DESIGN AND CONSTRUCTION OF AN AVALANCHE DEFLECTING BERM, MOUNT KITCHENER AVALANCHE PATH, AORAKI MOUNT COOK NATIONAL PARK, NEW ZEALAND

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ABSTRACT: The Mount Kitchener avalanche path produces large avalanches that have potential to affect parts of Aoraki Mount Cook Village, New Zealand. Numerous buildings located in the runout zone could be affected by avalanches, including the iconic Hermitage Hotel and several residences. Although there is no historical evidence of destructive avalanches reaching the village, statistical and dynamic avalanche modelling combined with field evidence confirmed the potential for Destructive Size 4 or 5 avalanches to reach the village with a return period between 100 and 300 years. The potential runout position of the dense component of 100 to 300-year avalanches was determined to be within the limits of the village. Powder avalanches could penetrate further into the village, as has been evidenced by historical events. Potential impact pressures within the village were estimated in the range of 1 to 70 kPa. The existing 2 m high deflection berm constructed on the debris fan has been overtopped on numerous occasions and was determined to be ineffective in reducing risk to acceptable levels. Construction of an improved berm was proposed to reduce the potential magnitude and frequency of avalanches reaching the village, and thus reduce risk to people and infrastructure. Construction of the berm was completed in two phases, with initial construction during 2015-2016, and a final phase of construction completed in April 2018. The completed earth fill berm is 305 m long, with a height varying from 3.5 to 10 m. The historical context and importance of this avalanche path is discussed, including description of the evaluation and design process for the deflection berm, and a summary of the challenge of constructing this berm within a heavily visited and environmentally sensitive national park.

KEYWORDS: Avalanche risk, hazard mapping, runout, dynamic model

1. INTRODUCTION

The Mount Kitchener avalanche path is located adjacent to the Aoraki Mount Cook Village, on the South Island of New Zealand (Figure 1). This path produces large avalanches (i.e. Size D4 or 5) that have the potential to affect parts of the village, including several residences and the iconic Hermitage Hotel, which has been at this location since 1958. Avalanches with over two hectares (ha) of debris have reached the fan during 1995, 2004 and 2009, and light powder flow has historically reached the village (Fitzharris, 1986; DOC, 2009).

Fitzharris (1986) identified the Kitchener avalanche path as a potential risk to the village. Geotechnical investigations completed in 1995 (McSaveney et al., 1995) and 1996 (McCahon, 1996) also identified the potential for avalanches to affect the village, in addition to potential debris flow risk.

A 2 m high diversion berm constructed on the debris fan in 1958 has been overtopped on numerous occasions and was determined to be ineffective in reducing risk to acceptable levels given the presence of important infrastructure and permanent populations in the village.

A variety of mitigation options were evaluated to reduce risk to structures and the public in the village, including increasing the height and potential re-alignment of the diversion berm; monitoring, evaluation and avalanche control; and structural reinforcement and/or structural protection of buildings (e.g. stopping walls, splitters, multi-purpose stopping/diversion berm). Ultimately, construction of an improved berm with a new alignment and increased height was chosen, which is discussed in the following sections.

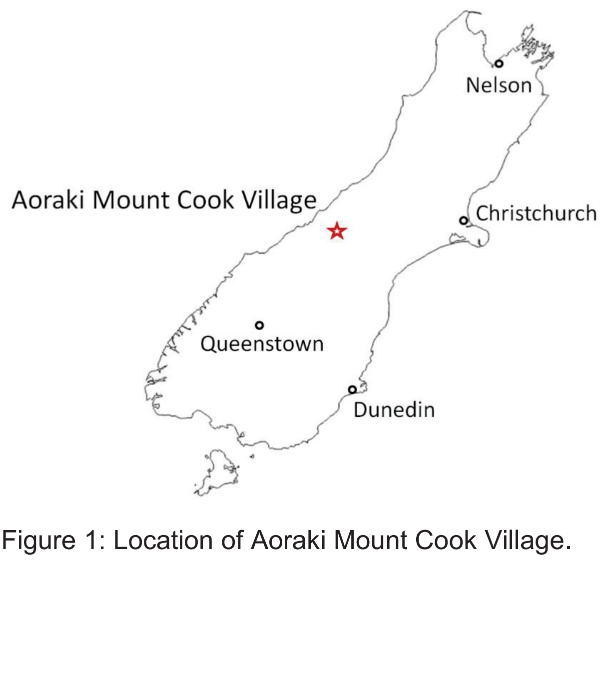

Figure 1: Location of Aoraki Mount Cook Village.

