conditions, the material quickly degenerated during wet weather, becoming unworkable. Furthermore, the siltier material had a lower friction angle than had been assumed in design. This was recognized in the first week of berm construction and an alternative source of material was sought. Instead, careful regrading and some sorting of the 1950's drill/blast waste-rock stockpiles around the upper Landing provided sufficient coarse, granular fill for construction.

Compaction efforts were specified based on standards for rock-fill (e.g. Breitenbach, 1993) that included lift thickness, compactor ratings and recommended number of passes. Adequate compaction was confirmed in the field by the settlement-per-roller-pass method described by Breitenback (1993).

5. CONCLUSIONS

The two geogrid-reinforced, earthen avalanche defence structures designed and constructed at Horetzky Landing form part of a comprehensive avalanche risk mitigation strategy for the Kemano T2 Completion Project that also includes active winter forecasting and control work and remote avalanche control systems in the start zones.

The 10 m high, 150 m long deflection berm in the upper runout was designed to defect the dense flow of a 10-year return-period avalanche away from the upper Landing, while the 8 m high, 120 m long, gabion-faced stopping wall in the lower runout was designed to stop the dense flow of a 30-year return period avalanche. The structures consume a minimal footprint on the crowded landing, satisfied specific geotechnical factors of safety, and successfully used local stockpiles of available drill/blast waste-rock fill for construction.

Construction took place over two months in the fall of 2018 and was completed prior to the first winter avalanche season.

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