TENSILE STRENGTH AND STRENGTH CHANGES IN NEW SNOW LAYERS

Arthur I. Mears*

ABSTRACT. The tensile strength (rupture modulus) of new snow layers was measured at a 3,200m elevation Colorado site during February and March, 1998 to determine a) if the cantilever-beam test produced consistent results within a layer at a given time and b) to measure the change in strength over a period of days. 80 tests were conducted on 16 layers by calculating tensile strength at ruptureon cantilever beams 10 to 16 cm thick which were excavated into the new snow. The strength tests a) produced reasonably consistent results, and b) indicated a substantial increase in tensile strength within the snow layers tested during a period of 2 to 4 days after a fresh snowfall. Two periods of widespread, natural soft-slab avalanches occurred in the new snow prior to tensile-strength increases. Natural avalanche activity stopped as the snow layers increased in strength by approximately a factor of two.

KEYWORDS. avalanches; snow mechanics; snow strength.

1. INTRODUCTION

In order for slab avalanches to release, tensile fracture at the crown must accompany widespread shear fracture within a weak layer at or immediately above the bed surface (McClung and Schaerer, 1993). A weak bed layer appears to be a pre-requisite for most slab avalanches because the bed is typically on the order of 100 times larger than the other fracture surfaces of the slab combined. Consequently, most tests of snowpack stability concentrate on identifying and evaluating weak shear layers.

A number of studies have also measured tensile strength at rupture of snow samples (Roch, 1966; Perla, 1969; McClung, 1979; Conway and Abrahamson, 1984; Russo, 1987; Jamieson and Johnson, 1990). These tensile-strength tests have used a variety of equipment, sampling methods, sample sizes and applied stress rates. In general they have found a) strength decreases with sample size, b) strength decreases with rate of stress application, c) strength increases with density increase in a given snow type.

Because settlement usually increases snow density quickly after a new snowfall, particularly at warmer snow temperatures, an increase in tensile strength probably also occurs. Tensile strength increase may be an important factor in re-stabilization of snow slabs. Therefore the magnitude of tensile strength increase in new snow immediately following a storm can be of interest in stability evaluation.

*Author Address: Art Mears, 555 County Rd. 16, Gunnison, CO 81230, U.S.A.; email: artmears@rmii.com.

The objectives of this study are two fold: a) to determine if the simple cantilever-beam test can produce consistent tensile-strength results in new snow layers thus avoiding the need for specialized equipment, and b) to determine the relative increase of tensile strength in a new snow layer during a few days following a snowfall.

2. EXPERIMENTAL PROCEDURE

The cantilever beam was used as the method to measure tensile strength because it does not require use of special equipment. The beams can easily be excavated and measured with a shovel, snow saw, tape measure, and density kit. This equipment is readily available, commonly used, and easily transported.

The cantilever beam tests were conducted as outlined below.

A trench approximately 3m wide was excavated through the full depth of the new snow layer. A wide trench was needed because five tests were done at each site each day to determine the consistency of results. Tests in this study were all done on at a level study area, although they can also be done on a slope as described in the following section.

Snow columns approximately 20cm wide were then cut into the trench wall in preparation for each test. Columns were not cut at the back. Care was taken to ensure each column was of constant width.

Cantilevered snow beams were then excavated into each column near the vertical mid-point of the new snow layer after removing the top 5cm of new snow. Beams were constructed 10-16cm thick and were carefully undercut ensuring that the thickness was constant for the entire length of the beam. The beams were undercut until they fractured in tension at the upper back end. The strength of a beam which is loaded only by its own weight is independent of width in uniform snow.

After the beam fractured, length, L (m), thickness, T (m), density ρ (kg/m^3) and snow temperature were recorded. In low-density new snow the beams were usually 5% to 10% longer at the top where the snow was less compressed and weaker. An average length was used in calculations.

To control the accuracy of the tests, each beam was carefully formed. The thickness and width were kept as constant as possible (in practice, to within about 5mm). Excavation of a single beam typically required 2 to 3 minutes, however, undercutting the final 10% to 20% of the length, which produced the highest tensile stresses, took only about 30 seconds. Although the rate of applied stress could not be accurately recorded, stress appeared to have been applied sufficiently fast to place factures within the brittle range (Narita, 1980; Jamieson and Johnson, 1990). Therefore tensile strength was probably not overestimated due to ductile deformation. The entire sampling procedure, including excavation, forming the five beams, and recording the data typically required about one hour.

