AVALANCHE HAZARD MANAGEMENT AT THE EAST TOBA RIVER AND MONTROSE CREEK HYDROELECTRIC PROJECT, SOUTH COAST RANGE, BRITISH COLUMBIA

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ABSTRACT: The East Toba River and Montrose Creek Hydroelectric Project is located in the South Coast Range 100 km north of Powell River, British Columbia. The project incorporates run-of-river intakes at East Toba River and Montrose Creek connected by 156 km of 230 kV transmission line, as well as diversion dams, penstocks, powerhouses and roads. 101 avalanche paths were identified in the project area capable of affecting facilities. These paths were mapped on a GIS and used for location planning of facilities, planning for mitigation and ultimately the avalanche atlas for the construction avalanche safety program. Due to other site constraints (engineering, hydrology, etc.), the Montrose Creek intake was located in the runout zone of a very large avalanche path which has the potential to produce Size 5 avalanches. Size 3-4 avalanches reached the intake site during each of the last 4 winters. The intake design was modified to account for impact pressures from direct avalanche impacts as well as large vertical snow loads from deposits and snow fall. The intake design included the construction of a 120 m long by 15 m high deflection berm that will keep more frequent avalanches out of the intake reservoir and reduce the impact pressure of less frequent, larger avalanches. Construction of various aspects of the project, including work at the Montrose intake site, was conducted during 2009-2010 and required an active avalanche safety program. On overview of the avalanche safety program is provided in this paper.

KEYWORDS: Hydroelectric, avalanche hazard, mitigation, deflection berm.

1. INTRODUCTION

The East Toba River and Montrose Creek Hydroelectric Project is located in the western side of the South Coast Mountain Range 100 km north of Powell River, British Columbia (BC) (Fig. 1). The project includes two hydroelectric generating facilities with a net capacity of 196 MW which delivers power to the BC Hydro delivery point at the Saltery Bay switching station.

The project is located in a very mountainous, high precipitation Maritime snow climate area with peaks reaching 2000-2400 m elevation. Glaciers are present on most of the high peaks. Local relief exceeds 1000 m in many areas due to the low elevation of the valley bottoms (e.g. < 100-500 m elevation), with up to 2300 m relief in the larger paths. The project is affected by numerous large and active snow avalanche paths.

The project incorporates run-of-river intakes at East Toba River and Montrose Creek connected by 156 km of 230 kV transmission line. Other features include diversion dams, penstocks, powerhouses and roads. It is the largest independent run-of-river hydro project in BC and became operational in August 2010 following a three-year design and construction program worth CAD $663 Million (Plutonic Power Corp., 2010).

This paper describes the mapping of avalanche areas, estimation of snow loads and impact pressures on structures, risk mitigation, and operation of a safety program during 2009-2010.The focus of this paper is on the Montrose Creek facilities where the greatest planning and operational challenges were encountered.

Fig. 1. East Toba-Montrose project location map.

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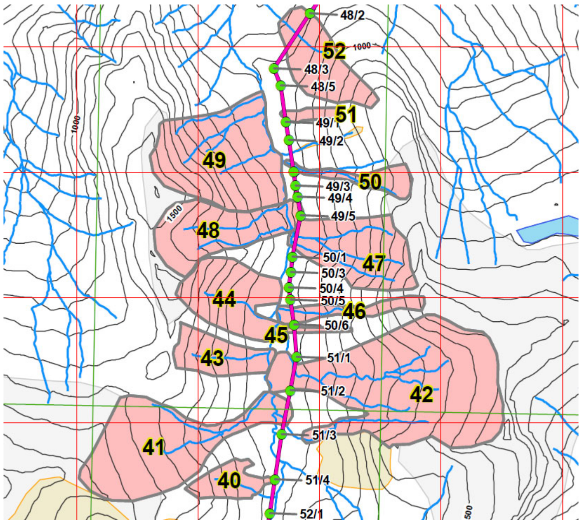

Fig. 2. Sample of avalanche atlas with paths (pink polygons) potentially affecting the transmission line (pink line) or towers (green circles).