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2. HAZARD MAPPING AND EVALUATION

2.1 Avalanche terrain

The Mt. Kitchener avalanche path is a large, east-facing path with a vertical fall height of 1,340 m. The start zone is a large alpine bowl feature with an area of approximately 6 ha and average slope angle of 29°. The track is a confined gully which is approximately 700 m long and has an average slope angle of 30°. The runout zone is a large 40 ha fan with several stream courses. The south side of the runout is heavily vegetated with older Totara forest (Figure 2).

Due to presence of a diversion berm which was originally constructed in 1958, the predominant flow direction of avalanches and debris flows is towards the north of the runout, which is therefore less vegetated and covered in course debris. The main creek drainage flows along the north extent of the runout zone.

Aoraki Mount Cook Village is in the extreme runout position on the far south side of the runout zone. The average slope angle of the runout zone at the uppermost edge of the village is 7 degrees, but slope angles in the runout zone vary between 0° (upper road bench) and approximately 12°.

The largest observed avalanche from the Mt. Kitchener path occurred in 1986. Fitzharris (1986) described the event as "*a typical mixed-motion event that included a dense layer of flowing snow near the ground, and a large airborne powder cloud that subsequently drifted over the Mt Cook Village*". This event was the largest to have occurred since 1968.

Local experts estimated that this path is capable of producing a Size D5 avalanche (DOC, 2009), which although it hasn't been observed to date is certainly possible given the large scale of the path and deep winter snowpack in the extensive starting zone.

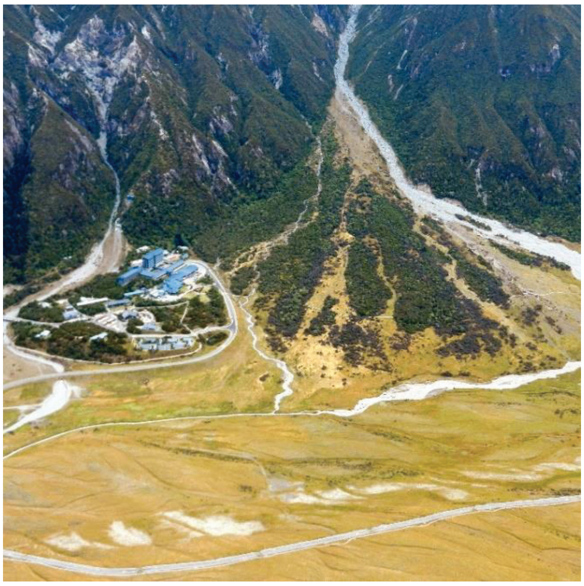

Figure 2: Debris fan on the Mount Kitchener avalanche path, with Aoraki Mount Cook Village on left.

2.2 Historical avalanche frequency analysis

Fitzharris (1986) provided an overview of historical avalanche activity in the Kitchener avalanche path (Figure 3 and Table 1). Additional observation of large avalanches in 2004 and 2009 built up the dataset so that there were 9 documented Size 3-4 avalanche events in this path during 1965 to 2009 (45 years), or an average return period of 5 years for avalanches reaching below the upper fan (i.e. 960 m elevation). From this data, it was possible to conclude that the 1986 event had a nominal return period of 50 years. By plotting these runout estimates on a semi-log graph of horizontal runout distance (i.e. total horizontal distance measured from the top of the starting zone) versus Return Period, a good relationship was developed that could be used to project runout to 100 years, and possibly longer (Figure 4).

