SNOW AVALANCHE PENETRATION INTO MATURE FOREST IN TIMBER HARVESTED TERRAIN

G. Anderson* and D. McClung
University of British Columbia

ABSTRACT: Clear cut logging in British Columbia, Canada is creating new avalanche start zones that can produce snow avalanches sufficient in size to penetrate and destroy mature forest cover. The presence of these logging cut blocks can augment the destructive potential of previously existing avalanche paths as well as create new avalanche start zones. These forest penetrating avalanches pose a risk to down-slope structures and resources. This study develops and utilises the first database (known of) containing information on avalanche forest penetration distances and lateral spread through forest cover. The study area for this research spans the Southern Coast and Columbia Mountains of British Columbia, Canada. Analysis focuses on terrain characteristics related to forest penetration and the resultant destruction of mature standing forest. Physical terrain and vegetation characteristics in the avalanche starting zone, track, and runout zones from 45 forest penetrating avalanches are described, measured, and parameterised. The results provide base tools to assess and evaluate potential avalanche terrain and to develop runout models for avalanches in forested terrain.

Keywords: snow avalanche, timber harvest, forest damage, clear-cut

1. INTRODUCTION

A rapidly expanding population is driving development deeper into the backcountry of British Columbia, Canada every year. This expansion means isolated areas in close proximity to logging cut blocks are being settled and developed.

Clear-cuts in high alpine areas of B.C. have sufficient snow supply and slope gradient to lead to the creation of new avalanche terrain (Stitzinger, 2001). This new avalanche terrain can lead to longitudinal and lateral expansion of existing paths as well as creating entirely new avalanche paths (Stitzinger *et al.*, 2001). This study is a continuation of research initiated by the Avalanche Research Group at the University of British Columbia in 1996. The ultimate goal is to gain a thorough understanding of the processes characterising the behaviour of snow avalanches caused by clear-cut logging and their destructive potential.

This is the first study to collect and analyse characteristics of avalanche paths that have penetrated mature forest cover (Weir, 2002). Avalanches occurring in timber harvested terrain have been classified by the UBC Avalanche Research group into three types:

Type I avalanches initiate within a logging cut block and terminate within or below the cut block.

Type II avalanches initiate above cut blocks and terminate within or below the cut block.

Type III avalanches are any of Type I or Type II that have penetrated and destroyed mature forest cover.

This study is focused on Type III avalanches and presents results of analysis on lateral spread, forest penetration distances, and runout distances. The basis for runout prediction tools are developed with the objective of assessing the potential for new avalanche paths to run through forest into down-slope resources.

2. STUDY AREA

The study area spans the Coast and Columbia Mountains of Southern British Columbia, Canada. Individual study sites are characterised by avalanches that have penetrated into and damaged mature forest cover. Figure 1 is a map of the 45 avalanche path locations used for the analysis.

* *Corresponding author address:* Geoff Anderson, UBC Avalanche Research Group, Vancouver, British Columbia; email: anderson@geog.ubc.ca

