FJELLSPRENGNINGSTEKNIKK
BERGMEKANIKK / GEOTEKNIKK 1975

LAWS OF FRICTION IN SNOW MECHANICS

Friksjonslover i snømekanikk

Dr. David M. McClung, Norwegian Geotechnical Institute

SUMMARY

Laws of sliding and friction are of primary importance in the determination of pre-fracture conditions for slab avalanches as well as for practical considerations such as determining snow pressure loads on constructions built in mountainous terrain.

This paper is concerned with the laws of friction and sliding for two cases: Snow gliding (when the entire snow pack slides over the ground) and 2. Shear failure within a thin layer of dry snow.

SAMMENDRAG

Lovmessige sammenhenger for glidning og friksjon i snø er av den største betydning for å bestemme betingelsene umiddelbart før brudd i et flakskred og likeledes for praktiske vurderinger som å bestemme snøtrykk mot bygningskonstruksjoner i fjellet.

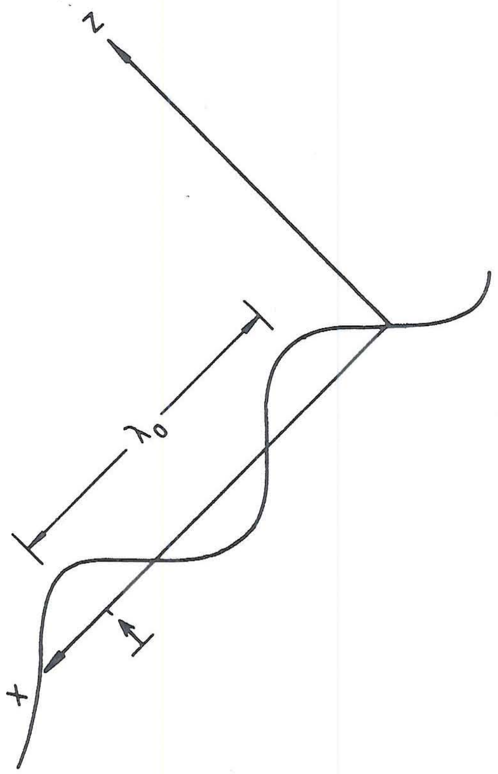
Denne artikkelen behandler lover for friksjon og glidning i to tilfeller: 1. Glidning av snø (når hele snølaget glir langs underlaget) og 2. Skjærbrudd i et tynt lag av tørr snø.

1. LAWS OF FRICTION IN RELATION TO SNOW GLIDING

Snow gliding is the slow, steady slip of the entire snow pack over the ground. The fundamental problem in relation to snow gliding is the relationship between the average shear stress τ_{xz} and the slip velocity U_o.

A. GLIDING ON ROUGH SURFACES

Consider first the problem where the ground over which the snow is gliding is composed of a spectrum of different sized and shaped roughness obstacles. We begin by considering the simple problem where the roughness obstacles are sinusoidal in shape (Figure 26.1). It is an experimental fact that water must be present at the base of the snow pack for glide to occur. Thus, we take the average shear stress, τ_{xz}, to be the downslope component of the normal stress on the obstacles.



BED GEOMETRY $Z_0 = A \cdot \sin(K_0 X)$

$$K_0 = \frac{2\pi}{\lambda_0}$$

Fig. 26-1. Definition of geometry for snow gliding over a rough surface.
Definisjon av geometri for glidning av snø på en ru flate.

One mechanism by which snow may glide over the obstacles is by slow, viscous creep. If we solve for the stress and flow over the roughness obstacles considering the snow to be Newtonian viscous we obtain the following sliding law:

$$\tau_{xz} = (\mu A^2 K_o^3) U_o \tag{1}$$

where μ is the shear viscosity and the other terms are defined in Figure 26.1.

Another mechanism which may be operative is pressure melting or regelation. Snow melts under pressure and this makes possible melting on the uphill sides of the obstacles with refreezing on the downhill sides with heat flow through the obstacles maintaining the sliding process. If this heat flow problem is solved, the relationship between the shear stress and the slip velocity is:

$$\tau_{xz} = \frac{A^2 L K_o}{4CK} U_o \tag{2}$$

where K is the thermal conductivity, L the latent heat and C the slope of the temperature-pressure curve in the pressure melting process.

