FIELD TESTS OF SNOW STABILITY

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Introduction

Snow stability evaluaton is a critical element in avalanche hazard evaluation. The procedure of stability evaluation encompasses an analysis of avalanche activity, snow cover distribution, snow stratigraphy, and meteorological data. The objectives of this study were to develop field tests of snow stability which can be used as input data in stability evaluation for avalanches or as direct tests of snow stability.

The tests were applied on Whistler, Blackcomb, and Granite mountains in study plots representative of the avalanche starting zones. Whistler and Blackcomb mountains are located at Whistler, B.C. in the centre of the South Coast mountain region. The climate here is of a mild, moist type typical of West Coast mountain regions. Granite Mountain is located at Rossland, B.C. in the West Kootenay district of the South Columbia mountain region. The climate here is of the cool, moist type typical of the interior highlands.

Observations taken in the study plots were correlated with time and type of avalanche occurrences, depth of slab fractures, and observations of snow structure at avalanche fracture lines. Study plot observations included the shear frame test, the shovel shear test, the ram profile test, and the tilt column test. Ram profiles were taken through the weak zone of the snowpack using both the standard Haefeli ram penetrometer and a lightweight ram penetrometer. Snow crystal forms and temperatures were observed in the critical layers.

The ramsonde data is not discussed in this report. Dynamic penetration of the heavy 1 kg ram causes it to pass through the surface of the snow cover which often contains critical failure planes. The 0.1 kg lightweight ram yields a complex illustration of the new snow cover which is fairly difficult to interpret.

During a portion of the study period, the tilt column test was also employed. It was found to be a time-consuming duplication of the shovel test and it was discontinued.

Shear Frame Tests

The shear frame test is an established indicator of stability in avalanche hazard evaluation. Roch (1966) describes the use of the shear frame to estimate shear strength at a failure plane. He defined the shear frame index (SFI) which is computed by dividing the force necessary to pull the frame to failure by the frame area. The ratio of shear frame index over weight per unit area provides a numerical estimate of snow stability commonly known as the stability factor. It is a standard input in the process of stability evaluation employed at Rogers Pass, B.C. (Schleiss and Schleiss, 1970).

The procedures employed in the shear test are described in the guidelines for snow observation (NRC, 1981). In the tests taken for this study, a variation was employed: prior to pulling the frame, a thin spatula was used to cut around the frame down through the failure plane. At the failure plane, five shear tests were taken with each of the 0.025 m^2 and 0.010 m^2 shear frames. Three observations were made of the weight of snow above the failure planes. The stability factors were then calculated.

During the 1978-79 Whistler observation periods, a study plot inclined at 10^0 and subject to wind transport of snow was used. Observations showed that the level study plot used in initial tests at Rossland in 1979-80 was also subject to wind influence. Testing on an inclined slope introduces an additional stress variable into controlled shear testing. Correct placement of the shear frames on inclined layers is also more difficult than on level sites. The influence of wind introduces variations in the depth of the failure plane which introduces testing inaccuracy. Relocation of both Whistler and Rossland study plots to level, protected sites at slightly lower elevations eliminated most of this problem. It is desirable to establish study plots which are representative of the aspects, elevations, and inclines of avalanche starting zones, but the number of study plots required would be prohibitive. Consequently, a representative, level, protected control site was used in the present study.

Perla (1977) showed that to find a mean shear frame index within 15% accuracy, to a confidence of 90%, required taking an average of four readings. In consideration of this, five readings were taken with each frame in the Whistler and Rossland 1979-80 studies.

Sommerfeld and King (1979) suggest a method which entails location of the potential failure plane in a snowpit followed by performance of approximately 50 shear frame measurements. It is suggested in the current study that although Sommerfeld and King may be correct in their analysis, a practical application of 50 tests would be prohibitive in terms of time for the field observer. The field observer's consideration is that after a few repetitions of the test, there is not sufficient refinement of the mean shear frame index to warrant the time spent. Also, as the number of tests in each observation period is increased, the undisturbed study plot area is decreased and spatial variations in strength become increasingly important.

Size Effects Using Shear Frames

Perla (1976) showed that size effects of shear frames were an important consideration. He showed that larger shear frames indicate significantly less strength than the smaller shear frames. Tests by Perla suggested that less readings were required with the 0.025 m^2 frame to find the mean SFI than with the 0.010 m^2 frame. He recommended the 0.025 m^2 frame despite the fact that smaller frames are easier to align on thin discontinuities.

