THE PROPAGATION SAW TEST (PST): A REVIEW OF ITS DEVELOPMENT, APPLICATIONS, AND RECENT RESEARCH

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ABSTRACT: The Propagation Saw Test (PST) method was developed independently in Switzerland and in Canada in 2005 and 2006. It was inspired partly by observations of fracture propagation in earlier cantilever beam tests, and was partly based on notched-specimen tests that are common in fracture mechanics research. The PST has been used - in various modified forms - for investigation and verification of both shear-fracture and weak layer collapse failure models, for spatial variability studies, and for real-world avalanche forecasting and instability assessment. Many PST research and development studies have been conducted over the last several years, and recently there has been some debate regarding the best methodology and interpretation or application of test results. For these reasons, and given the recent or forthcoming adoption and standardization of the PST method by a number of international avalanche associations, we feel that researchers and practitioners could benefit from a comprehensive review of the development of the PST, its applications, and recent research which makes use of it. In this paper, we briefly review peer-reviewed articles, conference papers and presentations, and academic theses related to: the general test configuration and its relationship to fracture mechanics; the results of field experiments designed to test the influence of column size, cut direction, and slope angle on the test method; observations of 'critical' cut lengths, independent of column size in standard and non-standard test geometries; the empirical relationship between snowpack parameters and PST results; the basis for the original and modified test dimensions and methods; the verification of the method and validation of its application to the initiation and propagation of fracture; its applications to other research problems, such as fracture mechanics and spatial variability.

1. INTRODUCTION

During the winters of 2005 and 2006, both Swiss and Canadian researchers developed an identical field method designed to investigate the propensity of a given slab-weak layer combination to propagate weak layer fracture or failure. That test has since come to be known as the 'Propagation saw test' or 'PST'. The method involves using a standard snow-saw to cut along a weak layer within a completely isolated column of snow, which measures 30 cm across-slope by 1 m or greater upslope (Figure 1). Typically, sustained self-propagation will occur across the test column where propagation propensity is high.

For this review paper, we have two main goals: First, to highlight the development, validation, and applications of the PST since 2005; and second, to compile a comprehensive reference list of PST-related research.

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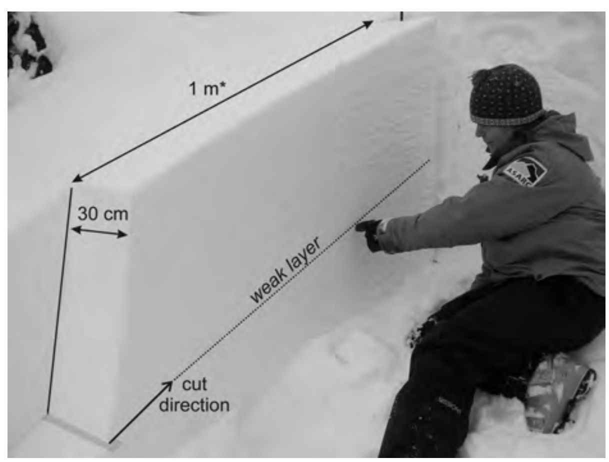

Figure 1. Example of a test column prepared for the PST. Weak layer is cut with a standard snow saw from the downslope end. ASARC photo.

2. DEVELOPMENT OF THE PST

Notched-specimen beam tests are common in fracture mechanics research, including for snow; Sigrist (2006) used one in the laboratory during experiments into the tensional fracture of snow slabs. Sigrist (2006) and Sigrist and Schweizer (2007) modified the method for use on in-situ snowpacks, and for weak layer fracture. They were able to evaluate the method analytically and estimate fracture energy (or resistance) from the slab properties and cut length.

Gauthier and Jamieson (2006a) based their version of the PST on cantilever-beam studies of Johnson (2000), Johnson et al (2000), van Herwijnen (2005), and van Herwijnen and Jamieson (2005) and described preliminary development work on the PST during the spring of 2005. They spent the winter of 2006 in the field evaluating the influence of test geometry, methodology, and snowpack properties on the PST. Gauthier and Jamieson (2006a,b,c; 2007) and Gauthier (2007) reported that:

- The cut length was often independent of column size, as expected of a fracture test
- The cut length sometimes got longer as the test columns were extended, although in weak layers this dependence broke down in columns greater than about 1 m long
- Propagation could arrest at an arbitrary location in the test column, at a break through the slab, or cross the test column uninterrupted
- The 'critical' cut length (independent of column size) and a consistent arrest type was identifiable in columns 1 m long in a typical selection of snowpacks. Longer columns did not provide additional information.
- The PST worked on flat terrain as well as on slopes, and with different thickness of saw cuts (Ross, 2010; Ross and Jamieson, 2012) from either end of the column. The slope effects were minimal, if they existed at all.
- The cut length was highly dependent on slab thickness, so that all things being equal a thicker slab required a longer cut (as expected by fracture theory).
- Therefore, the most important information about propagation propensity in the PST is related to the existence of the critical cut length, and the arrest condition.
- The test results indicating higher propagation propensity were shorter, column-size independent cut lengths with extensive propagation across the test column, and no arrest.