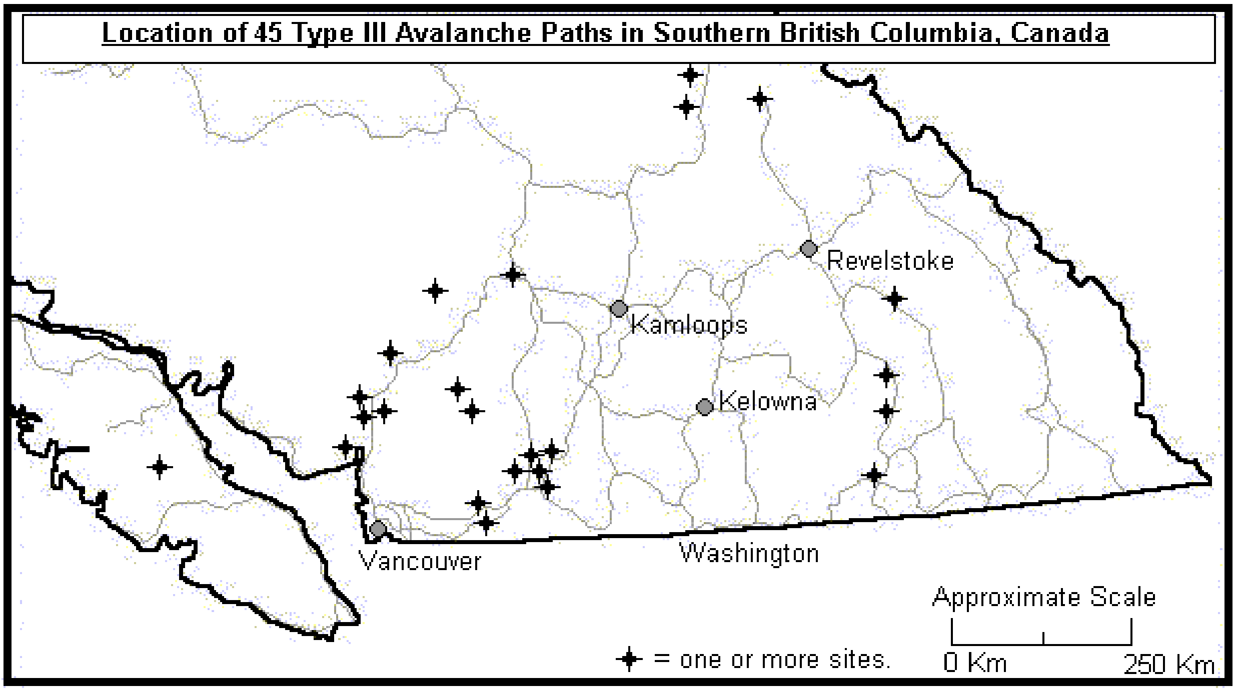

Figure 1. Southern British Columbia showing 45 Type III avalanche path locations.

3. METHODOLOGY

3.1 Site Selection and Data Collection

Avalanche path locations were initially identified by reports and word of mouth. Avalanche paths were also identified by extensive 1:15000 scale airphoto searches. Confirmation of the location of paths and measurement of the necessary variables was completed during field visits. Where possible, measurement of the variables was done on site. For cases where site visits had been conducted for previous studies, site photos, airphotos, field notes, Terrain Resource Information Maps, Forest Cover Survey Sheets and a GIS were used to calculate variables not collected during the initial visit.

Data collection methods followed and expanded upon those in McClung (2001) and focused on physical terrain variables. The Type I and Type II analysis was conducted using 40 physical terrain shape and vegetation variables. Here, we focus on Type III data for which a number of additional variables were measured or calculated as discussed in section 3.2.

The premise of the study is that mature forest cover may retard avalanche runout distances. Very young, weak forest is not included since its influence on the snowpack is minimal. For the purpose of this study forest cover is defined as living forest that is at least 5 m in height. This definition is important as re-growth in existing paths is destroyed every year by avalanches but is not substantial enough to be considered mature forest. The 5 m cut-off ensures that there was sufficient trunk length protruding above the snow surface in winter to interact with avalanche activity. At approximately 5 m there also seems to be a change in how trees react to the impact forces of avalanches. Data collected for this research show trees smaller than 5 m tended to bend when struck by avalanches and trees taller than 5 m tended to be broken or overturned when hit by an avalanche.

3.2 Type III Variables

Over 60 variables were collected, calculated, and measured for the Type III analysis. In addition to the 40 described in McClung (2001), Type III specific variables were collected as follows:

Distance to Forest Penetration: The horizontal and slope distance to forest penetration was measured on site with a laser range finder or in a GIS. The upper boundary is marked by the crown of the start zone; the lower boundary is the point of forest entry. The error in the GIS is estimated to be +/- 20 m. On site error is significantly less and is estimated at +/- 5 m.

Distance Below Forest Penetration: Horizontal and slope distance below the point of forest penetration were measured on site or in a GIS. This is the distance from the point of forest entry to the tip of the runout zone. Error is estimated at +/- 20 m.

