Available online at www.sciencedirect.com
ScienceDirect
Cold Regions Science and Technology 51 (2008) 87–97
cold regions science and technology
www.elsevier.com/locate/coldregions

Evaluation of a prototype field test for fracture and failure propagation propensity in weak snowpack layers

Dave Gauthier [a,*], Bruce Jamieson [a,b]

[a] Department of Civil Engineering, University of Calgary, 2500 University Drive NW, Calgary, AB, Canada T2N 1N4
[b] Department of Geology and Geophysics, University of Calgary, Calgary, AB, Canada

Received 24 October 2006; accepted 13 April 2007

Abstract

Researchers and practitioners currently lack a quantitative field test that indicates the propensity of a given slab and weak layer combination to propagate weak layer fracture and failure to an extent that leads to avalanching. We report on the development of such a test and the evaluation of a prototype test method. This test allows researchers to observe propagation and arrest away from the initial weak layer failure by extending the down slope dimension of the small column stability test. Weak layer failure is initiated by cutting the weak layer with a 2 mm thick snow saw either from the upslope or down slope end of the isolated column. Depending on slab and weak layer characteristics, weak layer fracture/failure propagates from the edge of the saw and propagates either to the end of the column, to an indistinct point, or to the vicinity of a fracture through the thickness of the slab. During the winter of 2006, University of Calgary researchers performed over 600 of these tests in the Columbia Mountains of British Columbia, Canada, and the Rocky Mountains in Alberta, Canada. Results of our experiments allow for an evaluation of the relationship between isolated column length and cut length required to initiate propagation in this test. We evaluate the effect of slope angle and cut direction on test results, and propose a standard test column geometry. We relate our results to shear fracture and weak layer collapse theoretical models.

Keywords: Fracture propagation; Field test; Extended column; Snowpack stability; Avalanche forecasting

1. Introduction

The failure in a weak snowpack layer that leads to a slab avalanche starts in a relatively small area and propagates up, down and across the slope. The result is often a large avalanche if the slab-weak layer system has a pre-existing propensity to propagate such failures (van Herwijnen and Jamieson, 2007). Existing snowpack stability tests are probably better at evaluating the likelihood of weak layer fracture and failure initiation than the likelihood of it propagating rapidly and widely. Therefore, avalanches sometimes occur unexpectedly when existing methods indicate stability. More often, conventional field tests indicate instability or high likelihood of initiation but fail to capture low propagation propensity, and therefore low likelihood of avalanche (Schweizer et al., 2006). For example, weak layers overlain by slabs less than approximately 0.2 m thick often fail in stability tests, but are rarely able to propagate fractures far enough to release a slab ava-

* Corresponding author.
E-mail address: davidmgauthier@gmail.com (D. Gauthier).

0165-232X/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.coldregions.2007.04.005

lanche (van Herwijnen and Jamieson, 2007). Schweizer et al. (2003) highlighted the need for a better understanding of the propagation process, and specifically recommended that future research seek to develop a test for propagation propensity in the field.

Both the solid-material shear fracture mechanics (FM; e.g. McClung, 1979, 1981; Bazant et al., 2003; Louchet, 2001a,b) and the weak layer collapse (WLC; Heierli, 2005; Heierli and Zaiser, 2006, 2007) models describing propagation provide descriptions of how a flaw or crack might start to propagate in a highly porous (weak) snowpack layer. Both types of theoretical models predict that in slab-weak layer systems with higher propagation propensity, a smaller initial failed area is required to trigger propagation at a given stress level, although they differ in describing what 'propagation propensity' means physically. In general, the current FM models are restricted to sloping snowpacks, whereas early WLC models describe propagation on horizontal terrain (e.g. whumpfs; Heierli, 2005; Heierli and Zaiser, 2006). Schweizer and Kronholm (2006) included components of collapse failure and shear fracture in their conceptual model, and calculations showed that shear fracture might be the dominant failure mode only on steeper slopes (Sigrist, 2006; Sigrist and Schweizer, 2007), which led to the application of WLC analytical models to sloping terrain (Heierli and Zaiser, 2007). In FM models, low *fracture* 'toughness' or 'resistance' at the weak layer indicates high propagation propensity. The equivalent property in WLC models is resistance to structural *failure* by a succession of *fractures* in the ice-skeleton of the weak layer. In this paper we use the term 'fracture propagation' without bias for the FM or WLC description of the progressive fracture processes that may lead to the failure of a weak snow layer's ability to provide vertical and shear support to the overlying slab.

We report on the evaluation of a prototype field test for propagation propensity. We used a test column geometry that allows for quantitative observations of propagating fractures (Gauthier and Jamieson, 2006a), and a method of initiating propagation that is consistent with both WLC and FM theories (Gauthier and Jamieson, 2006b; Sigrist and Schweizer, 2007). This test allows us to observe propagation and arrest away from the trigger of weak layer failure by extending the down slope dimension of a small column stability test method. Fracture propagation is initiated by cutting the weak layer with a 2 mm thick snow saw either from the upslope or down slope end of the isolated column. We consider this saw cut that leads to propagation in the field test to be analogous to the flaw or crack on a slope that propagates and leads to avalanche release, and we expect that where propagation propensity is high a shorter cut length, which is independent of test column length, will be required for propagation to cross the test column.

Based on results collected in the winter of 2005, Gauthier and Jamieson (2006b) described several possible relationships between the isolated column length and the cut length in this test in a given snowpack. They showed that in some cases a large proportion of the test column must be undercut prior to any propagation occurring, meaning that longer columns would require longer cuts (constant proportion; CP). Some of their data, like that of Sigrist (2006) and Sigrist and Schweizer (2007), showed that cutting a consistent absolute length of weak layer (critical length; CrL) would initiate propagation, regardless of column length.

In this paper, we report on approximately 600 tests performed in the winter of 2006. We use these results to evaluate our test method and further define the relationship between the length of saw cut and the column length in different snowpacks, and the role of fracture arrest in the column in defining propagation propensity. In addition, we attempt to assess the effect of slope angle and cut direction on test results. We discuss these relationships in terms of FM and WLC processes, and describe the further development of test geometry and methods.

2. Methods

2.1. Test geometry and method

For this study, we used a similar isolated column geometry to that presented by Gauthier and Jamieson (2006a), but here we initiate propagation as described by Gauthier and Jamieson (2006b). The test geometry and method are identical to the independently developed one presented and analyzed in Sigrist (2006) and Sigrist and Schweizer (2007). Simenhois and Birkeland (2006) also presented a similar geometry in their 'extended column test', in which the test column was extended *across* the slope. Our test columns were completely isolated or detached from the surrounding snowpack to a depth below a weak layer of interest, 0.3 m wide in the cross-slope direction, and between 0.3 m and greater than 4 m in the down slope dimension (Fig. 1a). The test columns usually had one side and the down slope end completely exposed by shovelling. The remaining side and upslope end were isolated from the surrounding snowpack using a vertical saw cut or by cutting with a cord. Rarely, we