Thus, both of these mechanisms show a linear dependence of shear stress on glide velocity with the constant of proportionality depending on geometry and physical constants relevant to snow.

The *creep mechanism* will be faster over large obstacles with respect to width. *Pressure melting* and subsequent gliding may be faster over the smaller obstacles with respect to width because such obstacles would present shorter heat conduction paths. These processes will, in general, proceed at different rates for a given geometry. The process which proceeds at the faster rate will most important to determining the sliding law under a given set of conditions.

B. SNOW GLIDING ON SMOOTH SURFACES

The fastest field measurements of snow gliding are on smooth surfaces such as smooth grass or rock surfaces. In this case, there are few obstacles to provide stress concentrations for creep or for pressure melting so it is possible that the snow pack may simply slide over the ground.

Hafeli (H. Bader, and others [1939]) conducted experiments of snow blocks sliding over a glass plate for various interface temperatures and applied normal stresses. Haefeli's experiments showed a linear relationship between τ_{xz} and slip velocity. The results of his experiments may be written:

$$\tau_{xz} = K'U_o \tag{3}$$

where K' depends upon the normal stress, σ_N and the interface temperature, T_i.

It is evident that if rougher surfaces had been used, K' would have been increased so that, in general, K' would depend upon geometry. Figure 26.2 shows Haefeli's results for the case where $\sigma_N = 0.49 \times 10^4$ N/m^2. The figure shows straight line relationships for a dry ($T_i < 0°C$) interface, a partly wet ($T_i \simeq 0°C$) interface and a wet ($T_i > 0°C$) interface.

C. TOWARD A GENERAL THEORY OF SNOW GLIDING

It seems evident that any of the mechanisms of gliding can as a first appromimation be described by the following equation:

$$\tau_{xz} = \Lambda\, U_o \tag{4}$$

where Λ depends on the geometry and the amount of water available for lubrication of the interface surface.

If more water is available than just a thin film, it is possible that on rough surfaces, small roughness obstacles will be drowned out increasing stress concentrations on the larger obstacles resulting in faster creep. On the other hand, regelation would tend to be suppressed under these conditions resulting in slower contribution from this mechanism. If obstacles were nearly drowned, separation might occur and sliding might take over as the mechanism.

Gliding measurements were conducted at the Norwegian Geotechnical Institute's research station in Grasdalen, Stryn, Western Norway during the 1974–75 sesson. These

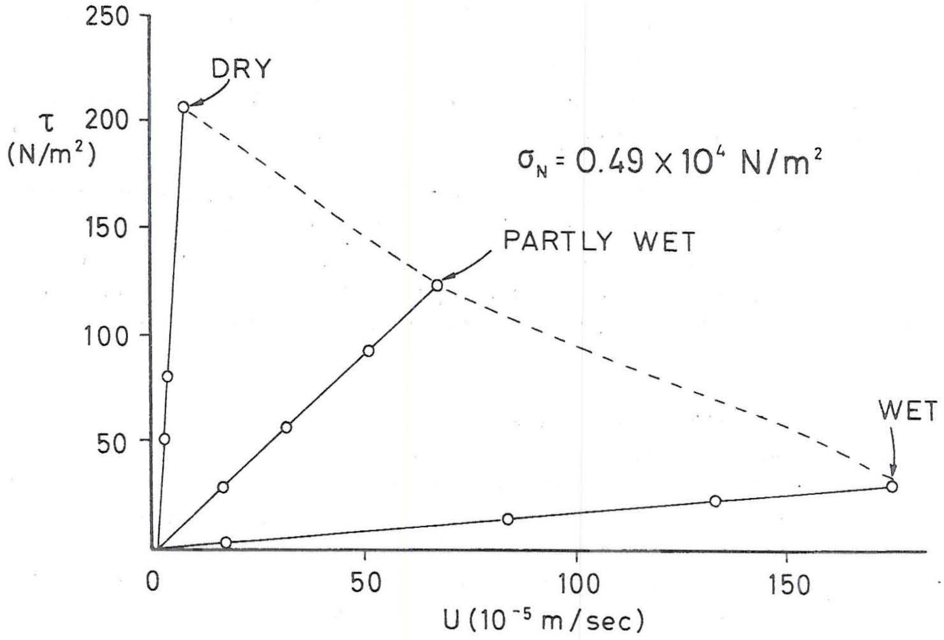


Fig. 26-2. Result of Haefeli's experiment of snow sliding over a glass plate.
Resultat av Haefeli's eksperiment med snø glidende på en glassplate.

