DISCUSSION OF DEFORMATION MEASUREMENTS IN RELATION TO SNOW SLAB RELEASE

D.M. McClung

Field Observations and Their Relation to Snow Slab Release

Snow stratigraphy studies at avalanche fracture lines indicate that the situation may be viewed essentially as a thick slab overlying a thin failure plane (often termed a sliding layer). If this simple picture is adopted, there are two basic types of deformation to be considered:

1. deformation in the body of the slab including shear deformation and settlement, and

2. deformation along the failure plane.

The first type of deformation is easily measured by inserting lightweight objects in the snow, e.g., ping-pong balls, poles, sawdust columns, etc. Figure 1 shows typical data obtained by measuring the tilt of poles with a Haefeli inclinometer (Haefeli, 1967).

Deformation along the failure plane is more inaccessible to measurement, and yet may be potentially the more important. In the absence of field measurements, one may only speculate on events that occur along the failure plane. A few clues are provided from inspection of slab fracture lines. In many cases, but not all, the failure plane is quite thin and weak and it is possible that shear failure propagated over a widespread area before the slab exhibited tension cracks. Since the tension fractures are generally perpendicular to the shear failure plane, the indication is that most, or all, of the friction in the sliding layer has been removed prior to, or simultaneous with, the tensile fracture (Haefeli, 1966; Perla and LaChapelle, 1970; Perla, 1975).

With respect to shear failure in the sliding layer, perhaps a key question is whether the initial failure is slow or rapid. If the initial failure in the sliding layer is a rapid, brittle fracture, then slab release may be so fast that deformation measurements may be of little use in providing precursor information for avalanche forecasting.

If the initial shear failure in the weak layer is slow, then it is possible that the snow is exhibiting "strain-softening", an effect observed in clays and similar materials.

Laboratory experiments (McClung, 1976) (Fig. 2) consistently show that snow samples lose their resistance to sustaining shear stresses after horizontal displacements of several millimeters. If this were to happen in a weak layer underlying a snow slab, a region of tensile stress would be produced in the slab. In the vicinity where the slow shear failure (softening) is taking place, the tensile stress would increase with time as would stored visco-elastic strain energy in the slab as the softened region expands.

Although there is some laboratory evidence that snow can strain-soften in shear, unfortunately, field evidence for this effect remains inconclusive, and the rate of progression of shear disturbances is still an open question. Some important implications for avalanche control depend on a knowledge of the shear disturbance. For example, if the conditions in the slab are near to critical and the friction in a bedding plane has been largely removed by a slow shear failure, then the best position to place a shot might be near the expected fracture line. However, if the conditions are not near to critical, as would be expected more often, then better results would be expected by shot placements near the centre or lower part of the slab. This would enable initiation of shear fracture in the bedding plane over as wide an area as possible and maximize the amount of bedding plane friction removed before tensile fracture through the body of the slab. Of course, this kind of reasoning ignores possibilities such as shooting at exposed masses of rocks near expected fracture lines to aid in propagation of shock over wide areas.

Deformation Measurements in Relation to Snow Slabs Underlain by Weak Layers Exhibiting Strain Softening

If a weak layer is undergoing plastic deformation (e.g., strain softening) while the main body of the slab is undergoing visco-elastic deformation, relative slip may be produced resulting in a situation analogous to glide. Under these conditions, if the softening progressed slowly up the slope, a distribution of relative slip would be produced in the weak layer.

A measure of the relative slip at a given point in relation to the deformation in the slab is the geometrical parameter, D, called the stagnation depth. The stagnation depth is defined as the point at which the averaged deformation profile meets the y axis (Fig. 3). By this definition, D=0 when there is no relative slip and D increases with relative slip, so that a distribution of relative slip implies a distribution of D. If one, however, defines an average, $\bar{D}$, over the region in which softening is taking place, it can be shown that tensile stresses in the slab increase with $\bar{D}$ (McClung, Paper in preparation). Also, for a given amount of slip, larger tensile stresses are expected for stiffer snow in the body of the slab.

However, there is a second aspect to the problem. If slip takes place coincident with expansion of the softened region, the material in the slab must be deformed (visco-elastic strain energy will be accumulated in the body of the slab). Resistance to expansion of the failed (softened) region in the weak layer is less if the slab material is softer.