2. AVALANCHE HAZARD MAPPING

Mapping of snow avalanche hazards was completed in 2008 using a combination of LIDAR and orthophotographic images, topographic maps and field verification by helicopter. At the time there were no facilities and little to no road access to the paths. 71 avalanche paths were identified that could affect the planned transmission alignment with Size 3 or 4 avalanches. An additional 132 paths were identified in the corridor that did not affect the planned line or towers.

18 avalanche paths were identified in the Montrose Creek valley and 12 were identified in the East Toba River valley with potential to affect the intake facilities (intake, access roads, powerhouse, etc.) with Size 3-5 avalanches.

In summary, 101 avalanche paths were identified in the project area capable of affecting facilities. These paths were mapped on a GIS (Fig. 2) and used for location planning of facilities, planning for mitigation and ultimately the avalanche atlas for the avalanche safety program.

3. MONTROSE CREEK INTAKE

The Montrose Intake is located at 520 m elevation in the Montrose valley, 4.4 km northeast of the powerhouse which is at 49 m elevation (Fig. 3). The Montrose Intake is affected by two large avalanche paths: MS-6 and MS-5 (Fig. 4). Path MS-6 is the largest path in the valley and, based on observations during 2006-2010, reaches the valley bottom at least once to several times per winter. Part of the runout tends to be diverted down Montrose Creek to the intake and overflow weir locations. Field evidence was observed of large avalanches crossing the valley and turning downstream for several hundred metres.

MS-6 comprises a very large (approx. 300 hectares) open bowl with numerous smaller starting zones that converge into a main bedrock-dominated gully. This path is capable of producing Size 5 avalanches that can descend a path length of about 5 km to the valley bottom over a vertical fall height of 1700 m. All avalanches that reach Montrose Creek from this path are Size 3 or larger. Path MS-5 can also affect the intake with Size 3 or 4 avalanches, but a natural berm in the lower part of the path directs most avalanches to the western part of the path, away from the intake.

A 5.8 km long access road was constructed from the powerhouse to the intake, one-third of which is affected by Size 3-4 avalanches mostly from the north side of the valley. Most of the penstock was buried adjacent to the road thus avoiding avalanche hazards, with the final drop down to the powerhouse on the surface and exposed to Size 2 avalanches.

Fig. 3. Looking west down the Montrose Creek Valley towards Filer Creek and Powerhouse. Intake site is off left-hand side of photo.

3.1 <u>Return Period Classification for Avalanches</u>

Size 4 avalanche deposits were observed near the Montrose intake during each of the winters of 2005/06 through 2009/10. These deposits provide a reference point for the potential volume of avalanche snow expected at the intake for calibrating the models used for analysis.

A Size 4 avalanche was triggered June 2, 2009 during explosive avalanche control. The avalanche had a crown depth averaging 2.5-3 m and temporarily blocked flow in Montrose Creek.

