EVALUATING THE STUFFBLOCK AND TILT BOARD SNOWPACK STABILITY TESTS AS SNOW AVALANCHE FORECASTING TOOLS

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ABSTRACT: Snow avalanche forecasting relies on, among other factors, an assessment of snowpack stability derived from careful observation of snow cover stratigraphy. Snowpack profiles and stability tests provide quantifiable information about the location and strength of weak layers in the snowpack. This study found:

1) good comparative results between the stuffblock and compression tests and,
2) a relationship between tilt board test results in level study sites and skier triggered avalanches.

KEYWORDS: snowpack stability tests, tilt board, stuffblock

1. INTRODUCTION:

The best way to get direct information about snowpack stability is by observing avalanches and by making snow stability measurements in the field. Collecting consistent snow stability measurements to assess snowpack stability is difficult due to avalanche hazard, rapidly changing conditions, spatial variability, methodology problems, and the challenges of performing laboratory experiments in adverse weather.

Avalanche forecasters use a variety of tests to assess stability. This study, conducted at Eaglecrest ski area over the winter of 2003-2004, assessed the operational utility of the stuffblock and tilt board tests evaluated against the compression test, the shear frame test and triggered avalanches. Professional ski patrollers mitigating hazard triggered the avalanches observed in this study.

The shear frame test, developed by the Swiss André Roch, has been used extensively to index the shear strength of weak snowpack layers (Föhn 1987). The test uses a frame placed just above a weak layer and pulled with a gauge that records the maximum force. The shear strength is calculated by dividing the maximum force by the area of the frame.

The tilt board test is a simple method for avalanche forecasters to observe the stability of the surface 40cm of the snowpack. This test was first outlined in the Canadian Avalanche Association (CAA) Observation Guidelines and Recording Standards (OGRS) as part of the process to identify weak layers to be tested using a shear frame. The test puts a block of snow extracted from the snowpack on an angle (and tapping it if necessary) to identify the shears within it. The test has recently been promulgated as a stand alone stability test by the American

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Avalanche Association (AAA) and USDA Forest Service National Avalanche Center.[1]

The compression test was developed by Canadian park wardens in the 1970s. This test identifies weak layers within 1.2 meters of the snow surface using increasing dynamic force applied to a shovel blade resting on an isolated test column of snow (Jamieson, 1999).

The stuffblock test, developed in Montana in 1993 (Birkeland, 1996, 1999), is also performed on an isolated test column of snow using a nylon stuff sack filled with snow and dropped on the column until a shear failure occurs.

2. SITE DESCRIPTION AND METHODS

2.1 *Study Site*

The 300 ha ski area located five kilometers west of Juneau, Alaska, is on Douglas Island at the headwaters of Fish Creek, a northwest facing drainage. Eaglecrest rises in elevation from 400 to 820 meters above sea level. Snowpack observations made at treeline snow study plots located at 720m and 790m were in accordance with OGRS as required by Eaglecrest's subscription to the CAA Infoex data exchange.

2.2 *Snowpack Observations*

Thirty-four snowpack profiles were observed between November 22nd and March 28th. The profiles recorded weather, snowpack stratigraphy, temperature, density, and snow water equivalent (SWE). Profiles also include the stability tests outlined below, as well as other observations not part of this study.

[1] Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States, 2004.

2.2.1 *Shear Frame Test*

Shear strength of weak layers is best measured with the shear frame (Schweizer, 2003, Figure 1). The baseline data for this study came from 40 shear frame tests conducted in the level snow study plots. Shear frame tests were also conducted in test profiles in avalanche start zones and along avalanche fracture lines.

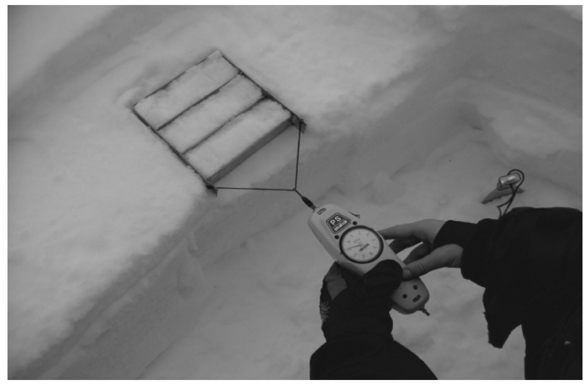

Figure 1 – Shear Frame Test

Conducting shear frame tests requires discipline, particularly in adverse weather conditions. While providing quantifiable shear strength data, the test is time consuming and difficult (Perla and Beck, 1982). Each shear frame test was conducted at least five times to ensure shear results were accurately reproducible. The equipment used for the shear frame test included a $100 cm^2$ shear frame, 2kg and 5kg Imada pull gauges, digital and mechanical weigh scales, two sampling tubes and a large putty knife.