Knowledge of relative slip produced in a weak layer is not generally accessible to measurement. However, it may still be profitable to record average creep rates through the new snow layers in connection with the direct action soft slab as measured, for example, with the Haefeli inclinometer.

If the creep rates are high, indicating low viscosity, the probability that the failed (softened) region can extend is higher. This is so since the necessarily accompanying deformation in the slab is easier for softer material in the slab. On the other hand, for the same slip, the stiffer the slab, the higher the tensile stresses.

For thin slabs subject to warming, creep rates will increase, resulting in lower viscosity in the body of the slab, thereby possibly provoking release.

It should be remarked that sliding of new layers of snow of low viscosity can also provide additional shear stresses to participate in sympathetic release of deep slabs which are near to critical conditions. However, it would be expected that increases in shear stress due to the loading effect of new snow falling would be the most common effect precipitating natural deep slab release. Such reasoning, however, might provide a partial explanation of the apparent observed increase in deep slab instability accompanied by warming trends without additional snow loads (Wilson, 1976).

References

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Discussion

BAY: You mentioned that you measure creep on a slope by measuring the inclination of poles. How deep do you insert your poles?

MCCLUNG: One to three meters, depending on snow depth.

KUCERA: Is bending of the poles a problem?

MCCLUNG: The poles are relatively rigid and pole bending does not lead to a serious error. It is possible to account for the bending error.

LACHAPELLE: A brief comment. The technology for making tilt measurements with electronic tiltmeters is quite advanced. Tilt could be a useful index if we knew how to interpret the measurements.

LANG: In the analysis of tilt measurements, is it possible to differentiate the creep from glide or slip?

MCCLUNG: I know of no way to separate the effects. Measurement of the deformation across a shear discontinuity is an interesting problem and central to the slab avalanche release mechanism.

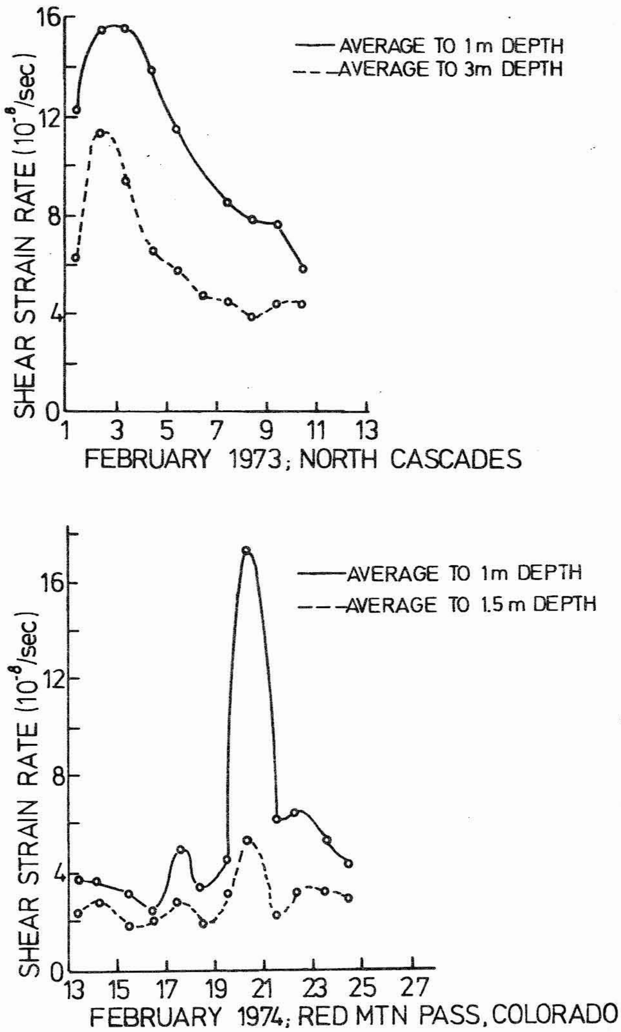

FIGURE 1 CREEP RATES MEASURED WITH THE HAEFELI INCLINOMETER IN THE NORTH CASCADES (a) AND NEAR RED MOUNTAIN PASS, COLORADO (b) SMALL DIRECT ACTION SOFT SLABS WERE OBSERVED ON FEBRUARY 2 NEAR WHERE THE MEASUREMENTS WERE MADE FOR (a). FOR (b), SMALL DIRECT ACTION SOFT SLABS WERE OBSERVED IN THE AREA AROUND FEBRUARY 20. THE HIGH CREEP RATES WERE COINCIDENT WITH NEW SNOWFALL