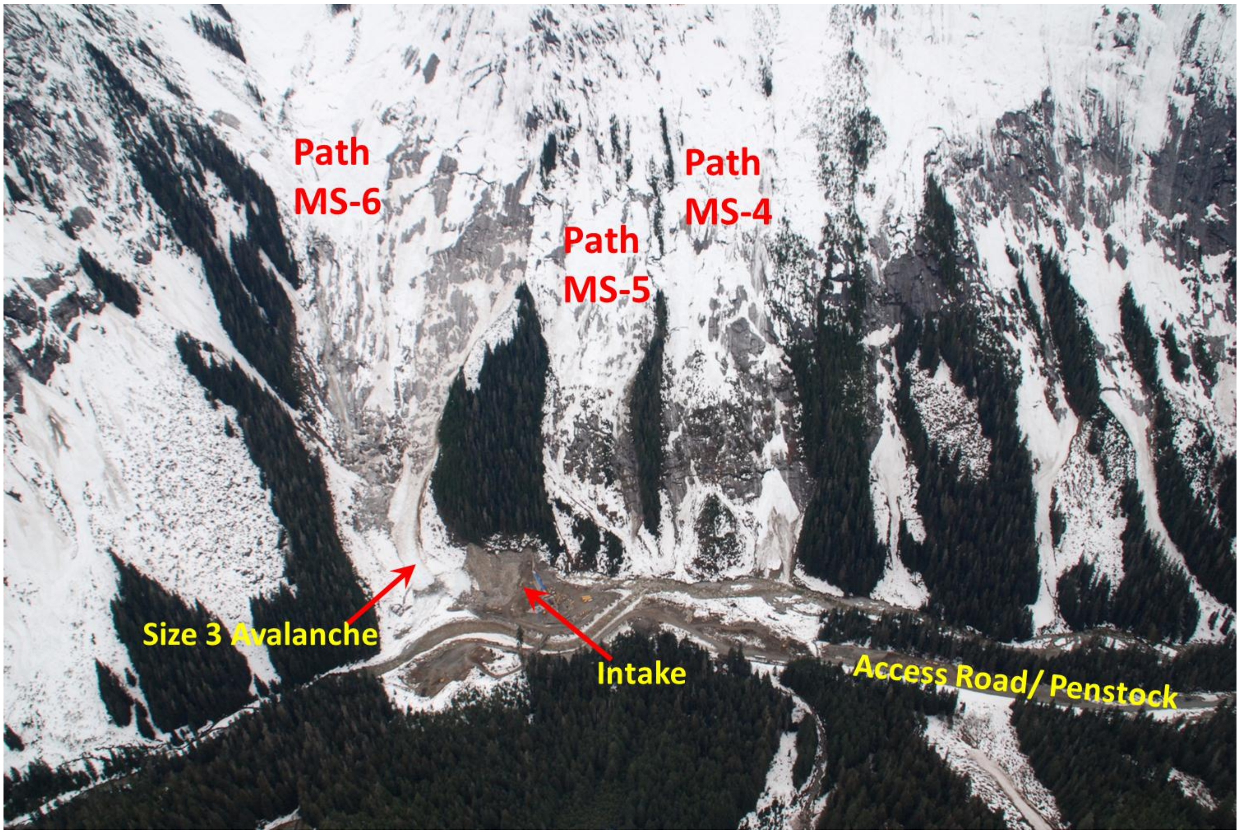

Fig. 4. Montrose Creek intake and access road. Photo taken looking south at lower third of path MS-6 with a Size 3 avalanche deposit for scale.

Table 1 provides a summary of the estimated volume and mass of the deposits based on GIS analysis and field estimates of the lateral extents and deposit thickness.

Of the four observed natural Size 3.5 to 4 avalanches from MS-6, the 2008 event was most destructive (Fig. 5). Even though the 2008 event had a smaller volume estimate than the 2007 and 2009 avalanches, the avalanche had a higher destructive potential due to a break-out flood which followed. The interpreted return period for this event was estimated around 30 years. This is evidenced by the resulting tree damage and scouring of material at the distal edge of the avalanche deposit.

Table 1. *Estimated volume and mass of Montrose avalanche deposits, 2006-2009.*

Year	Estimated Volume (m^3)	Estimated Mass (T)	Size
2006	59,000	29,500	3.5
2007	252,000	126,000	4
2008	189,500	95,000	4
2009	245,000	122,500	4
Average	186,500	93,000	4

Fig. 5. Montrose Intake and Path MS-6, May 2008 avalanche event (Jun. 26, 2008 Photo). Deposit blocked Montrose Creek with a thickness up to 20 m which persisted well through the summer.