Vertical Fall to Forest Penetration Point and Vertical Fall of Forest Penetration: The vertical fall was measured in metres from the top of the start zone to the point of forest penetration and from the point of forest penetration to the tip of the runout zone. Values were initially obtained with a hand held GPS unit, and then confirmed on 1:20000 scale topographic maps. The values were calculated in metres and the estimated error is +/- 10 vertical metres.

Slope Angle at Forest Penetration: The slope angle at the forest penetration point was measured with a clinometer. Angles were measured in degrees and measurements are accurate to 1°.

Alpha and Beta Angles: Alpha and Beta angles were measured with a clinometer accurate to 1°. The Beta point is defined as the point on the slope's surface that first becomes 10°, starting at the ridge-top. Beta angles were taken as the angle between horizontal at the Beta point and the top of the start zone. The Alpha angle is the angle from the bottom of the runout zone to the top of the start zone.

Crown Closure Class (CCC): CCC is the best proxy for forest stand density for these data. CCC is an 11 category classification found on Forest Cover Survey Sheets (FCS) which describes the percentage of ground covered by vegetation. It is estimated from above, normal to the surface.

Age of Damaged Forest Area: The age of forest destroyed at each site was taken from FCS sheets in order to assess the loss sustained from forest destroying avalanches. Age class is a 9 part categorical classification that classifies forest stands according to the age of the stand. The classification places forest stands in groups of 20 years.

Damage Area: the area of destroyed forest was measured in hectares with measurements taken by laser range finder or by drawing polygons in a GIS. The error is estimated at 10% of the area calculation.

Maximum Damage Width: The maximum width of damage at each site was documented. This variable was measured by laser range finder and in a GIS.

3.3 Analysis

Distributions of the various parameters were plotted to evaluate the physical terrain differences between characteristics of Type III avalanche paths and Type I and II avalanche paths. Descriptive statistics of the physical terrain characteristics in the start zone, track and runout zone were produced for all the variables collected. Tests of significance were applied to variables that could potentially be used to distinguish between terrain that leads to forest penetration and terrain that does not lead to forest penetration.

For the Beta point runout ratio analysis (section 4.2) a ratio of the distance to runout zone tip from the Beta point over the distance from the beta point to the top of the start zone was calculated. The Beta point itself is assigned a value of zero so that distances measured down-slope from the Beta point are positive values and distances measured up-slope from the Beta point are negative values. A resulting negative ratio indicates a runout termination point above the Beta point, and a positive value indicates the avalanche ran to a point below the Beta point.

4. SELECTED RESULTS

Since the forest penetration occurs in the track and runout zones, the focus of the study centred on these segments of the avalanche path. No single variable could be correlated with the extent of damage, lateral spread or distance of penetration. Analysis is ongoing to develop more complicated predictive runout models and, so, the results presented here are largely descriptive.

4.1 Lateral Spread

Lateral spread is the horizontal spread of an avalanche as it slows in the runout zone. It was calculated by subtracting the average width of the runout zone from the average width of the track for each path. Extensive testing was conducted on horizontal slope shape (HSS) as an indicator of potential lateral spread. The horizontal slope shape is a five part categorical system ranging from –2 to +2 reflecting the degree of confinement in the avalanche path. Negative values represent horizontally convex terrain and positive values represent concave (gullied) terrain (a full description of the horizontal slope shape parameter can be found in McClung, 2001).

No significant relationship could be found between any one variable and lateral spread. The main reason for the lack of a relationship is that the slope shape distribution in the runout zone is skewed to the right (concave) with only 2 cases having negative values (convex) (Figure 2). This means that even if the track were extremely gullied, there would be little opportunity for the avalanche to spread in the runout zone because it would remain confined.