Based on these evaluation results, the test configuration and method were settled upon, at least in draft; see addendums to CAA (2007), or Gauthier and Jamieson (2007b), Greene et al (2010), Ross et al (2008a,b), for the complete descriptions.

For particular research applications, the PST has been modified at times to have longer or shorter columns, or have not ben completely isolated from the surrounding snowpack. These variations have not been validated for skier-triggering or avalanche release, and are therefore difficult to interpret, despite their research utility.

3. PST VALIDATION STUDIES

With the goal of understanding how the test related to avalanche release, Gauthier (2007) Gauthier and Jamieson (2008b), Ross (2010), and Ross and Jamieson (2008c, 2009, 2012) compared test results next to skier-triggered slopes, whumpfs, downed-avalanches, with those from 'stable' snow packs. They confirmed that PST was providing faithful data regarding the propagation part of avalanche release using a novel method of identifying cases with initiation of a sub-critical crack but no propagation. Their results showed that cut lengths of less than half the length of the column, followed by uninterrupted propagation to the end of the column, were far more likely to be observed on slopes with confirmed propagation propensity (e.g. whumpfs or avalanches) than those without. However, they also found a relatively high proportion of 'false-stable' results. They also made comparisons with other instability tests, and found that the PST performed well, although was not the best predictor of skier-triggering. Simenhois and Birkeland (2009) and Birkeland and Simenhois (2008) included comparisons between the PST and their extended column test (ECT). Schweizer and Jamieson (2009, 2010) summarized the development and validation of the PST, along with the other common instability tests, for the international audience.

Note that no validation studies have shown that the absolute value of the cut length, alone, is related to avalanche release.

Ross (2010) and Ross and Jamieson (2012) investigated the false stable problem by varying the column size to scale more closely with snow conditions, although they still found that softer, thinner slabs were more prone to false stable results. Bair (2011) and Bair et al (2012a,b) found a similar false-stable issue in non-persistent weak layers.

4. APPLICATONS TO FRACTURE MECHANICS

Sigrist (2006) and Sigrist and Schweizer (2007) used directly the results of the PST to determine the energy release during propagation in the test in various snowpacks, with the goal of characterizing that property of the snowpack. They used a combined shear and collapse model for the failure process, whereas Heierli (2009), Heierli and Zaiser (2007), Heierli et al (2008a,b) leveraged observations of propagation in PSTs on nearly flat terrain, as well as the weak slope dependence of test results (Gauthier, 2007; Gauthier and Jamieson, 2006b, 2007) to validate and explore their anti-crack model. Alternatively, McClung (2008, 2009, 2011a,b) used many of the same data, as well as some from modified PST (no upslope cut to isolate the column from the snowpack) to support a shear-only propagation process model, making a compelling case that the anti-crack is not required to explain propagation on slopes. In any case, all of these are parametric studies that describe and interpret the PST according to a preferred model of the propagation process. As the fracture energy (or its release rate) is a critical parameter in the fracture mechanics approach, other workers have collected PST results for the purpose of calculating it: van Herwijnen and Heierli (2008, 2010), Schweizer and van Herwijnen (2010), Schweizer et al (2010, 2011), McClung and Borstad (2012).

Gauthier (2007) and Gauthier and Jamieson (2007) showed that PST results performed on flat terrain, i.e. replicating a whumpf, did not differ significantly from those performed in the same snowpack on a nearby slope, i.e. replicating an avalanche. Where there was a weak slope dependence, cut lengths were actually shorter on flat terrain. This appears to be a feature predicted by the anti-crack models (Heierli, 2009; Heierli and Zaiser, 2007; Heierli et al, 2008a,b), although McClung (2011a,b) showed that a shear model could explain the same data. Slope dependence of cut lengths notwithstanding, the fact that the PST functions at all on flat terrain, in the absence of shear, and similarly on nearby slopes suggests that weak layer collapse is party to the failure process in both whumpfs and avalanches.

