VALIDATION OF THE PROPAGATION SAW TEST NEAR WHUMPFS AND AVALANCHES

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ABSTRACT: The Propagation Saw Test (PST) is a recently developed field test method for evaluating the fracture propagation propensity of slab and weak layer combinations. The PST is intended to replicate the fracture propagation behaviour found on nearby slopes. By following a simple interpretation guideline, PST results can indicate the propensity of a given snowpack to propagate weak layer fractures to an extent that would lead to avalanche release. We review a recent PST validation study in which fracture propagation was observed (or not) on nearby slopes for cases of confirmed fracture initiation. In addition, we present new PST results from 17 whumpf and avalanche sites in the Columbia Mountains of British Columbia, Canada. At these sites, the PST correctly predicted the high propagation propensity 71% of the time. However, as in the previous validation study, a relatively high proportion of tests (29%) incorrectly predicted low propagation propensity adjacent to whumpfs and avalanches. We review and discuss conditions associated with the false predictions, and we present suggestions for refining the test method and interpretation guidelines to reduce the occurrence of misleading results.

KEYWORDS: Propagation propensity, field test, instability assessment, snowpack properties, forecasting

1. INTRODUCTION

The Propagation Saw Test (PST) is a recently developed field test method for evaluating the fracture propagation propensity of slab and weak layer combinations (Gauthier and Jamieson, 2006, 2008a,b; Sigrist and Schweizer, 2007). The PST has proven to be a useful tool, both for research into the mechanics of weak layer fracture propagation and to support instability assessments by professionals. Gauthier and Jamieson (2008b) analyzed the success of the PST at predicting fracture propagation, by comparing results of tests performed near sites that had recently whumpfed or avalanched, with those from sites where weak layer fractures had initiated but not propagated, using data collected over a single season. That study showed that the PST can capture the propagation part of the avalanche release sequence better than other existing instability tests, although it is not perfect at predicting skier-triggering.

In fact, Gauthier and Jamieson (this volume) showed that the PST makes more ‘false stable’ predictions than the Compression test, Rutschblock test, and Yellow Flags structural stability index; however, the PST performed better at predicting that fracture propagation would not occur than the other methods. As with all instability assessment methods, the ‘false stable’ predictions are more hazardous than the ‘false unstable’ predictions, although both are incorrect.

In this study, we present the results of two seasons of PST results collected at sites that had recently whumpfed or avalanched, and compare the correct predictions of the instability with the incorrect ones – all of which are false stables in this dataset. Unlike that of Gauthier and Jamieson (2008b), this validation dataset includes only tests of that followed the size and methods recommended by Gauthier and Jamieson (2008a). In addition, we expand on the analysis of the slab and weak layer properties related to the false stable cases, and

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suggest some modifications to the PST method to help reduce their frequency.

2. METHODS AND DATA

Data for this study were collected at 33 sites in the Columbia and Rocky Mountains of British Columbia, Canada, in the winters of 2007 and 2008. We tested at and below treeline, as well as in the alpine, of the the Purcell Range near Kicking Horse Mountain Resort, the Selkirk Mountains at Glacier National Park, the Cariboo and Monashee Ranges near Blue River, and the west slopes of the Rocky Mountains near Chatter Creek. Study sites were small avalanche slopes or flat areas at which we had observed a propagation event. These sites had either: released a skier-controlled or remotely triggered avalanche on the day of, or a day prior to testing; released an accidentally or naturally triggered avalanche a day or two prior to testing; or whumpfed on the day of testing. At each site, we did several PSTs adjacent to the whumpf or avalanche in an undisturbed (i.e. not fractured) snowpack, along with a detailed snow profile to a depth below the weak layer of interest. Most often the failure occurred in a persistent weak layer composed of surface hoar or faceted crystals, with slabs less than 1 m thick.