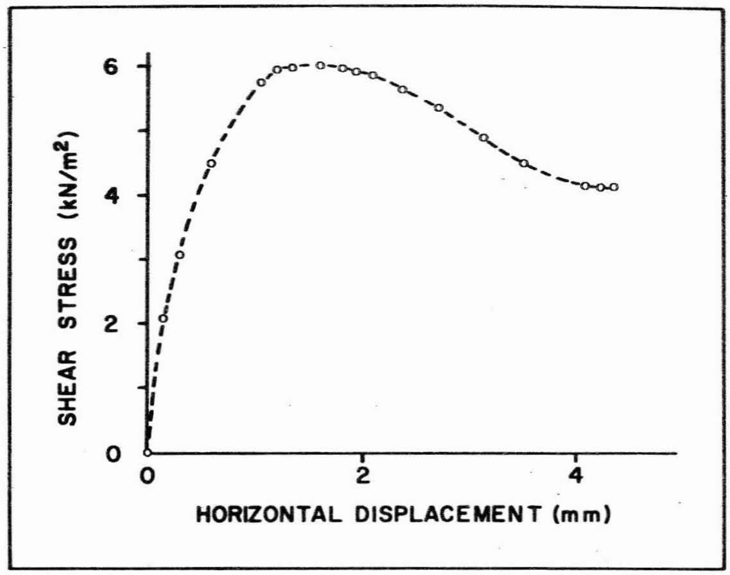

FIGURE 2 LABORATORY MEASUREMENT OF SHEAR STRESS VERSUS HORIZONTAL DISPLACEMENT FOR A THIN, DRY SAMPLE OF SNOW

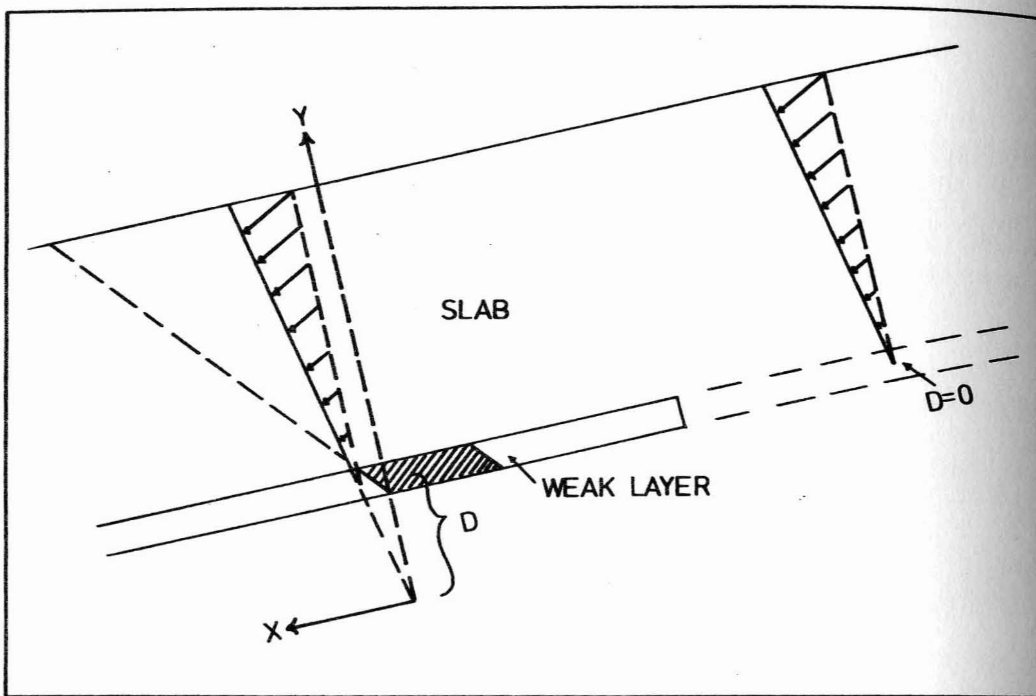

FIGURE 3 SCHEMATIC SHOWING DEFINITION OF STAGNATION DEPTH AS A RESULT OF PLASTIC DEFORMATION IN WEAK LAYER