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A RECOMMENDATION FOR THE APPLICATION OF THE ROCH INDEX FOR SLAB AVALANCHE RELEASE

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ABSTRACT. Detailed measurements on several avalanches verify that a Daniels' (1945) type statistical correction to Roch's (1966) stability index would accurately predict snow-slope instability. It is recommended that one-half the median of at least 50 shear-strength measurements be used as a measure of the strength of a weak layer.

RÉSUMÉ. *Conseils pour l'application de l'indice de Roch pour le déclenchement des avalanches de plaque.* Des mesures détaillées sur de nombreuses avalanches vérifient qu'une correction statistique du type de celle de Daniels (1945) apportée à l'indice de stabilité de Roch (1966) procurerait une prévision précise de l'instabilité d'une pente de neige. On recommande de prendre comme résistance de la couche fragile la moitié de la moyenne d'au moins 50 essais de cisaillements.

ZUSAMMENFASSUNG. *Eine Empfehlung zur Anwendung des Roch-Index für den Abgang von Schneebrett-Lawinen.* Detaillierte Messungen an verschiedenen Lawinen bestätigen, dass eine von Daniels (1945) angegebene, statistische Korrektur zu Rochs (1966) Stabilitätsindex die Instabilität eines verschneiten Hanges exakt voraussagen würde. Es wird empfohlen, die Hälfte des Mittels von wenigstens 50 Messungen der Scherfestigkeit als Festigkeit einer schwachen Schicht anzunehmen.

INTRODUCTION

Sommerfeld and others (1976) proposed a correction factor for Roch's (1966) stability index based on the thread-bundle statistics of Daniels (1945). Support for the application of such statistics to shear measurements in snow was obtained from unpublished data collected by R. I. Perla. The data used, however, were mixed data in that they consisted of only a few shear-strength measurements, each on many avalanches. We would like to present some data from experiments designed specifically to test the application of Daniels' (1945) statistics to shear measurements. In these tests many measurements were made on a few avalanches.

The relevant relationship from Daniels (1945) is

$$\frac{\mathrm{d}S}{\mathrm{d}s}=\frac{\mathrm{d}}{\mathrm{d}s}\left\{s\int_{s}^{\infty}f(\sigma)\,\mathrm{d}\sigma\right\}=0 \qquad (1)$$

where $f(\sigma)$ is the probability density of the breaking stresses within the body, s is the stress on each surviving element, and S is the stress on the tested surface at failure. Daniels developed this relationship for bodies with discrete elements (thread bundles) but the use of the integral implies that the body is continuous, and has a continuous distribution of strengths within it. Because of the large number of grain-to-grain bonds in macroscopic samples of snow, this assumption does not lead to significant error. The assumptions implicit in Daniels' analysis are that a continuous distribution of strengths exists in the body under test, and that the failure of one part of the body does not lead to a catastrophic failure of the entire body, as would be the case with a Griffith (1920) type failure. Although Daniels applied his theory to tensile tests, it is seen that it can be applied in general to strength tests where the two assumptions are valid.

In common with other statistical strength theories, Daniels' theory predicts that the particular distribution parameters will depend on the area of the shear frame. However, if the theory is correct, the calculated Daniels strength should be the same regardless of the area of the shear tester. In Daniels' terms, the strength of a bundle of threads will not vary whether $f(\sigma)$ is determined for individual threads, or for groups of threads.

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DATA

Eight avalanches, generally less than 24 h old, were studied. The sliding layer was identified for each avalanche. Three stations were established at spots along the slab crown. In one case (Alta, 1/14/76 I) only one station showed a well-defined sliding layer so only data from that station were used. At each station the slab thickness and the bed-surface inclination were measured. The density of the slab at each station was determined by sampling at several points through the thickness of the slab, then the snow was excavated to a point approximately one meter uphill from the crown at each station. This was done to avoid the possibility that the sliding layer had been disturbed by the avalanche release (personal communication from C. C. Bradley). A number of shear measurements were then performed with the Roch (1966) 100 cm^2 frame according to the method illustrated in Perla and Martinelli (1976).