For the PST, we followed the column size, field method, and interpretation guidelines shown in figure 1 and presented in Gauthier and Jamieson (2008a,b):

- Test column completely isolated from the surrounding snowpack, with vertical side and end walls, dimensions 0.3 m by approximately 1 m, oriented with the long axis parallel to the fall-line of the slope;
- Weak layer cut from the downslope end using a standard snow saw inserted completely through the width of the test column;
- High propagation propensity indicated where less than 50% (i.e. < 0.5 m) was cut at the onset of rapid weak layer fracture propagation *and* the fracture crossed the remainder of the length of the test column without arrest or interruption;

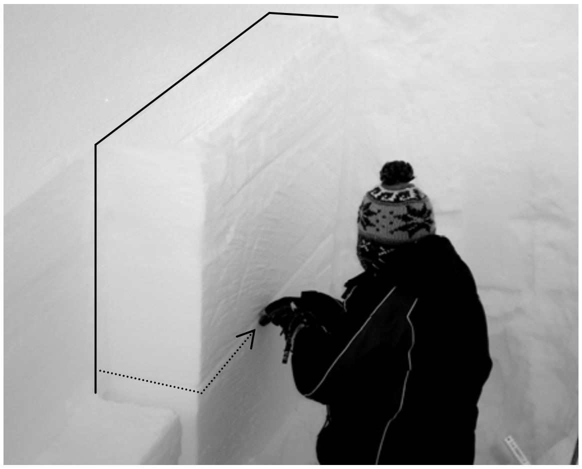

Figure 1. Photo of Propagation Saw Test (PST) in use, showing outline of column dimensions (0.3m x 1.0m) and cut direction (upslope) along the weak layer. (ASARC photo)

- Low propagation propensity indicated where greater than 50% was cut at the onset of fracture propagation *or* the fracture arrested prior to reaching the end of the test column (at a fracture through the slab or an otherwise indistinct point), regardless of the amount of column cut.

The column length of the tests often varied by up to 15%, such that test columns with lengths between 0.85 m and 1.15 m are included in the dataset. Better precision is difficult to achieve in the field, and based on the results of Gauthier and Jamieson (2006) we expect that this range of column sizes is acceptable.

To expand on Gauthier and Jamieson's (2008b) investigation into the snowpack properties associated with false stable predictions of the PST, we compiled the slab and weak layer properties for each site, and compared them between sites with false and correct predictions using the non-parametric Mann-Whitney U-test. This statistical tool compares the distributions of the value of several parameters between two groups, and computes the probability that they were selected from different populations. For this study, we compared slab properties: thickness, density, bridging, hardness, and normal and shear stress on the weak layer resulting from the weight of the slab and the slope angle; and weak layer properties: crystal size, thickness, and hardness. In addition, for the comparison we expanded the dataset to include test columns that were outside the recommended standard length (i.e. less than 0.85 m and more than 1.15 m) to investigate the role of test column dimensions in controlling predictive success of the PST.

3. RESULTS

Table 1 summarizes the results of testing at the whumpf and avalanche sites for each season, individually and combined. The predictive success of the PST is relatively consistent between the seasons, with 76% and 71% of tests in 2007 and 2008, respectively, correctly predicting the fracture propagation that led to the whumpf or avalanche. The rate of false stable predictions is therefore 24% and 29% for the two seasons. Combined, 73% of tests made correct predictions about the propagation propensity in this dataset, while 27% of tests made false stable predictions. In 2007, only two sites had tests that made contradictory predictions, i.e. both a correct and a false stable; in 2008 there was only one such site. This suggests that PST results are relatively consistent at a given site, whether or not the prediction is correct.

As reported by Gauthier and Jamieson (2008b), false stable predictions of the PST were more often found in thinner, and less stiff (less bridging) slabs, with larger weak layer crystals. Those properties were significantly different ($p < 0.05$) between the sites with correct and false stable PST results. Slab density, hardness, and overburden stress at the weak layer were not significantly different between the groups, and nor were weak layer thickness or hardness.