experiments were conducted on rock slabs which had only small scale roughnesses. These experiments showed very small glide rates unless rain or melt water was reaching the interface. These experiments indicate that the pressure melting mechanism is very slow in the natural snow pack and perhaps it is not a viable sliding mechanism. This is a reasonable result since body weight stresses in the seasonal snow pack would not be expected to be high enough to provide pressure melting.

Crack formation and full depth spring wet avalanches are associated with times when excessive melt water or rain water is present in the snow pack. Under these conditions we expect that increased creep rates or sliding rates over a region at the base of the slab will result in high tensile stresses and promote wet slab avalanche release. The transition from a region of slow sliding to a region of fast sliding in a wet snow slab is analogous to strain softening processes seen in other geotechnical sliding processes.

2. FAILURE WITHIN A THIN WEAK LAYER OF DRY SNOW: FRICTION OF SNOW ON SNOW

Snow stratigraphy studies at the fracture line of slab avalanches show that the situation often consists of a layer of harder, wind packed snow overlying a thin weak layer. Shear failure within a weak layer is the most obvious starting point for evaluating the conditions previous to fracture for this situation.

In order to determine the field conditions relevant to this problem in-situ shear creep rates were undertaken in Grasdalen, during the 1974–75 season. These creep rates along with similar data measured by the author during 1972–73 and 1973–74 in the USA indicate

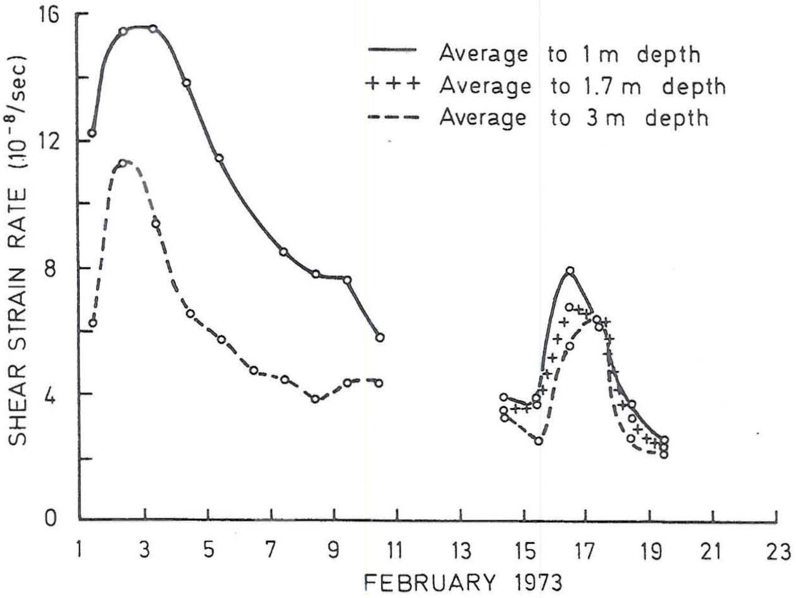


Fig. 26-3. Estimates of insitu shear strain rate in snow.
Anslag over insitu skjærdeformasjonshastighet i snø.

that during times when slab avalanche hazard is high, shear creep rates are high and snow properties are rapidly changing. Figure 26.3 shows an example of the data measured during 1973 by the author. Slab avalanche fracture lines were observed on February 2 following a storm with a deposit of new snow, while conditions were stable by February 10. The peak near February 17 is due to rain. These measurements qualitatively indicate that time dependence will be important in dealing with slab avalanche problems.

The most important measurement relevant to studying the failure conditions at the fracture line is the relationship between the shear stress τ_{xz} and the deformation under the expected conditions. Such measurements were initiated during the 1974–75 season in the cold laboratory of the research station in Grasdalen. The measurements were made with the direct simple shear equipment described by Bjerrum and Landva (1966) employing wire reinforced rubber membranes to maintain plane strain conditions.