3.2. Volume Estimates for Avalanche Deposits from Path MS-6

Fig. 6 provides avalanche deposit volume estimates used for design purposes at the Montrose Intake. Estimates were based on a combination of the observed/estimated volumes (Table 1) and the Rational Method (Canadian

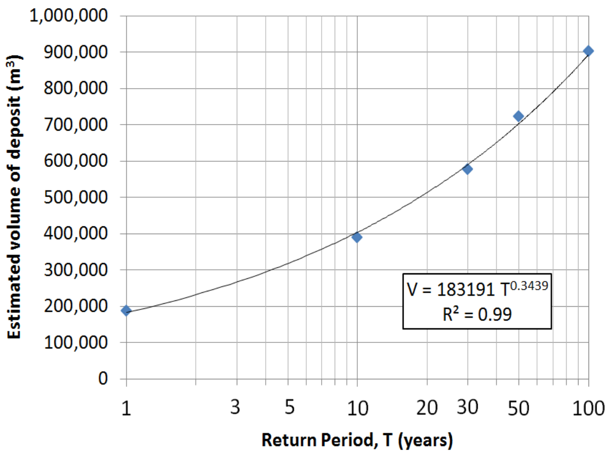

Fig. 6. Estimated volume of avalanche deposits from Path MS-6, Montrose Intake.

Fig. 7. Deflection berm at Montrose Intake. Photo taken looking north down the length of the berm, intake shown at left near the crane.

Avalanche Association, 2008). This method allows one to extrapolate mass and volume from the 100-year event to higher frequency events. Avalanches with a 30-year return period typically have a mass of 60% of the 100-year event, while 10-year avalanches have a mass of 30% of the 100-year avalanche (Schaerer and Fitzharris, 1984).

The resulting 100-year avalanche volume from Path MS-6 is approximately 800,000 m^3, totaling 900,000m^3 when two smaller early season deposits are added to the larger avalanche. A deposit volume of 800,000 m^3 translates to an estimated mass of 400,000 Tonnes, assuming an average density of 500 kg m^{-3}, which is a Size 5 avalanche (McClung and Schaerer, 1980) based on the destructive potential and mass. This method provides reasonable ‘order of magnitude’ estimates that are consistent with large, infrequent avalanches in BC (Schaerer and Fitzharris, 1984).

3.3 Impact Pressures and Design Modifications

Initial impact pressure estimates at the intake were deemed sufficiently high to require modification of the intake design to reduce the impact pressures. The structure was moved both in location (i.e. downstream) and orientation (i.e. reduced angle of incidence) to the main avalanche flow from MS-6. A 15 m high by 120 m long earth fill and rock armoured deflection berm was constructed at the toe of MS-6 (Figs. 7, 8). These revisions greatly reduced the forces at the intake.

The resulting estimated impact pressures at the 25 m wide intake structure were on the order of 20-60 kPa for events with return periods in the range of 30-100 years. These impact pressure estimates were incorporated into the design of the intake structure which was constructed primarily of reinforced concrete. The most vulnerable part of the structure was the metal Coanda Screen which shears off layers of river flow into the intake while allowing remaining water, along with debris, to travel downstream past the intake. The Coanda Screen was designed to be replaced several times during the 40-year design life of the facility, so it has a higher tolerance for destructive avalanche events.

The berm was designed so that avalanches with return periods of 30 years or more could overtop the berm and continue onto the intake structure. The intent was to keep the more frequent (i.e. 1-10 year) avalanche deposits clear of the head-pond while allowing less frequent 30-100 year events to impact the intake which was designed to withstand the potential impact pressures and considered an acceptable risk.

Consideration was also given to the potential for avalanches to wrap around the end of the berm and reach the intake, again with consideration of the 30-year or greater avalanche.

Fig. 8. Nearly completed deflection berm shown at right, Size 3 deposit shown in path at left for scale.

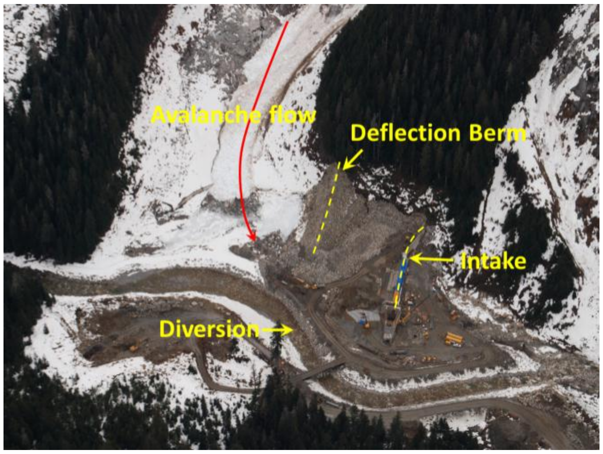

Fig. 9. Aerial view of Montrose Intake.