Using only the data from 2007, when we compared the column lengths of tests with correct and false stable predictions, we found that false stable tests had significantly longer test columns ($p < 0.01$) than those making correct predictions. In this dataset, most of the tests were close to either 1 m or 1.5 m long, suggesting that tests of the recommended 1 m length have fewer, although not zero, false stable predictions.

4. DISCUSSION

The comparison of test predictions presented here, and the more complete

Table 1. Summary of results of testing at whumpf and avalanche sites in 2007 and 2008, showing rates of correct and false stable predictions, as well as number of sites having conflicting predictions.

Season	2007	2008	2007+2008
Sites tested	17	16	33
Tests Performed by event type:			
Sr	*15*	*15*	*30*
Sa/Sc	*4*	*13*	*17*
Whumpf	*10*	*6*	*16*
Na	*0*	*4*	*4*
Total	29	38	67
Tests that correctly predicted event	22 (76%)	27 (71%)	49 (73%)
Tests with false stable prediction	7 (24%)	11 (29%)	18 (27%)
Slopes with both	*2*	*1*	*3*

Avalanche event types: Sr, remotely triggered by skier; Sa/Sc, accidentally or intentionally triggered by skier; Na, natural or spontaneous trigger; whumpf, propagation on low angle terrain triggered intentionally or accidentally.

comparison presented by Gauthier and Jamieson (this volume) shows that the PST is relatively successful at predicting the weak layer fracture propagation associated with whumpfs or avalanches. Birkeland and Simenhois (this volume) have found correct predictions by the PST in 65% of tests on unstable slopes, albeit with some identified limitations in the sample. The PST also seems able to correctly predict that propagation will not occur better than other methods; however, this skill comes at the expense of making a relatively high rate of false stable predictions. For practical uses in instability assessments in the field, this type of error can be high consequence – most professionals would likely prefer to err on the side of caution and predict instability and back away from a slope when the snowpack is in fact stable, than make the opposite mistake and trigger a dangerous avalanche when a slope is assumed stable.

The analysis of test dimensions and snowpack properties between correct and false stable predictions showed that false stable test results are more likely in thinner, less stiff slabs, with larger weak layer crystals. In addition, longer test columns (i.e. 1.5 m) tended to have more false stable predictions, although many were also found in tests of the recommended length, and many correct predictions came from longer columns. Taken together, the snowpack and column size control over the success of the PST suggest that rather than having a single column size for every snowpack, the better approach may be to scale the test dimensions to the slab of interest. This type of dynamic test method based on snowpack properties reduces the practicality and ease of use of the PST, but may improve the success of its predictions and confidence in using the PST as part of an instability assessment. For example, the recommended column size could be scaled to the thickness of the slab, e.g. column length equal to slab thickness. This would require an extra measurement (slab thickness), but might reduce the ratio of correct to false stable predictions to a more acceptable level.

Physically, some of the dependencies of the predictive success of the PST on slab and weak layer properties and test dimensions may be due to mechanical effects that cause the PST to poorly reproduce the interaction between the slab and fracturing weak layer under certain conditions. The PST was designed to faithfully replicate the propagation process that occurs in an undisturbed snowpack during avalanche release or whumpfing; however, we are aware that the ‘beam’ geometry of the PST is distinct from the more three-dimensional ‘slab’ geometry of the natural process. Especially for collapsing weak layers, in the PST the slab is put into a state of more or less two-dimensional bending with the passage of the weak layer fracture that propagates uniformly upslope (Figure 1). Alternatively, a slab in the field may behave more like a ‘tensile mesh’ as weak layer collapse and fracture, and associated slab bending, propagates radially away from the trigger (Figure 2). Beam geometry and bending are well known by engineers, and this behaviour has been used to develop new theories on how the mechanics of weak layer collapse and slab bending may occur (Heierli, 2005; Heierli and Zaiser, 2006, 2008). Similar principles have been applied to the dynamic structural collapse of slab-style

Figure 2. A researcher investigates the perimeter slab fracture surrounding a small whumpf. Note the radial propagation pattern from the trigger point (foreground), which is distinct from the more two-dimensional geometry of the PST (e.g. Figure 1). (Bruce Jamieson photo)

concrete buildings and other structures (like parking garages), except in three dimensions both the behaviours of the structural elements, and the equations describing them, are different.