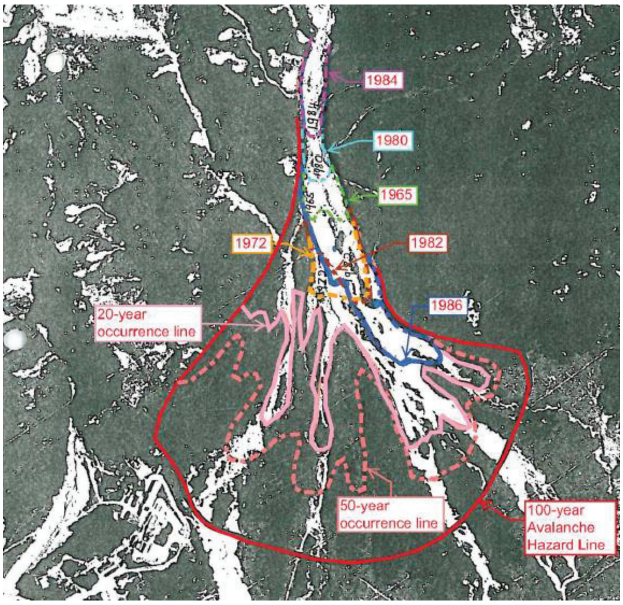

Figure 3: Reproduction of Figure 6 from Fitzharris (1986) with highlighted historical avalanche outlines and avalanche hazard lines (50 and 100-year lines).

Table 1: Estimated return period of historical avalanches in Kitchener Path, 1965-2009

Year	Elevation of toe of deposit (m)	Horizontal Runout Distance (m)	Approx. Return Period (years)	Nominal Return Period (years)
1984	960	1727	5	~
1980	930	1823	6	~
1965	910	1909	6	5
1972	880	2037	8	~
1982	870	2058	9	~
1995	850	2122	11	10
2009	840	2154	15	15
2004	810	2258	23	30
1986	785	2339	45	50

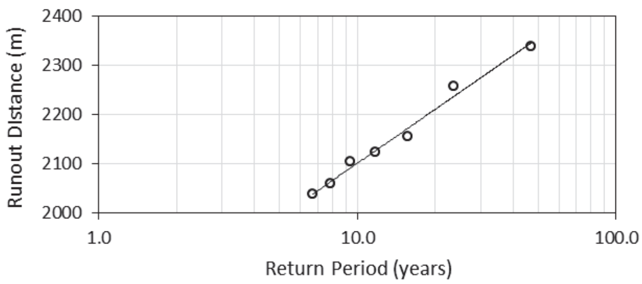

Figure 4: Runout distance of historical avalanches in the Kitchener avalanche path during 1965-2009, with a logarithmic fit of runout distance as a function of return period ($R^2 = 0.99$).

The 1986 avalanche was the longest running historical event in this path, but it did not reach the 10° β-Point. This is typical in avalanche terrain where the runout zones are normally free of snow or have a shallow snowpack and rough terrain. Bare ground causes avalanches to start slowing down on steeper slopes (e.g. 15-20°) rather than continue on inclines less than 10°.

It was observed that annual events reach the bottom of the gully, which is coincident with the typical winter snowline for this path; avalanches with 10 to 50-year return periods stop above the β-point and are not expected to affect the village. The 100-year avalanche is expected to stop just above the loop road (road is visible around the village in Figure 2), which was consistent with the Fitzharris (1986) 100-year hazard line (Figure 3). 300-year events were interpreted to be capable of reaching Aoraki Mt Cook Village, potentially affecting permanently occupied structures.

2.3 <u>Avalanche hazard evaluation</u>

Although there is no historical evidence of destructive avalanches reaching the village, statistical and dynamic avalanche modelling combined with field evidence confirmed the potential for Destructive Size 4 or 5 avalanches to reach the village with a return period between 100 and 300 years, which indicated the village was within the Blue hazard zone. The potential runout position of the dense component of 100 to 300-year avalanches was determined to be within the limits of the village. Powder avalanches could penetrate further into the village, as has been evidenced by historical events (e.g. Fitzharris, 1986). Potential impact pressures within the village were estimated in the range of 1 to 70 kPa, depending on the location within the village.

The existing 2 m high deflection berm constructed on the debris fan has been overtopped on numerous occasions and was determined to be ineffective in reducing risk to acceptable levels. Construction of an improved berm was proposed to reduce the potential magnitude and frequency of avalanches reaching the village, and thus reduce risk to people and infrastructure.