In addition to the potential impact pressure from flowing avalanches, the intake was designed to withstand the potential weight of avalanche deposits (9-14 m deep for 30-100 year events) and the natural snowpack height which ranged from 2-4 m for 30-100 year return periods. The total additional vertical load from the combined deposit and natural snowpack was up to 92 kPa for the 100 year event, which added a very significant load in addition to the potential impact pressure from flowing avalanches.

4. AVALANCHE SAFETY PROGRAM DURING CONSTRUCTION

An avalanche safety program for construction personnel was implemented during the Spring-early Summer 2009 and during Winter 2009-10. The avalanche program included implementation of avalanche safety protocols and training, avalanche hazard evaluation, and active and passive avalanche control measures.

Commencement of construction at the Montrose Intake was delayed during Spring 2009 until the avalanche hazard could be reduced to a sufficiently low level to permanently open the Montrose Access Road for the summer. A monitoring and control program was conducted during April-June 2009 to reduce the hazard. Extensive avalanche control on the bedrock slab starting zones above the access road allowed the road to be opened for construction in May. However, the intake site which was below the largest path (MS-6) was closed until June 2 due to the presence of deep slabs with a persistent weak layer from December buried 2.5-3 m deep. This layer was difficult to trigger and large charges were required to trigger the large, season ending avalanche in the MS-6 path (Fig. 10). The effective multi-bag method included detonation of a 25 kg crater with an initial charge, then slinging in a bag with up to 16 x 25 kg unprimed ANFO bags (Fig. 11), and finally detonation of a final primed 25 kg charge on top of the sling load.


Fig. 10. The season ending slab avalanche on June 2, 2009 which opened the Montrose Intake site for construction. Slab is 2.5-3 m thick.


Fig. 11. 16 unprimed 25 kg ANFO bags ready for sling loading into the bomb crater.

The construction program on the access road, powerhouse and Montrose intake continued at a rapid pace throughout summer/fall 2009. The construction program was temporarily shut down with the first of a series of heavy snow and rain events in mid-November 2009. The construction contractor decided to continue with their program as long as safely possible into the winter, which initiated the 2009-10 avalanche safety program.

From late November to the beginning of May a rotating team of two full-time avalanche technicians worked at the site. Additional technicians were brought into camp from Campbell River when needed for short-term, high intensity periods. The technicians were responsible for monitoring numerous concurrent construction sites, including: Montrose Creek powerhouse, intake, penstock (Fig. 12) and access road; East Toba River access road and intake sites; as well as various work sites located along the 156 km long transmission line corridor.

There were up to several hundred personnel at the Toba Camp, all of which were

Fig. 12. Installing penstock along the Montrose Intake access road. Note welder on pipe in centre of photo (red circle), directly in an avalanche path.

required to take a 1-day avalanche safety and rescue training course. Over 300 personnel were trained in the first few weeks of the safety program in addition to the regular avalanche monitoring and control duties for the avalanche technicians. At any given time there were up to approximately 60 construction workers in avalanche terrain using the available supply of avalanche beacons.

Avalanche rescue caches were established at numerous sites, including the Montrose and East Toba Intakes, camp and the remote Powell Lake camp powerline worksite.

Avalanche control was conducted by helicopter bombing on 12 days during November to May. The control work produced a variety of avalanche sizes and types, ranging from small Size 1, loose snow to Size 3 slab avalanches.

Glide slabs required monitoring and control on the bedrock slabs above the Montrose Access Road and on the slabs located directly above the Montrose Intake worksite (Fig. 13). Long sections of cornice were also removed, primarily in the MS-6 path directly above the Montrose Intake worksite.