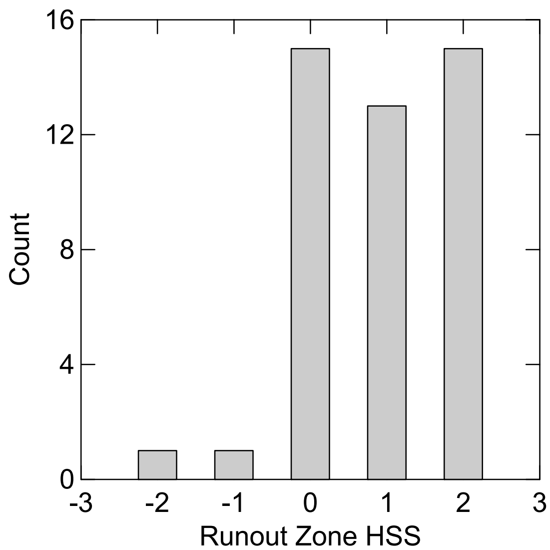

Figure 2. Bar chart distribution of runout zone horizontal slope shapes.

Figure 2 demonstrates a clear propensity for gullied terrain in the runout zone to produce forest penetrating avalanches. The distribution is significantly different from the Type I dataset. The largest spread measurement was 55 m wider in the runout zone than in the track. This is a lateral expansion of 27.5 m on either side of the avalanche as it slowed in the runout zone. Figure 3 presents a quantile plot of the range of spread values. Negative values indicate a narrowing (in metres) and positive values indicate a lateral expansion of the path in the runout zone.

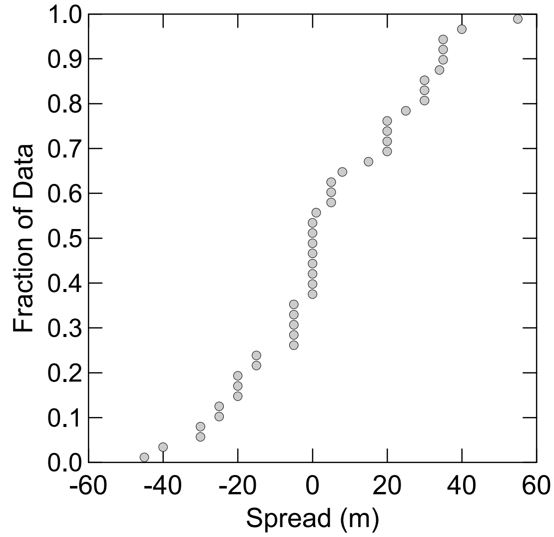

Figure 3. Quantile plot of lateral spread values (m) for forest penetrating avalanches.

4.2 Runout Distance

Slope Shape

The physical terrain variable most positively correlated with damage areas and distance of penetration is the horizontal slope shape. The HSS difference between start zone and track may be the best predictor of penetration distance potential. A slope shape transition index is being developed to enable prediction of penetration distance according to the difference in horizontal slope shape between the start zone and track with a scaling parameter such as vertical fall.

The Type III data shows significantly greater horizontal slope shape categories than Type I and Type II. This confirms that confined paths (positive values) have a greater tendency to penetrate forest than those in horizontally flat or convex terrain. Horizontal slope shapes in the track and runout zone are skewed strongly toward the positive.

Figure 4 is a bar chart distribution of the track and runout zone average horizontal slope shape. The figure shows only 3 cases where forest damage occurred on horizontally convex terrain. All other cases were flat (0) to highly gullied (2) in the track and runout zones.

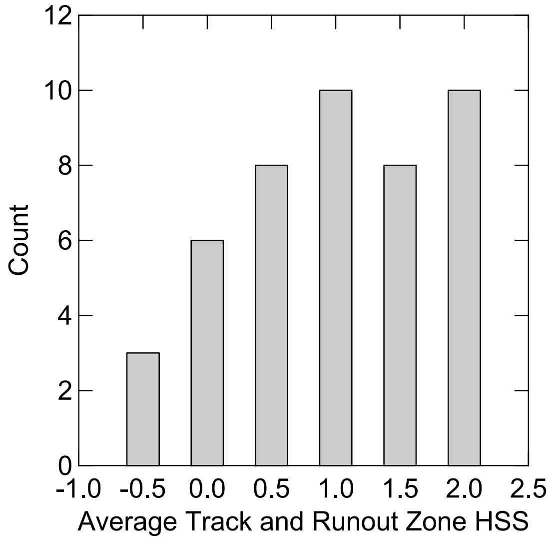

Figure 4. Bar chart distribution of average track and runout zone horizontal slope shape.