Several other studies were mostly non-parametric, investigating empirically the deformation in the slab during propagation (e.g. Bair, 2011; Bair et al 2012a,b; Borstad and McClung, 2010; van Herwijnen et al, 2010) or crack-face friction (Simenhois et al, 2012; van Herwijnen and Heierli, 2009a,b) in the PST, and by extension, during avalanche release.

5. APPLICATION TO FIELD PROPAGATION PROPENSITY

One of the emerging strengths of the PST seems to be its ability to both measure fracture mechanical properties based on model parameters, and to index propagation propensity in the field, even in the absence of a theoretical framework for the propagation process. Gauthier (2007) provided an extensive discussion of how the cut length and arrest condition related to the test and slope scales, and suggested that the PST indexes the ‘sustainability’ of fracture, by testing the ability of the slab to transmit the failure from place to place via the arrest condition. Gauthier and Jamieson (2010) expanded on this idea, and suggested that propagation models for avalanche release include a sustainability term, which is lacking intrinsically in the fracture mechanics approach, but is tested by the PST.

Studies leveraging the propagation propensity indexing power of the PST typically relate results of the test to different snow conditions (e.g. Bair, 2011; Bair et al, 2012a,b), hypothetical avalanche scenarios (e.g. Harvey and Heierli, 2009; Gauthier and Jamieson, 2010), surface warming (e.g. Reuter and Schweizer, 2012a,b;, Simenhois and Birkeland, 2008a), slab thickness (e.g. Simenhois and Birkeland, 2008b), or even moisture in the slab (e.g. Brown, 2008).

6. OTHER APPLIED STUDIES

Whereas most instability or other field tests rely on some dynamic load to initiate weak layer fracture or failure in isolated columns, which becomes increasingly difficult with increasing slab thickness, the PST has the advantage of being mostly insensitive to slab thickness. Normally, the only practical limit in test scale is the time required to excavate very large columns. This makes the PST ideally suited to studying the problem of deep slab avalanches in the field (Tracz, 2012; Conlan and Jamieson, 2012; Conlan et al, 2012).

Furthermore, the PST has been used in the study of evolving weak layers, particularly buried melt-freeze crusts (Smith et al, 2008; Smith and Jamieson, 2009), and for assessing the stability and evolution of wet slabs (Borgeson and Hartman, 2010).

7. DISCUSSION

In this paper we tried to describe briefly and provide complete references for all of the publications relevant to the PST. We included articles found in peer reviewed journals, conference proceedings (including ISSW 2012, this volume), association or trade journals, self-published items, and standards documents. The only significant source that we omitted intentionally was abstracts presented at the various assemblies of the European Geophysical Union. We chose to omit them because typically only abstracts are published, and because for the vast majority, similar studies were presented in other formats that are included here.

The propagation saw test was developed as a tool for both researchers and practitioners, and has been used extensively to study theoretical and empirical fracture mechanics, field instability assessment and propagation propensity, and to track the evolution of the propagation potential of various snow conditions. It is not likely the best possible propagation test, and is certainly not perfect. However, the strength of the PST method is in its ability to separate the initiation of sub-critical weak layer fracture or failure from its propagation.

The PST seems to have significant limitations in its use as a general instability test for skier-triggering, given its relatively high false stable rate; however, the ECT has proven to be impressive in this aspect. Birkeland and Chabot (2012) compiled user statistics for many instability tests, and the impressive uptake of the ECT by practitioners.

One practical application of the PST not well captured in the reference list is its use as a teaching or demonstration tool. On many Canadian professional level avalanche courses the PST is used to demonstrate propagation, slabs, weak layers, collapse, and about current conditions. The PST has also helped forecasters demonstrate instability conditions in videos posted on the internet.

8. CONCLUSIONS

Hopefully we have succeeded in summarizing the state-of-the-art with regards to the propagation saw test. We have been intentionally cursory in describing the research we cite, with the further hope that the interested reader will seek out the papers on the list and draw their own conclusions.

The PST is clearly not a perfect research tool, nor is it a perfect instability assessment test. We feel that an on-going effort at validating the method and refining interpretation guidelines is critical to its continued success. This will help applied studies have more significant impact, and may spur the development of a refined or redesigned propagation test method.

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1. What is Exploratory Testing? Exploratory testing is a hands-on approach in which testers are involved in minimum planning and maximum test execution. The planning involves the creation of a test charter, a short declaration of the scope of a short (1 to 2 hour) time-boxed test effort, the objectives and possible approaches to be used. The test design and test execution activities are performed in parallel typically without formally documenting the test conditions, test cases or test scripts. This does not mean that other, more formal testing techniques will not be used. For example, the tes...