Spatial variability of slab stability in avalanche start zones

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Abstract

Spatial variability of slab stability in avalanche start zones has been observed by avalanche professionals but little research has been published that shows the amount or causes of this variability, or patterns of stability.

A quantitative variation of the compression test was refined to test stability many times within a few hours. Each of these tests consists of an annular brass weight dropped from 5 to 55 cm in 5 cm increments, down a guide rod onto a 30 cm by 30 cm rigid plate until fracture occurred in the weak layer.

Between December 2000 and April 2002, thirty-nine spatial arrays were conducted on slabs in the Columbia Mountains of British Columbia. Each array consisted of between 40 and 120 drop hammer tests, each conducted in a single day in an avalanche start zone.

Many arrays show relatively consistent stability within the start zone. Clusters of low or high scores (stability) ranging in size upwards from 2 m were observed in some of the arrays.

1.0 Introduction

The mountain snowpack varies on various scales: between mountain ranges, within mountain ranges, and within a single slope (e.g. Birkeland et al., 1995; Conway and Abrahamson, 1984, 1988; Föhn, 1989; Jamieson, 1995; Haegeli and McClung, 2001; Krohnolm et al., 2001; Kronholm et al., 2002; Landry, 2002).

The objectives of this study were use a relatively new stability test to document spatial variability of stability in avalanche start zones, to compare variability in start zones with variability in relatively sheltered study slopes, and to compare results of the new stability test to results of the compression test.

2.0 Methods

Two field operations were established by the Applied Snow and Avalanche Research Group, one based in Glacier National Park in Rogers Pass, BC in conjunction with Parks Canada and one in Blue River, BC in cooperation with Mike Wiegele Helicopter Skiing. Field stations operated from early December to late March or April.

Spatial variability was studied by making arrays of closely spaced stability tests in avalanche starting zones. Study sites for arrays were chosen with the following attributes:

1. an avalanche start zone (with a slope angle of at least 28°),
2. undisturbed by recreationists,
3. at least 40 to 60 m^2 in the up-slope and cross slope directions.

The drop hammer tester is similar to the Rammrutsch used by Schweizer et al. (1995) but with a smaller base plate (Figure 1). Our tester was constructed of a 0.30 m by 0.30 m by 0.01 m (very strong plastic base plate. A round stainless steel

Figure 1 Drop hammer tester in use.

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striking plate, 0.15 m in diameter by 0.01 m thick, was bolted in the middle of the plate. A 0.60 m guide rod was affixed into the middle of the striking plate and perpendicular to it. The rod was 0.01 m in diameter. Lines were etched into the rod starting at 5 cm above the striking plate to 55 cm, which represents the maximum drop height.

Brass weights were used to cause fracture in the weak layers. The weights (hammers) were cylindrical in shape with a 0.012 m whole drilled in the middle allowing for the weight to be dropped down the rod. The weights had a mass of 1 and 3 kilograms.

The first step in performing the drop hammer test was to isolate a 30 cm by 30 cm column of snow. The column was then levelled with a shovel creating a flat surface on which to place the drop hammer tester.

The second step was to load the column, creating fracture in the identified weak layer. This was done by carefully placing the drop hammer tester on the column. The weight was then lifted to a height of 5 cm and then dropped onto the plate (Figure 1). If the weak layer failed, the drop height was recorded as 5 cm. If the weak layer did not fracture the weight was subsequently dropped in 5 cm steps from 10 cm, 15 cm, 20 cm, to a maximum height of 55 cm then dropped. When fracture occurred, the height from which the weight was dropped was recorded. If the weak layer did not fracture after the weight was been dropped from 55 cm, "no fracture" was recorded and a score of 70 was assigned for analysis.

The third step was to record the following snowpack and ground variables for each test: depth of the weak layer, damping snow, ground hardness, and height of snow. Associations between these variables and drop height are analyzed in Stewart (2002).

Arrays of tests were conducted with 30 cm between tests in the up-slope and cross-slope directions (Figure 2).

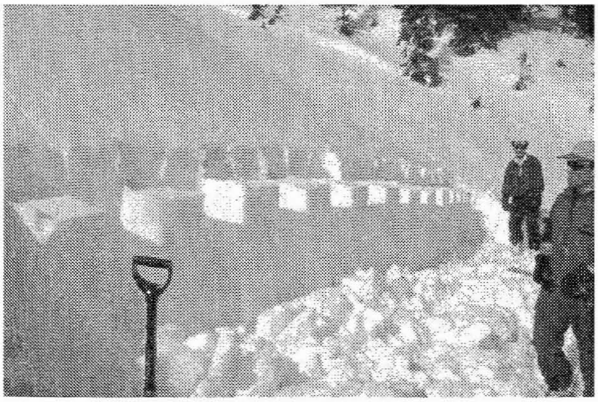


Figure 2 A row of columns ready for drop hammer tests.