Alpha Angles

One Alpha angle measured was 21°; all others were greater than 25°. In B.C., the Ministry of Transportation uses 25° as the lower limit to assess whether or not an avalanche could reach a highway with significant risk to traffic. Figure 5 is a quantile plot of the distribution of Alpha angles, which validates the Ministry of Transportation's 25° benchmark. The highest Alpha angle measured was 36° with a mean of 30°.

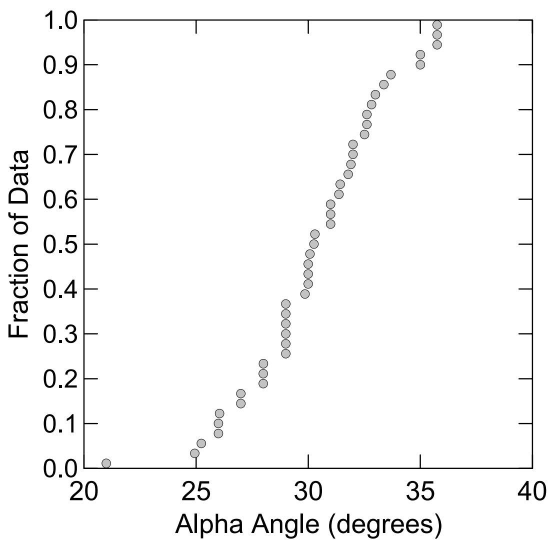

Figure 5. Quantile plot of Alpha angles measured at 45 forest penetrating avalanches.

Beta Point Analysis

Only one of 45 forest penetrating avalanches stopped down-slope of the Beta point. The remaining 44 stopped up-slope or just at the Beta point. Figure 6 is a quantile plot of the Beta point angle distribution. The minimum value measured was 20°, the maximum was 35°, and the mean was 29°.

The one case that terminated down-slope of the Beta point did not encounter forest cover until below the Beta point. Every other avalanche ran into forest cover up-slope of the Beta point indicating that forest cover could be acting as a retardant to the runout distance.

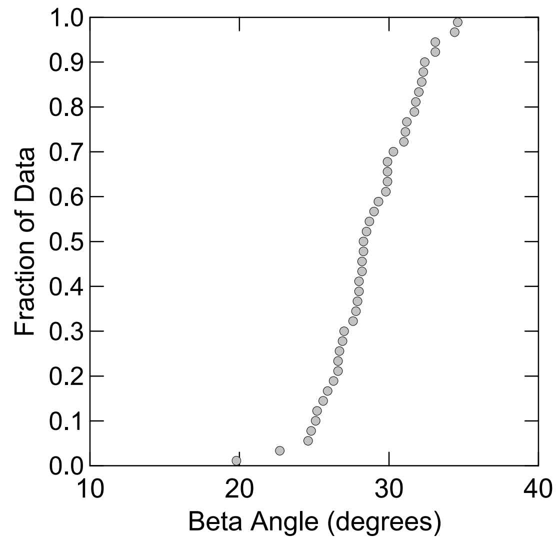

Figure 6. Quantile plot of Beta angles measured at 45 forest penetrating avalanches.

Runout Ratios

Horizontal distance ratios to the Beta point were calculated for each path. These ratios are the ratio of horizontal distance of the runout zone tip to the Beta point divided by the horizontal distance from the avalanche crown to the Beta point. Since only one path ran beyond the Beta point, forest cover seems to be a retardant to runout distances. The average runout zone angle for forest penetrating avalanches was 22°, significantly higher than a typical 15° reported in McClung and Schaerer, (1993) and the 18° average of the Type II dataset.