In the 1979-80 sampling at Whistler and Rossland, the 0.025 m^2 and 0.010 m^1 frames were tested simultaneously. Table 1 summarizes this comparison. Analysis of the sample shear frame indices measured with both frame sizes indicates a distribution skewed toward smaller strengths. This seems reasonable because of the tendency of observers to test when unstable conditions, and hence lower shear strengths, prevail. A logarithmic transformation of the sample data yields a near normal distribution for both frames. Statistical testing of the logarithmic distributions demonstrates that the mean shear strength value observed with the 0.025 m^2 frame is less than that observed with the 0.010 m^2 frame to a confidence interval of 90%. Figure 1 is a scattergram of the paired observations. The shear frame index of the 0.025 m^2 frame is plotted along the X axis while the index of the 0.010 m^2 frame is plotted on the

Y axis with both Y and X in N/m^2. A linear regression provides the best fit to the data with a coefficient of determination r^2 of 0.83. With only 14 sets of observations, strong conclusions may not be drawn. A minimum of statistical testing has been done due to the limited number of observations. The data do, however, support Perla's findings. Further testing will be required to quantify the ratio between the two frame sizes.

Snow type and snow temperature are influencing factors in the scatter of the shear frame index readings during ech observation period. These factors can influence the ease of use of the various frames and, hence, repeatability. Also, the variations in mechanical strength across a snow layer may vary with different snow forms. Further observation will be required to identify some of these characteristics.

No significant difference in the ease of use of either the 0.025 m^2 frame or the 0.010^2 frame was identified.

Shovel Shear Tests

During the 1978-79 winter at Whistler, tests were carried out using a collapsible snow shovel 20 cm wide and 25 cm high. Three block sizes were tested to determine the optimum: 40 x 40 cm, 30 x 30 cm, and 20 x 20 cm. In tests involving light, unconsolidated new snow, the 40 cm test was difficult to perform. On the other hand, the 20 cm test often revealed too many layers to indicate trends in stability. It was decided to use a 35 x 35 cm block in 1979-80, employing a specially made flat plate-like shovel 30 cm wide and 45 cm long.

The procedure for shovel shear testing is outlined in the guidelines for snow observation (T.M. 132, ACGR/NRC). Figur 2, drawn from these guidelines, illustrates the technique. The test was repeated three times to check consistency of results.

Analysis of the observations indicates that the shovel shear test did not identify unstable layers near the surface of the new snow cover as well as the tilt platform used in shear testing. This is to be expected because the soft layers are compressed rather than moved by the shovel. The length of the test shovel used in 1979-80 may also have been a factor in limiting new snow shears. The test should be performed using the collapsible shovel commonly carried by snow observers. Other specialized tools such as the plate shovel have not shown sufficient superiority to warrant their use.

Stability Tests and Avalanche Observations

One important aspect of the correlation of physical parameters with avalanche activity is often overlooked in avalanche studies. This is the question of natural versus controlled avalanche release. Logically, one must conclude that natural releases would yield a true illustration of natural failure stresses. In artificial avalanche releases, a large dynamic increase in load is obviously the determining factor. In discussion of the Whistler and Rossland studies, a comparison of stability test results related to artificial avalanche release is contrasted with test results for natural release. Significant avalanching is defined as more than one isolated event and that which seems reasonable for association with the failure plane tested.

During the 1978-79 season, a well developed depth hoar layer was evident at the base of the snowpack and its presence continually influenced avalanche conditions. As a result of this, a poor correlation is sometimes observed between the failure planes revealed by the tests in the upper layers of the snowpack and the depth of avalanche activity.

An overview of the observations shows that avalanche control was often the determining factor in avalanche release during related storm periods. An example of this occurred during the period of February 8 to 9, 1979. The stability factor was first observed as 1.0 at the 0.18 m level. Artificial avalanche control removed the unconsolidated surface of the snowcover in the form of 0.05 to 0.10 m deep, loose snow sloughs. The stability factor for this new snow failure plane was then observed as 1.4 at 0.22 m (0820 hours, 1979-02-09). At this time, several 0.10 to 0.15 m Size 1 slab avalanches were artificially triggered. (The avalanche size classification system used here is described in the NRC guidelines for avalanche observation). The factor then decreased to 1.1 at 0.27 m (1400 hours, 1979-02-09) as the new slow load increased. The unstable snow had, however, already been removed from most of the avalanche observation sites.

Table 2 compares observed stability factors for natural versus artificial slab avalanche occurrences within the new snow cover. A weakness in the data lies in accurately pinpointing the time of natural avalanche occurrences during storm periods. Study plot observation times are more easily co-ordinated with artificially triggered avalanche occurrences.

Analysis of the observations clearly illustrated the advantage of combining the shear test and the shovel tet in overall stability evaluation. The shovel test is more easily used in identifying instabilities below the new snow accumulation. Natural avalanching within the new snow or old snow layers was observed with very easy or easy shovel shear classification described in the NRC guidelines. Controlled avalanche releases were observed with the "easy" and "moderate" classifications for tests both within the new and the old snow cover.

Conclusion

Logically, the observed shear test stability factor should be higher for artifically controlled avalanches, than that observed in natural avalanche occurrences. The difference should describe the effect of the additional loading needed in artificial control. The observations presented tend to support these theories, though admittedly the data base is small. Exactly what these differences in the stability factors are is a key point of interest to the avalanche forecaster. Further shear frame studies are necessary both in the study plot and at the fracture line to quantify the relationship between the stability factor, natural avalanche failure and controlled avalanche failure.