Shear frame test results are used to calculate a unitless stability ratio to formulate stability indices for the triggering of avalanches (naturally or artificially). Snow stability is a ratio of strength to stress on a weak layer or interface. The shear frame measures the strength of a snow layer, while snowpack weight determines the stress on the layer. Stability ratio is calculated as shear strength divided by the weight of snow per unit area thus an increase in the stability ratio is indicative of an increase in snowpack strength.[2]

2.2.2 *Stuffblock Test*

The stuffblock test is a variation of the compression test. A 4.5 kg weight is progressively dropped higher in 10cm increments onto a 30cm by 30cm isolated column. The tests were conducted in profiles on 35º to 40º slopes with generally north aspects representing avalanche start zones (Figure 2).

Figure 2 – Conducting a Stuffblock Test at Eaglecrest

2.2.3 *Tilt Board Test*

The tilt board test was primarily conducted at the 790m treeline weather plot. Tests were conducted at the 720m study site when severe weather conditions affected the results obtained at the higher study site. The test isolates a 30cm by 30 cm column, tilting the extracted column to 15° angle and gently tapping until a shear is identified. In this study, very easy shears are defined as failure on tilt, easy shears with failure after one gentle tap, moderate shears with failure after the second gentle tap, and hard shears with failure after three or more taps.

The equipment used for the tilt board tests included tilt boards located at both treeline study plots, each equipped with a 30cm by 30cm metal cutting plate and a crosscut saw used for extracting the test snow sample from the snowpack. Irrespective of the depth of new or storm snow, the maximum test depth was 40cm from the surface of the snowpack. When the snow tested exceeded 200kg/m^3 the test depth was less than 40cm.

3. RESULTS AND DISCUSSION

From December 11th 2003 to April 3rd 2004, 658.1 cm of snowfall (with 113.2cm SWE) was recorded at the 790m snow study site. During the winter there were eight major avalanche cycles with each cycle producing numerous natural avalanches outside the ski area. On 40 days, 416 avalanches were triggered within the ski area ranging from destructive size 0.5 to 2.0.[3] Of those avalanches, 227 were triggered using explosives and 189 were skier triggered. The triggered avalanche activity reflected new snow or surface instabilities. A destructive size 2.5 natural avalanche occurred within the ski area. There was an avalanche involvement just outside the ski area boundary on March 5th with a snowboarder carried 200m without injury.

3.1 *Shear Frame Test – Stability ratio*

A comparison of skier triggered avalanches with the stability ratio calculated from the shear frame measurements shows that high stability ratios tend to be associated with lower numbers of triggered avalanches (Figure 3). This study supports previous research showing that stability indices measured in level study plots are effective predictors of snow stability on proximate slopes (Jamieson, 1995).

[2] CAA OGRS, 2002, AAA, 2004

[3] CAA OGRS, 2002, AAA, 2004

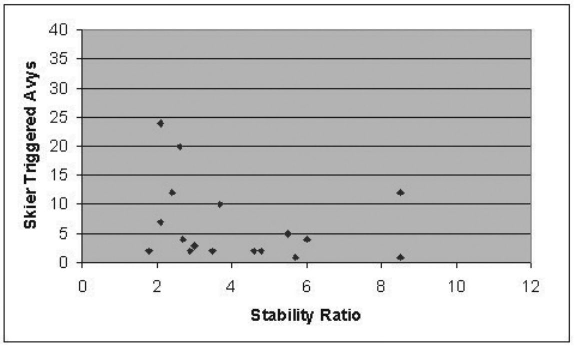

Figure 3 – Stability Ratio and Skier Triggered Avalanches

Avalanche forecasters develop stability ratio indices specific to their operation. Comparing shear frame test stability ratios and skier triggered avalanches at Eaglecrest is a start to the development of an index specific to the Juneau area.

The outlier in Figure 3 occurred January 8th. On that day the shear tested was 11cm from the surface at the interface between a moist slab (described as "sticky") and dry old snow. Although the stability ratio was calculated at 8.5, one natural, 18 explosive triggered, and 12 skier triggered avalanches were recorded. There were variably wind distributed near-surface facets observed in the study plot. These findings suggest that the shear strength interface between moist new and dry (faceted) old snow needs further study.