3. DESIGN OF THE DIVERSION BERM

Investigations and historical observations of avalanches in the path led to the conclusion that the existing 2 m high berm was only effective for relatively small avalanches and could be easily overtopped by larger (Size D3 or D4) avalanches. This is illustrated by events in 1995 (Figure 5) and 2009 (Figure 6).

Figure 5: Avalanche debris onto the Kitchener fan in 1995. Debris covered approximately 2.7 ha with 70,000-90,000 m^3 of debris, some of which overtopped the original diversion berm.

Figure 6: Avalanche in the Kitchener path, 24 July, 2009. Dashed blue line delineates approximate toe of deposit which overtopped the diversion berm (DOC photo).

Another deficiency with the existing berm was that it did not start high enough on the slope to prevent overtopping at the top of the berm. It was also not aligned sufficiently oblique to the main flow direction to deflect avalanches without excessive overtopping. Due to these factors, construction of a new berm (location and geometry) was recommended, rather than improvement of the existing berm.

The improved berm was designed to mitigate the 100-year design dense-flowing avalanche, which would reduce risk to the village to acceptable limits.

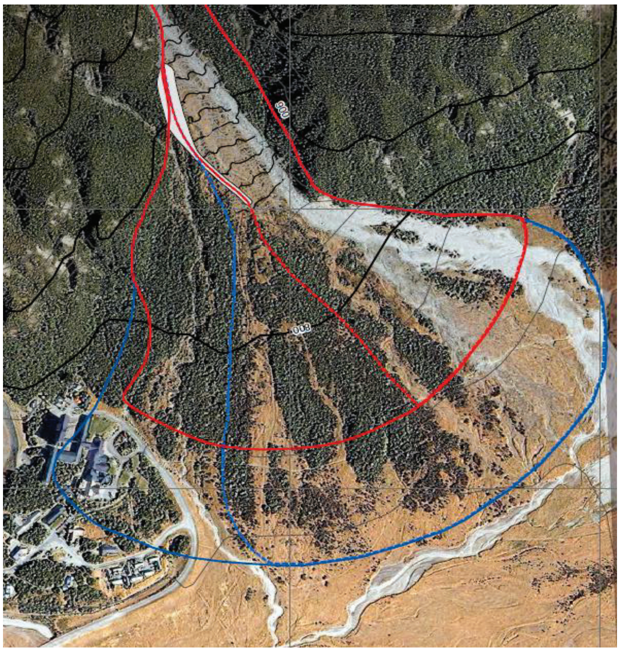

Figure 7: Avalanche hazard zones (Red and Blue) for the Kitchener path with (inside lines) and without (outer red and blue lines) the improved diversion berm. The berm (outlined in white in the upper fan) moves the Blue line outside of the village area.

The berm was designed to accommodate an avalanche with a velocity of 35 m/s at the upper intersection with the berm, with a flow height of 2.5 m. The angle of incidence was 19 degrees based on the assumption that an avalanche banks from the north side of the gully before it impacts the berm. A relatively thin snowpack of 1 m was estimated to be present, which reflects long-term snowpack height data. Because re-contouring of the slope was planned adjacent to the berm, it was assumed that no previous deposit would be present behind the berm. Additional snow storage capacity was created in front of the berm to allow avalanches to spread laterally within the catchment area of the berm.

The design berm had a height of 10 m at the upper end, tapering down to 3.5 m at the lower end where it acts as a guiding berm rather than a diversion. The berm was designed with a 1.5 horizontal to 1.0 vertical (1.5H:1V) fill slope on both sides, with a 3 m crest.

Avalanche hazard zone mapping determined that the Blue Zone extends approximately 150 m from the upper loop road into the Village. This represents potential avalanche risk from low frequency powder avalanche impact pressures that exceed 1 kPa and with a return period of less than 300 years. Dense flowing avalanches were not expected to flow past the upper loop road, but rather stop on the slope upslope of the northwest edge of the road. The Red/Blue hazard line was interpreted to be located approximately 30 m upslope of the upper loop road.

With the diversion berm, the Red/Blue hazard line (which includes more frequent, dense flow avalanches) will follow the crest of the diversion berm (Figure 7). The berm will direct most avalanches down the main stream channel and away from the village. Once avalanches reach the lower end of the berm they can turn towards the village, but the terrain will direct flow down the topographic fall line. The Blue hazard line was revised to show the diversion berm directing most flow down the fall line into the main stream channel, but with some dense and powder flow expected to overtop the lower part of the berm where it drops to a height of 3.5 m. However, by that point flow will be directed downstream and not be able to turn back towards the village. The revised hazard zoning resulted in a reduction in risk such that avalanches would not affect the upper loop road or the village, thus achieving the project goal.