DATA ANALYSIS

Shear stresses on the sliding layers were calculated assuming a planar slab of uniform thickness equal to the crown height D from the relationship

$$\tau_{xy} = D\sigma g \sin \theta \qquad (2)$$

where τ_{xy} is the shear stress, ρ the slab density, g the acceleration of gravity, and θ the slope inclination (Perla and Martinelli, 1976).

Finite-element analysis by Curtis and Smith (1974) shows this to be an accurate estimate for cases where large shear displacement has not occurred in the basal layer. For cases where large displacement has occurred, the shear stress may be 50% to 60% higher than Equation (2) indicates. Since the analysis of Curtis and Smith is based on the assumption that all shear support is lost well down-slope from the crown, their analysis probably overestimates the increase in shear stress. However, the fact that the shear stress would increase indicates that once a significant portion of the slope has failed (at the Daniels strength) the shear stress would rise and the shear failure would propagate in an unstable manner throughout the layer. These results provide strong support for Perla's ([1975]) notion of progressive fracture in snow-slab release.

The measured shear strengths were fitted to three different distributions: the normal, log-normal, and gamma distributions. In each case the distribution with the best fit, determined by χ-square and log-likelihood tests, was used to find the Daniels failure stress. Results are given in Table I. No single distribution function accurately represented all the cases. Although there is some theoretical evidence that the normal distribution is not realistic for snow strength, it was the only distribution function that accurately fitted the data in two cases. In other cases only one of the other two functions fitted the data adequately. In general

TABLE I. AVALANCHE DETAILS AND STATISTICAL DATA DERIVED FROM THE MEASUREMENTS

Avalanche	*Trigger*	*Distribution with best fit*	*Number of samples*	α*	β*	*Median strength* N m^{-2}	*Daniels' strength* N m^{-2}	τ_{xy} *stress* N m^{-2}
Alta, 14 Jan. 76 I	HE	Normal	20	2 423	1 300	2 379	1 257	1 260
Berthoud, 14 Jan. 76	N	Normal	50	1 345	693	1 290	703	702
Loveland, 15 Jan. 76	N	Gamma	50	1.975	528.5	1 023	437	527
Alta, 17 Jan. 76	N	Gamma	55	2.173	610.98	1 030	567	587
Berthoud, 17 Jan. 76	HE	Log-normal	50	8.345	0.586 0	4 003	2 183	2 153
Alta, 25 Mar. 76	Ski	Normal	71	2 410	1 493	2 550	1 224	496
Bridger, 21 Apr. 76 I	Ski	Gamma	60	5.266	18.488	90.5	50	48
Bridger, 21 Apr. 76 II	HE	Gamma	60	7.384	115.63	855	470	280

* α and β are the mean and standard deviation for the normal and log-normal distributions and the shape and scale parameters for the gamma distribution.

the function which fitted the data best also gave a Daniels stress closest to the calculated shear stress. The Loveland and Bridger I avalanches were exceptions to this. In each case, Equation (1) was solved for s by numerical methods.

DISCUSSION

In six of the eight cases studied the agreement between the calculated stress and the Daniels strength is remarkable. In most cases, the slide was less than 24 h old when tested. In one case (Alta, 25 March 1976) the slide had occurred more than 48 h before the measurements. It shows a Daniels strength 2.5 times the calculated stress. This result is expected since snow rebonds within 48 h.

Table I lists the sample median strengths. In each case the Daniels strength is approximately one-half the median (average = 0.52). This result is a reflection of the fact that the coefficient of variation is approximately the same for all the avalanches. Since the coefficient of variation should be a function of the shear-frame area, the factor of one-half should only hold for the 100 cm^2 shear frame. The fact that the coefficient of variation is relatively constant for many different types of snow must be related in some fundamental way to snow texture and the relationships of the grain bonds.

The data indicate that a practical method of predicting instability could be developed by using a statistical correction of the Daniels type to Roch's stability index. It would be necessary to locate potential sliding layers in a snow pit, and perform approximately 50 shear-frame measurements. A sufficiently close approximation to the Daniels strength would be one-half the median of these measurements. This corrected strength would then be compared with the shear load on the layer, calculated according to Equation (2).

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