Our tests also revealed that although the shear frame, stuffblock and compression tests all introduce rapid loading, often an easy shear was observed with the stuffblock and compression tests yet the pull gauge would reach its maximum limit of 50 newtons force without shear failure. This suggests a difference between the dynamic shock of the dropped stuffblock (or tapping of the compression test) and the increasing static force applied with the pull gauge (or shovel shear test[4]).

3.2 *Stuffblock Test*

Thirty-five stuffblock shears were compared against the compression test where a strong relationship was found (Figure 4). The stuffblock test results were better replicated between observers than the compression test because of the consistency of the force applied (4.5 kg weight and increments of 10cm drop heights).

Comparison of these tests also revealed:

1) that stuffblock tests of less sensitive, or hard, shears appeared to reproduce more consistently than the compression test and,
2) that stuffblock tests of more sensitive, or easy, shears appear to suggest the stuffblock test may be a less sensitive test than the compression test. Part of the reason may be because easy shears are recorded only when the failure occurs with the static load of the stuffblock sitting on the isolated column tested (SB0) or with a drop height of 10cm (SB10) or 20cm (SB20).[5] Very easy shears, that is, failure while isolating the column are recorded as SBV.

A SB10 was often recorded where the pull gauge would reach its maximum limit of 50 newtons force without shear failure. We were unable to test any SB20 or greater with the shear frame. Again this suggests a difference between the dynamic shock applied with the stuffblock and compression

[4] CAA OGRS, 2002, AAA, 2004

[5] The stuffblock test is designed with three subsets of shears recorded as easy; the compression test has 10 subsets of shears recorded as easy.

tests and the increasing static force applied with the pull gauge.

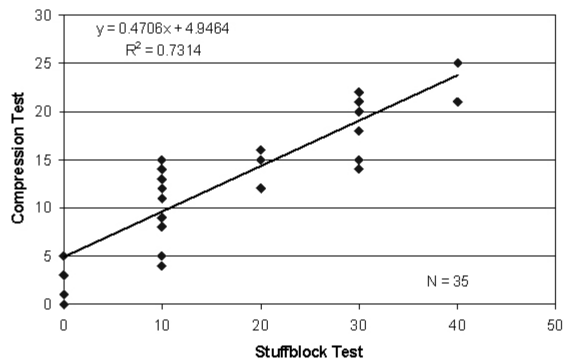

Figure 4 – Stuffblock Test results measuring height of dropped weight compared with the number of taps of the Compression Test

3.3 *Tilt Board Test*

Tilt board tests were conducted on 107 days. This was the second season using this stability test at Eaglecrest. The tilt board test was compared with 189 skier-triggered avalanches (Figure 5). We found this test to be a quick and easy method to obtain pertinent information about new snow slab and shear characteristics.

The tilt board test gives the avalanche forecaster an opportunity to quickly and safely test the top 40cm of the snowpack. While the test primarily identifies shear location, it also provides information about the bond between new and old snow, the weak layer shear quality (Birkeland, 2003, Herwijnen, 2003) and the slab thickness and hardness. For example, a thick, hard moist slab over a moderate to hard rough shear has operational consequences quite different than those for a thin dry soft slab over an easy smooth shear.

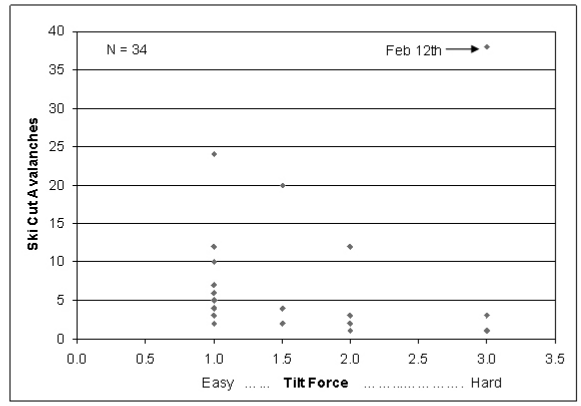

Figure 5 – Tilt Board Test and Skier Triggered Avalanches (0.0 = failure on isolation, 0.5 = failure on tilt, 1.0 = failure with one tap, 1.5 = failure on second tap, 2.0 = failure on third tap, 2.5 = failure on fourth tap, 3.0 = no failure with gentle taps)

The tilt board test worked well with dry snow. Data scatter occurred with moist and wet snow. The outlier in Figure 5 occurred February 12th where a hard tilt was recorded along with 38 skier triggered point release avalanches. On that day there was 20cm of $260 kg/m^3$ moist new snow on a melt-freeze crust. Similar tilt results occurred under similarly wet conditions on other days suggesting the need for further study of shears involving moist new snow and wet old snow.