4. CONSTRUCTION

Construction of the improved diversion berm was completed in two phases, first during 2015-2016, and a second phase completed in April 2018.

The first phase was intended to include the full completion of the berm. When the post construction survey was undertaken in 2016, it was discovered that the berm was one metre lower than its design height and that the total volume of material moved was less than the construction company had claimed had been moved. As the contract was based on cubic metres of material moved, this affected the cost of the project. The effectiveness of the shorter berm was evaluated to determine if it would provide sufficient protection. After re-analysis of a design avalanche, the decision was made that the berm needed to be brought up to design height to provide the required amount of protection to the village. After nearly two years of protracted negotiations, a re-measure by the contractor, and the invoking of the arbitration clause in the contract, the contractor returned and completed the berm to the original design height in 2018.

As the Kitchener path is within Aoraki Mount Cook National Park, it was necessary to complete an assessment of environmental impacts prior to gaining approval for the work. As the site of the proposed works was in the village amenities area, the park management plan permitted the construction of protective structures.

Being a heavily disturbed avalanche path also subject to debris flows, there were no threatened plant species or mature forest growing on the footprint of the berm. The area has a population of native skinks and geckos that were relocated to another suitable habitat. From a visual perspective a curved rock wall was not out of place with the natural and artificial features in the vicinity of the works. There were already several protective berms in the village providing protection from debris flows and the finished berm was not to unlike a natural moraine wall. On the advice of the landscape architect for the project, the length of the berm was shortened slightly and the side of the berm facing the village was left rough by scattering moderate sized boulders on its surface.

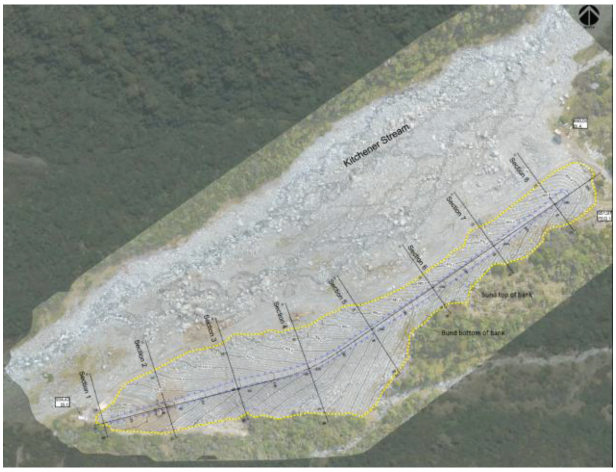

Figure 8: As-built diversion berm in plan view.

The final cost of the project was NZ $700,000 (€430,000). An as-built survey was completed, which showed the final constructed fill to be 46,369 m^3, with construction as per the original design concept (Figure 8). Figures 9 through 11 show three views of the completed structure.

Figure 9: Completed diversion berm looking downslope.

Figure 10: Completed diversion berm.

Figure 11: Completed diversion berm viewed from Aoraki Mt. Cook Village.

5. CONCLUSION

The Mount Kitchener avalanche path produces large avalanches that have potential to affect parts of Aoraki Mount Cook Village, New Zealand. Numerous buildings located in the runout zone could be affected by avalanches, including the iconic Hermitage Hotel and several residences. Statistical and dynamic avalanche modelling combined with field evidence confirmed the potential for Destructive Size 4 or 5 avalanches to reach the village with a return period of 100 and 300 years.

The 2 m high deflection berm constructed on the debris fan had been overtopped on numerous occasions and was determined to be ineffective in reducing risk to acceptable levels.

An improved berm was constructed during 2015-16, with a second final phase of construction completed in April 2018. The completed berm is 305 m long, with a height varying from 10 m at the upper end to 3.5 m in the lower end where it serves as a guiding berm.

This berm will reduce the potential magnitude and frequency of avalanches reaching the village, and thus reduce risk to people and infrastructure.

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