The 2009-10 El Nino winter resulted in

Fig. 13. Glide slabs located directly upslope of Montrose Intake worksite in Path MS-5.

unseasonably warm and dry conditions that persisted from January to March. This allowed the construction program to continue right through the winter with only short-term delays during storm periods. The avalanche technicians remained at camp until May, after which a remote monitoring and control program was run by technicians based in Campbell River. The end of the 2009-10 avalanche season was called in mid-June.

5. DISCUSSION AND CONCLUSION

5.1 Hydroelectric development in avalanche terrain in British Columbia

The East Toba River and Montrose Creek Hydroelectric project is typical of a recent trend in British Columbia to develop run-of-river projects in very steep, mountainous regions with high precipitation. This often translates into projects with a significant avalanche hazard to the intakes access roads and other project components.

The construction season in these areas is often short, which leads to the pushing of the construction schedule as far into the winter season as possible, if not right through the winter as occurred on this project. Although this project is on a much larger scale than most other run-of-river projects, the authors have completed planning work on two other recent projects with similarly large and complicated avalanche terrain: Glacier Howser project in the BC Purcell Range and the Bute Inlet project in the South Coast Range. These projects will present similar, if not greater avalanche mitigation challenges than the Toba-Montrose project if they are developed.

The Toba-Montrose project was bid by the construction contractor on a design-build basis in which there was a strong financial incentive for the builder to complete construction ahead of schedule. This contributed to the desire to continue construction as far as possible into the winter with due consideration of worker safety. This was feasible during 2009-10, but would likely not have been possible at this worksite in a more active avalanche winter. As it were, the project was completed ahead of schedule despite the significant winter and avalanche challenges.

5.2 Typical mass characteristics for large avalanches

The advent of high resolution LIDAR mapping of the ground surface and GIS software offer a relatively easy and accurate method of estimating volume from field observations of avalanche deposits. The volume and mass estimates from the Montrose intake underline a discussion about avalanche size which has been building in Canada in recent years. The primary characteristic for classification of avalanches in Canada is the destructive potential (Canadian Avalanche Association, 2007). Groups of experienced practitioners will generally agree on these sizes (size range 1-5) and sometimes use half sizes to further classify the in-between events.

The destructive potential system was introduced into Canada by Ron Perla and adopted by the Canadian Avalanche Committee in 1977 (McClung and Schaerer, 1980). McClung and Schaerer (1980) described the basic idea as the destructive potential of the avalanche in roughly the middle of the path. Further, they analyzed the Rogers Pass avalanche occurrence data from 1978 and 1979 to identify additional parameters of typical mass, path length and impact pressure.

Today engineers relying on these typical mass parameters to classify size may disagree with field practitioners who are using the traditional method of destructive potential. If the Montrose avalanches of 2007 – 2009 were sized solely on typical mass, three of these (95,000-126,000 Tonnes) would have been Size 5 events as opposed to the Size 4 classification given by the avalanche technicians at the site. The characteristics of damage in the runout zone clearly showed these observed events were not near the maximum potential for the site, which would be a Size 5 and have an expected mass on the order of 400,000 Tonnes.

In the Rogers Pass database from 1966 to 1980 only one Size 5 event was recorded in a 6534 event sample (McClung and Schaerer, 1980). Given the number of avalanches and the terrain characteristics of the avalanche paths in Rogers Pass, this invites a reconsideration of the typical mass characteristics for larger avalanches. Interestingly, Perla (1980) in his description of the destructive scale used order of magnitude estimates of volume for the larger sizes, which if translated into mass would be at least one order of magnitude higher than the typical mass/size for large events described today.

Observations of large avalanches in the MS-6 path are consistent with recent work (e.g. McClung, 2009; Sovilla et al., 2006) that suggest for large Size 4 to 5 avalanches, consideration of entrainment may result in a total mass approaching 10 times the initial slab mass. The 2006-2010 field observations at the Montrose Intake show that annual Size 4 avalanche deposits have a mass on the order of 100,000 Tonnes. The potential for a Size 5 avalanche in this path clearly exists, but the potential mass may be expected to be a half to full order of magnitude greater than what has been observed to date.

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