4. CONCLUSIONS

While natural avalanches are the best indicator of instability, this study used the shear frame test to provide quantitative baseline data and focused on the shear strength of a weak layer relative to applied stress (*mechanical instability*).

Against shear frame data and observed triggered avalanches, this study compared stuffblock test results with compression test results and evaluated the suitability of the tilt board test as a simple method for avalanche forecasters to identify the properties of new snow and near surface instabilities.

This study showed the stuffblock test compared well with the compression test and has good replication between observers. The tilt board test readily identifies shears with good replication between observers. However, the forces applied for the delineation of easy, moderate and hard shears needs further study.

The issue of stability tests using dynamic vs. static loads also needs further study. Differences were observed in the stresses or forces applied to the weak layer between the static force of shear frame test and the dynamic force of the stuffblock test and tilt board tests.

In summary, this study showed the value of both the stuffblock and the tilt board tests for avalanche forecasters.

ACKNOWLEDGEMENTS

Funding for this project came from the University of Alaska Southeast Chancellor's Special Project Fund and the Eaglecrest ski area. We thank Bruce Jamieson for the shear frame specifications and Sarah Carter, Kanaan Bausler, Brian Davies and Brooke Munro for data collection and administrative support. The Canadian and American Avalanche Associations allowed Eaglecrest ski area to become the first American subscriber to the daily CAA Infoex data exchange. The Juneau Ski Patrol paid the Infoex fee.

LITERATURE CITED

American Avalanche Association, Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States, 2004.

Birkeland, K.W., Johnson, R.F., 2003. Integrating Shear Quality into Stability Test Results. Avalanche News. Canadian Avalanche Association.

Birkeland, K.W., Johnson, R.F., Herzberg, D., 1996. The stuffblock snow stability test. US Forest Service Tech. Rep. 9623-2836-MTDC, 20 pp.

Birkeland, K.W., Johnson, R.F., 1999. The stuffblock snow stability test: comparability with the rutschblock, usefulness in different snow climates, and repeatability between observers. Cold Regions Science and Technology. Volume 30, Issues 1-3, December 1999, Pages 115-123.

Canadian Avalanche Association, Observation Guidelines and Recording Standards for Weather, Snowpack and Avalanches, September 2002, National Research Council of Canada Technical Memorandum No. 132.

Carter, S., Eaglecrest Weather and Snow Observations: Three Experimental Study Plots, Environmental Science Practicum 2004, University of Alaska Southeast.

Fohn, P.M.B., 1987. The stability index and various triggering mechanisms. *In* Salm, B. and H. Gubler, eds. *Avalanche Formation, Movement and Effects,* International Association of Hydrological Sciences Publ. 162 (Symposium at Davos 1986), 195-211.

Herwijnen, Alec van and Jamieson, B., 2003. An Update on Fracture Character in Stability Tests. CAA Avalanche News. Volume 66, Pages 26-28, (updated in 2004, Volume 68, Pages 38-41).

Jamieson, Bruce, 1999. The Compression Test – after 25 Years. The Avalanche Review 18(1), 10-12.

Perla, R.I. and T.M.H. Beck, 1983. Experience with shear frames. J. Glaciology, 29(103):485-491.

Perla, R., Beck, T.M.H., Cheng, T.T., 1982. The shear strength index of alpine snow. Cold Regions Science and Technology. Volume 6, Pages 11-20.

Schweizer, J., Lutschg, M., 2001. Characteristics of human-triggered avalanches. Cold Regions Science and Technology. Volume 33, Pages 147-162.

Schweizer, J., Jamieson, J.B., Schneebeli, M., 2003. Snow Avalanche Formation. Reviews of Geophysics, 41(4).

Schweizer, J., Jamieson, J.B., 2001. Snow cover properties for skier triggering of avalanches. Cold Regions Science and Technology. Volume 33, Pages 207-221.

Schweizer, J., Wiesinger, T., 2001. Snow profile interpretation for stability evaluation. Cold Regions Science and Technology. Volume 33, Pages 179-188.

Schweizer, J., Jamieson, J.B., 2003. Snow Stability Measurements, Seminar on Snow and Avalanche Test Sites, Grenoble, France, 22-23 November 2001, CEMAGREF Editions: 317-331.