3.0 Results

3.1 Repeatability

To avoid the effect of the number of tests (and area) on variability, a measure of variability that was independent of the number of tests was used to compare the variability between avalanche start zones and study plots. Perla (1977) used the following formula to determine the percent repeatability between adjacent shear frame tests:

$$\% REP = \frac{2|S1 - S2|}{S1 + S2} * 100\,\% \qquad (1)$$

where S1 is a shear frame test and S2 is an adjacent shear frame test. The same formula was used to calculate the percent repeatability between drop hammer tests in avalanche start zones and study slopes. For each drop hammer test in an array, a value was calculated for each adjacent test both across the slope and upslope. These values were averaged to find the percent repeatability within the set. The same was done for all the groups of three drop hammer test that were performed in the study slopes.

The percent repeatability within the drop hammer arrays had a low of 8.4%, a high of 84.8% and a mean of 42.3%. The study plot results had a low of 0%, a high of 85.7% and an average of 27.1%. These values indicate that there is substantially more variability and less repeatability between drop hammer tests in avalanche start zones than in study plots. This result combined with the correlations between study plot stability indices in the Columbia Mountains and surrounding avalanche activity (e.g. Jamieson and Johnston, 1993; Jamieson, 1995; Chalmers, 2001) suggests that results of stability tests in Columbia Mountain study plots can often be related to avalanche activity in surrounding terrain.

3.2 Comparison with compression test

The compression test is a common test used by most avalanche workers and backcountry enthusiasts as an indication of the stability of the snowpack. Jamieson (1999) has shown that as compression test scores increase, the frequency of skier-triggered avalanches on slopes adjacent to the test decreases, which is what one expects of a stability test.

Data for this comparison were collected in two ways:

1 three compression tests were performed beside 16 of the 39 spatial arrays, and
2. three drop hammer tests were performed next to three compression tests on 17 days in which study calculated. For each of the comparisons, the load was applied in the drop hammer test with the 3 kg hammer.

A total of 44 pairs of mean drop heights and mean compression scores were available for this comparison. Mean drop heights are plotted against mean compression scores in Figure 3 showing that Drop Height correlates with compression test scores ($R=0.64$, $p<0.05$). This result indicates that as Drop Height increases, compression test scores significantly increase, indicating that the drop hammer test can be used as an indication of stability. Table 1 shows the middle 50% of DH values that correspond to Easy, Moderate, Hard and No Fracture results of the compression test.

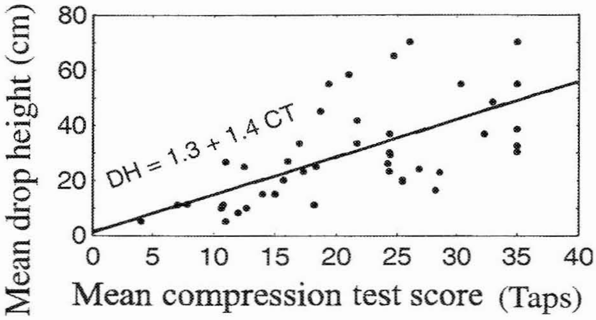


Figure 3 As compression test scores increase, so do drop heights. Data are for 3 kg hammer.

Table 1 Comparison of Compression Test Scores and Drop Hammer Scores with the 3 kg Hammer

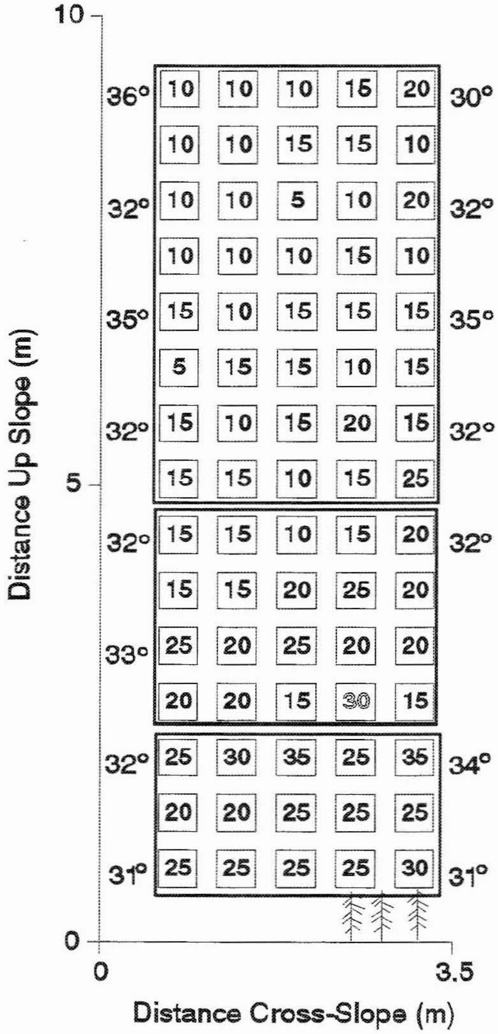
Middle 50% of Drop Height (cm)	Compression Scores	Number of Taps
8-11	Easy	0-10
11-27	Moderate	11-20
23-39	Hard	21-30
37-55	No Failure	35

