THE EFFECTS OF TEMPERATURE ON SHEAR FAILURE OF ALPINE SNOW

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INTRODUCTION

Studies at fracture lines of fallen dry snow slabs show that the stratigraphy consists of a relatively thick slab on top of a thin, weak layer. A principal result of Perla's (1971) doctoral thesis is that shear failure in the weak layer (or at the slab-weak layer boundary) is a pre-requisite for slab avalanche release.

The strength and deformation characteristics of alpine snow depend on the rate of deformation as well as the physical properties of the material. One of these properties which has not received much attention is snow temperature. In this paper, we discuss temperature effects on shear failure from two perspectives: (1) evidence from slab avalanche fracture line data, and (2) failure characteristics as a function of temperature measured in a cold laboratory.

FRACTURE LINE DATA

Perla (1976) published fracture line data which included failure (bed surface) temperature and estimates of applied bed surface shear failure stress. Since the shear stress estimates in the data are not normally distributed, we used rank correlation to relate the two variables. The analysis showed that bed surface shear stress level had positive rank correlation (0.29) with temperature. Thus, there is a slight tendency for higher shear failure level to be associated with warmer bed surface temperature. We attribute this to a "height" effect: warmer bed surface temperatures will generally be found deeper in the snow cover and avalanches which fail at these depths generally do so at higher applied shear stress. The rank correlation coefficients for failure temperature with average slab density and slab thickness are 0.24 and 0.23 respectively. We conclude that the fracture line data yield little physical information about the effects of temperature on slab release: the data merely conform to the known result that temperatures in an alpine snow cover usually increase with depth.

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COLD LAB TESTS

Since the field data do not yield much insight, we performed slow shearing tests in a laboratory. The tests were done using an NGI (Norwegian Geotechnical Institute) direct simple shear apparatus (see e.g. Bjerrum and Landva, 1966). The equipment requires a cylindrical sample 115 mm in diameter and about 20 mm high. Our results were obtained by shearing the individual samples at a constant temperature and displacement rate, but we varied the rates from test to test to illustrate temperature effects in combination with rate effects. In addition to force and displacement measurements during shearing, we also measured acoustic emissions. Acoustic emissions are elastic waves generated as the sample deforms. They are caused by brittle bond fractures and possibly by rubbing of adjacent crystals during the deformation. If a sample is sheared with a near absence of emissions, it is deforming plastically and the chances of catastrophic brittle fracture are reduced.

The lab results show that test temperature has profound effects on shear failure characteristics. When samples of similar type are sheared under the same normal load, our data show that acoustic emissions increase by an order of magnitude as test temperature decreases from -1°C to -15°C (rate of shearing 0.1 mm/min). However, at a slower rate of shearing (0.01 mm/min), the number of emissions remains negligibly small in the temperature range of interest (-1°C to -15°C). Therefore, two further results seem evident: (1) a critical rate of shearing (0.1 mm/min) is needed to get significant numbers of acoustic emissions, and (2) the critical rate is nearly independent of test temperature in the range of interest for slab failures.

The tests also show that initial sample stiffness increases substantially as the test temperature decreases. This result is expected to have relevance to natural slab release. Colder bed surface temperatures will cause the material to deform more slowly under the same applied load (slab of same density and thickness). Therefore, with colder bed surface temperatures it will be more difficult to achieve the critical rate of shearing needed before brittle fracture can take place. Of course, temperature effects in the slab will also influence stability but a discussion of these is beyond the scope of the present paper.

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