3. FORMULAS USED TO CALCULATE STRESS

Calculation of stresses applied engineering formulas which are widely used in design of structures (e.g. Timoshenko and Young, 1962). Maximum tensile and compressive stresses develop in the plane where a horizontally cantilevered beam is attached to a vertical wall, (the snow trench wall, in this case). Maximum tensile stresses occur at the top of the intersection of the beam with the wall. During all cases observed in this study the tensile fractures first occurred at this upper, back location. The magnitude of the maximum tensile stress in a horizontal cantilever is calculated

$$\sigma = (3\rho g L^2)/T, \qquad (1)$$

where σ is the maximum tensile stress at rupture (Nt/m^2, or Pa), ρ is the snow density (kg/m^3), g is gravitational acceleration (m/s^2), L is beam length (m), and T is beam thickness (m). The computed tensile stress was converted to kPa by dividing the results by 1000.

In addition to the tensile stresses discussed above, the fracture surface is also subject to shear stresses resulting from the weight of the beam. The fact that shear stresses act on the fracture surface simultaneously with tensile stresses does not appear to significantly affect the shape of the fracture in these tests.

A snow beam, however, unlike most engineering materials, is highly porous, compressible, and very near its melting point. The strength of snow is known to be highly dependent on the rate of applied stress, (McClung, 1979; Narita, 1980; Conway and Abramson, 1984; Jamieson and Johnson, 1990) because, if given sufficient time dutile deformation, compression, and rearrangement of grains will occur in the snow and the strength will change. To minimize time-dependent strength variations, the rate of applied stresses was kept fairly constant in these tests. Because stresses increase in proportion to L^2 (equation [1]) and the plane of tensile stress shifts inward toward the final fracture plane as the beam is undercut, the maximum stresses developed in less than 30 seconds in all cases.

All of the tests in this study were done on a level study plot at 3,200m elevation. They can also be done on a slope. However on a slope a component of gravitational acceleration acts parallel to the beam, therefore equation (1) must be modified to

$$\sigma = [\rho g(3L^2\cos\theta + TL\sin\theta)]/T \qquad (2)$$

where θ is the slope angle, in degrees and T is beam thickness (m). The cantilever beam test can therefore be done at an avalanche crown surface fracture face by applying equation (2).

4. TEST RESULTS

4.1 Consistency of results

Consistency of results is shown by comparison of tensile strength values obtained within each layer on each test day. The 16 groups of five tests conducted for this study had an average coefficient of variation of 0.15 and a range of 0.03 to 0.32. The results are reasonably consistent.

4.2 Strength change with time

Substantial increases in tensile strength also occurred as the new snow layers increased in age and density. Within the four layers tested, tensile strength increased substantially, (Table 1).

Table 1. Strength change with time

Layer	Beg σ	End σ	Age
A	1.69kPa	9.25kPa	4 days
B	0.77kPa	2.46kPa	3 days
C	0.65kPa	8.29kPa	3 days
D	0.86kPa	1.37kPa	2 days

In Table 1, σ = mean tensile strength of the five tests in each layer at the beginning of testing on each layer (Beg) and at the end of testing (End). The age of the layer at time of the last test is also given.

5. DISCUSSION OF RESULTS

The tensile-strength tests conducted indicate the following: a) tensile strength values can be consistently estimated with the simple cantilever-beam test, and b) the tensile strength increases substantially over time within a given layer.

A widespread cycle of spontaneous or "natural" soft-slab avalanche activity occurred the first day of tests on two layers but was not observed on subsequent days as the tensile strength increased by approximately a factor of two. This suggests the instability and tendency for natural slab releases may be correlated with tensile strength increase within the new snow layers.

The cantilever-beam is clearly inferior to the various uniaxial tensile-strength tests because only the top fiber of the snow is subject to the maximum tension, thus only a small surface area is tested. In spite of this important limitation, the test does appear to produce reasonably consistent results and can be used to document tensile strength changes within new snow layers over time. An increase in tensile strength appears to be correlated with restabilization of natural, soft-slab avalanches, based on the limited number of observations made in this study.

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