One of the limitations of the drop hammer test is the weight of the hammer and tester which limits its portability. For a quick stability test for the recreational skier, a stability test such as the compression test or stuffblock test (Birkeland and Johnson, 1996) are practical but less quantifiable; however, for scientific research the drop hammer test can be used by a number of technicians to give quantifiable results.

3.3 Clusters of low and high scores

When plotted, the data showed some visual clustering of low and high scores, as well as some trends across some arrays (Stewart, 2002).

On March 15, 2001, 75 drop hammer tests were conducted on an east-facing slope of Mt. Fidelity at 1880 m (Figure 4) The slope inclination ranged from 31° at the bottom of the array to 36° at the top of the array on a convex roll. The fractures occurred, using a 1 kg weight, on a poorly bonded, pencil-hard melt-freeze crust, situated below a 0.21 m to 0.32 m thick slab. Overall, drop heights ranged from 10 to 35 cm, with a mean score of 17.2 cm. This array shows an example of a spatial trend consisting of a zone of relatively high scores, a transition zone and a zone of relatively low. Rows 1-3 have a mean score of 26.3 cm, rows 4-7 have an average of 19 cm and rows 8-15 have an average score of 13 cm. The variation in scores can be explained by the variation in slab thickness, which increased in depth in the upslope direction.



36°	10	10	10	15	20	30°
	10	10	15	15	10	
32°	10	10	5	10	20	32°
	10	10	10	15	10	
35°	15	10	15	15	15	35°
	5	15	15	10	15	
32°	15	10	15	20	15	32°
	15	15	10	15	25	
32°	15	15	10	15	20	32°
	15	15	20	25	20	
33°	25	20	25	20	20	
	20	20	15	30	15	
32°	25	30	35	25	35	34°
	20	20	25	25	25	
31°	25	25	25	25	30	31°

Figure 4. Drop hammer scores on an east-facing slope of Mt. Fidelity on March 15, 2001. A spatial trend is observed in this array consisting of a zone of relatively high scores at the bottom, a transition zone in the middle and a zone of relatively low scores at the top.

Figure 5 shows another example of visual clustering of scores. On February 7, 2001, an array of 40 drop hammer tests was performed on a southeast–facing slope of Christiana Ridge at 1930 m. The slope inclination was consistent at 35°. Fractures occurred, using a 1 kg hammer, in a layer of 5-7 mm surface hoar beneath a 0.37 m to 0.51 m slab. Drop heights ranged from a low of 20 cm, to a high of 45 cm. A cluster of high scores wss situated in the top left corner of the array, where the average drop height is 42 cm. A cluster of lower scores was located in the top right corner, where the mean drop height was 26 cm.

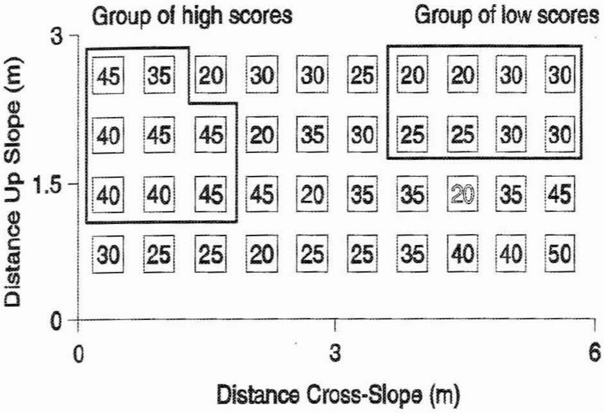


Figure 5 Drop hammer scores on a southeast-facing slope at Christiana Ridge on February 7, 2001. A cluster of high scores is located in the left corner of the array. A cluster of low scores is located in the top right corner of the array.

4.0 Summary

The drop hammer test provides an indication of stability in the field. Two people can do approximately 100 closely spaced stability tests within a few hours. Results of the drop hammer test correlate with results of the compression test.

Less variability and more repeatability of drop hammer scores are found in sheltered study slopes than in start zones.

The results of 39 spatial arrays of drop hammer tests in avalanche start zones indicated that visual clusters of low and high scores were found in the majority of spatial arrays.

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