The shovel test results indicate that easy strength classifications are observed in association with natural avalanching with both the new and old snow layers. A tendency toward moderate tests accompanies these observations of old snow layers. In regard to controlled avalanching, moderate shears are often evident within both the new and the old layers. Again, the number of observations is small and further testing is necessary both in the study plot and at the fracture line.

Tests such as the shear test and the shovel shear test must be considered in combination with one another. A subjective note from the observers is that good testing, in particular the shear test, requires practise. This study does not consider meteorological parameters which should be considered as the most important input in the process of snow stability evaluation.

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Table 1. 1979-80 Size Effect Comparison

Shear Frame Size M^2	Mean Shear Frame Index N/m^2	Standard Deviation N/m^2	Minimum Shear Frame Index N/m^2	Maximum Shear Frame Index N/m^2
0.010	950	550	310	2140
0.025	840	470	270	1960

Table 2. Comparison of Observed Stability Factors

Frame Size m^2	Trigger	No. of Observations	Mean Stab. Factor	Min. Stab. Factor	Max. Stab. Factor
0.010	Natural	2	1.02	0.86	1.18
0.025	Natural	2	0.97	0.93	1.00
0.010	Artificial	7	1.87	0.86	3.50
0.025	Artificial	10	1.29	0.93	2.56

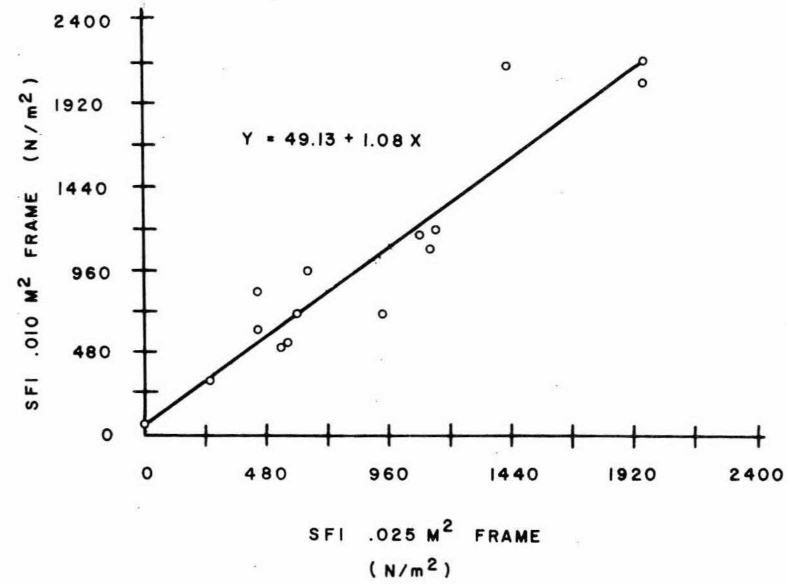

Figure 1. Comparison of the shear frame index for two sizes of shear frame.

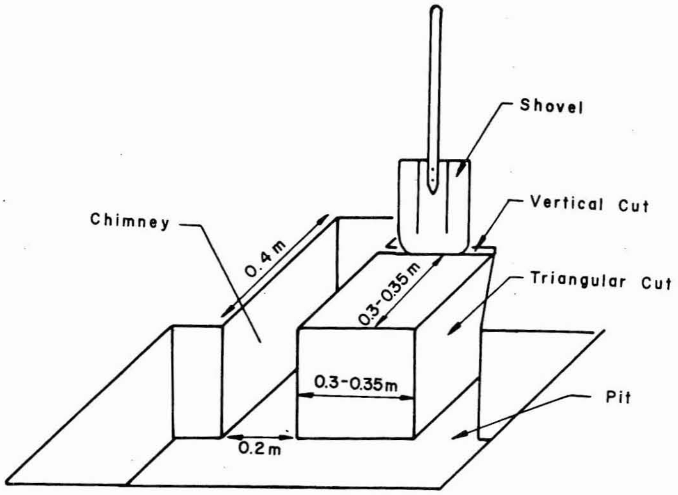

Figure 2. Shovel Shear Test.

Discussion

Johnston:

I don't think you should be surprised that there is a difference between the results from the 100 cm^2 shear frame tests and the 250 cm^2 shear frame tests. If you can get a handle on such size effects, then it might in fact be more accurate or more realistic to extrapolate your stability indices to 50 or 100 m of slope.

Stethem:

Yes, size effects are well known in snow strength tests and it isn't a revelation. There is a great deal of argument, however, as to which frame to use and we are asking, "How much different is one from the other?" I quite agree with you that there are strong and weak spots in the snow and that, logically, if you can test bigger size samples, you are probably doing a better job.