In the PST, we have found that often the false stable test results require a relatively short cut length to initiate propagation (less than 50% of the test column), but that propagation is unsustainable by the slab, which fractures after a short distance and interrupts propagation. This highlights the idea that the third dimension on the slope provides support to the slab, and may enable it to sustain the bending associated with weak layer collapse and fracture propagation. In the PST, the slab may fail under the demands of propagating the weak layer fracture, in the same snowpack that could propagate fractures on an adjacent slope. All of this suggests that future analytical or theoretical models describing the fracture propagation process should be expanded into the third dimension, and include some term to account for the ability of the slab to sustain propagation over a large distance. Ideally, we could better understand the mechanics of how the PST column behaves compared to adjacent slopes.

5. CONCLUSIONS

This study, and several previous ones, have shown that the PST has a relatively consistent false stable rate of 25-30% at whumpf or avalanche sites. The false stable test predictions are more likely in thinner, softer slabs with larger weak layer crystals, and longer test columns. The dataset in this study shows that at a given site, usually all tests make correct predictions, or all make false stable predictions. This suggests that doing more than one or two tests doesn’t necessarily improve the chance of getting a better prediction, although we always recommend that instability assessments be based on the results of several tests and using several different methods, along with other snowpack, weather, and terrain observations.

Future research into the snowpack properties and column size control over the accuracy of the PST predictions is required, and should focus on determining the ideal or best performing column size for a given slab and weak layer combination. One idea would be to scale the test column length to slab thickness, so that as the slab gets thicker and stiffer the tests get longer. This might help improve the accuracy of and confidence in the predictions of the PST, and may help drive the next stages of modeling how fractures propagate in the PST and on adjacent slopes.

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7. REFERENCES

Birkeland, K., and Simenhois, R., 2008 (this volume). The Extended Column Test: Test effectiveness, spatial variability, and comparison with the propagation saw test. Proceedings: 2008 International Snow Science Workshop, Whistler, BC, *In Press*.

Gauthier, D., and Jamieson, B., 2006. Understanding the propagation of fractures and failures leading to dangerous and destructive snow avalanches: recent developments. Proceedings: 2006 Annual Conference of the Canadian Society for Civil Engineering, First Specialty Conference on Disaster Mitigation, Calgary, AB, 010-1 – 010-9.

Gauthier, D., and Jamieson, B., 2008 (this volume). Predictions of the Propagation Saw Test: Comparisons with other instability test at skier tested slopes. Proceedings: 2008 International Snow Science Workshop, Whistler, BC.

Gauthier, D. and B. Jamieson. 2008a. Evaluating a prototype field test for fracture and failure propagation in weak snowpack layers. Cold Regions Science and Technology, 51(2-3), 87-97, doi:10.1016/j.coldregions.2007.04.005.

Gauthier, D. and Jamieson, B., 2008b. Fracture propagation propensity in relation to snow slab avalanche release: Validating the Propagation Saw Test, Geophysical Research Letters, 35, L13501, doi:10.1029/2008GL034245

Heierli, J., 2005. Solitary fracture waves in metastable snow stratifications. Journal of Geophysical Research, 110, F02008, doi:10.1029/2004JF000178.

Heierli, J., and Zaiser, M., 2006. An analytical model for fracture nucleation in collapsible stratifications. Geophysical Research Letters, 33: L06501, doi:10.1029/2005GL025311.

Heierli, J., and Zaiser, M., 2008. Failure initiation in snow stratifications containing weak layers: Nucleation of whumpfs and slab avalanches. Cold Regions Science and Technology, 10.1016/j.coldregions.2007.02.07

Sigrist, C., and Schweizer, J., 2007. Critical energy release rates of weak snowpack layers determined in field experiments. Geophysical Research Letters, 34, L03502, doi:10.1029/2006GL028576