Figure 26.4 shows a typical set of results from these tests. The shear strength of the snow is taken to be composed of cohesion in the form of bonds between snow crystals and a residual friction after the bonds are broken. If a region at the base of a snow slab has softened to a residual friction, high tensile stresses will be promoted in the region between the softened area and the unsoftened area and the likelihood of tensile fracture and subsequent avalanching is greatly promoted.

These tests represent the first reported measurements of peak to residual strength for snow and they show the effect of strain-softening for the first time in snow. These properties will be important to the evaluation of shear failure as a mechanism of slab avalanche release.

All of the concepts and field and laboratory tests mentioned in this paper will be reported in detail in the Norwegian Geotechnical Institute Publication series.

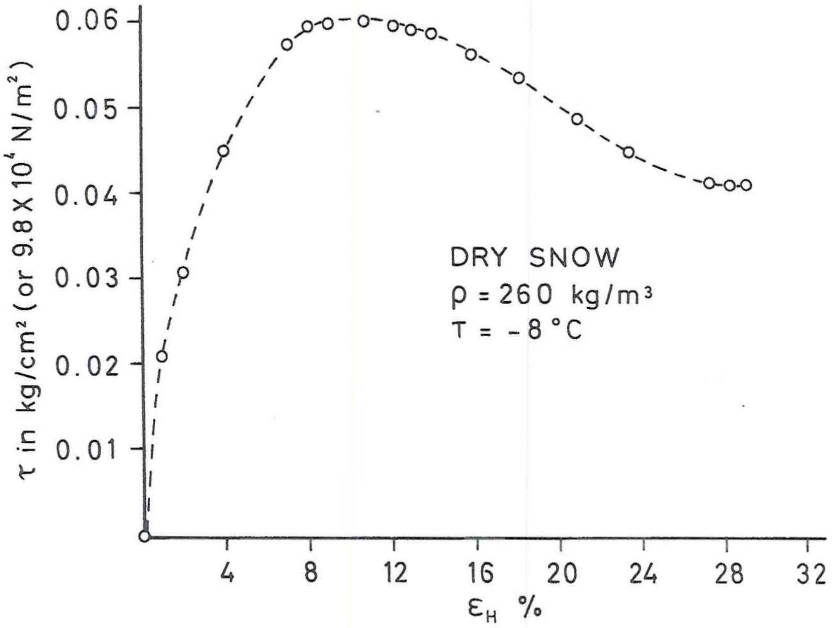


Fig. 26-4. Typical result of direct simple-shear test on cohesive snow.
Typisk resultat av direkte skjærforsøk på kohesiv snø.

REFERENCES

H. BADER, R. HAEFELI, E. BUCHER, J. NEHER, O. ECKE, C. THAMS, P. NIGGLI. Beitrage zur Geologie der Schweiz. Geotechnische Serie. Hydrologie, Lief. 3. (English Translation: U.S. Snow, Ice and Permafrost Research Establisement. Translation 19, 1954).

BJERRUM, L. AND A. LANDVA, 1966. Direct Simple-Shear Tests on a Norwegian Quick Clay. Geotechnique, Vol. 16, No. 1. London, p. 1–20.

PERLA, R. I. (1974). Stress and Progressive Fracture of Snow Slabs. Union Géodésie et Géophysique Internationale. Association Internationale d'Hydrologie Scientifique. Commission des Neiges et des Claces. Symposium on Snow Mechanics, Grindelwald, Switzerland, 1–4, 5–4, 1974. In press.

McCLUNG, D. M. (1974). Creep and the Snow-Earth Interface Condition in the Seasonal Alpine Snow-Pack.

Union Géodésie et Géophysique Internationale. Association Internationale d'Hydrologie Scientifique. Commission des Neiges et des Glaces. Symposium on Snow Mechanics, Grindelwald, Switzerland, 1–4, 5–4, 1974. In press.

McCLUNG, D. M. (1974). Avalanche Defense Mechanics. (Ph. D. Thesis, University of Washington, Seattle, Washington, 1974). Unpublished.