Negative horizontal distance ratios in Figure 7 indicate the runout zone tip to be up-slope of the Beta point and positive values indicate a runout tip below the Beta point. In Jones, (2002) a mean Beta point runout ratio of 0.051 was reported. The mean ratio for the Type III dataset was -0.20 indicating the mean runout tip for forest penetrating avalanches occurs up-slope of the Jones (2002) short slope (non-forested) avalanche dataset.

A Weibull distribution provided the best fit for the ratio data and can be used to predict the probability of a given avalanche path reaching a point on the slope relative to the Beta point. The figure shows the horizontal distance ratios plotted against the Weibull parameter.

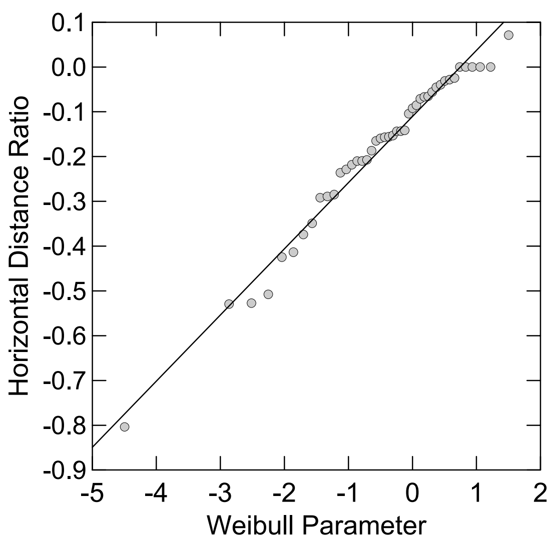

Figure 7. Weibull distribution for Beta point horizontal distance ratios.

5. CONCLUSIONS

This study presents selected results on the first terrain shape analysis for forest penetrating avalanches. The varying nature of the individual sites has thus far made it difficult to produce a predictive tool for evaluating the potential for avalanches to reach a given point on a forested slope. A number of promising indicators are revealed through the analysis:

Flat and concave horizontal slope shapes in the track and runout zone prevent significant lateral expansion of avalanches in the runout zone.

Beta point analysis shows all but one of the 45 forest penetrating avalanches stopping up-slope of the Beta point. Further analysis is needed on a similarly scaled database for avalanches that did not run through forest cover to determine whether a significant difference in the runout tip angle exists.

Horizontal or cross slope shape is the best indicator of penetration distance potential for avalanches running through forest cover. The forest penetrating avalanches show significantly higher cross slope shape values compared to the Type I and Type II datasets.

An horizontal slope shape transition index is being developed to estimate runout distance according to slope shape and a scaling parameter such as distance to or vertical fall to forest cover.

Horizontal distance Beta point ratios fit best to a Weibull distribution. The distribution can be used to determine the probability that an avalanche will reach a given point on a slope in forest cover, relative to the Beta point.

ACKNOWLEDGEMENTS

The funding for this research came in part from the former Forest Renewal B.C., from Canadian Mountain Holidays and The Natural Sciences and Engineering Research Council of Canada. Their support is greatly appreciated.

REFERENCES

Jones, A. 2002. Avalanche runout prediction for short slopes. (Master's thesis, University of Calgary).

McClung, D. M. 2001. Characteristics of terrain, snow supply and forest cover for avalanche initiation caused by logging. *Annals of Glaciology, 32, 223-229.*

McClung, D.M. and P. Schaerer, 1993. The avalanche handbook. The Mountaineers; Seattle, Washington.

Stitzinger, K. 2001. Snow avalanche risk and decision support for clear-cut harvested terrain. (Master's thesis, University of British Columbia).

Stitzinger, K, P Weisinger, and D McClung, 2001. Avalanche activity and interaction with harvested terrain: Terrain analysis and decision support systems for risk management. International Snow Science Workshop 2000. ISSW-meeting Big Sky, Montana. 2000. p.458-461.

Weir, P. 2002. Snow avalanche management in forested terrain. Res. Br., B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 55. www.for.gov.bc.ca/hfd/pubs/Docs/Lmh55.htm