SOME INSIGHTS INTO FRACTURE PROPAGATION IN WEAK SNOWPACK LAYERS

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ABSTRACT: Dry snow slab avalanches form when fracture, once initiated in a weak snowpack layer, propagates over large distances, progressively debonding a vast area of slab on its passage. Over the past decades the underlying fracture process has mostly been attributed to the growth of a volume-conserving shear crack, but in reality the fracture is most often accompanied by a rearrangement of the grains in the weak layer, causing a reduction in specific volume and a slope-perpendicular settling of the slab during the fracture process. This has important consequences both in theory and in practice. This contribution presents insights into a new theory of fracture propagation in snow based on the principles of mixed-mode anticracking at the fracture front. We find that fracture is propagated by a stable, kink-shaped wave travelling with sub-shear velocity through the snowpack. We also find that the fracture energy, despite being a crucial factor that determines whether fracture can be triggered or not, has negligible influence on the propagation of fracture after a supercritical crack has been formed. We use our model to calculate the deformation profile at the fracture front and compare the mathematical results with measured deformation profiles obtained from field experiments. The accordance between the theoretical and experimental results is very satisfying.

1. INTRODUCTION

The purpose of this contribution is to give a few insights into a newly developed theory of fracture propagation in snow. The theory is based on the principles of mixed-mode anticracking at the fracture front (Heierli et al., 2008, 2010) and describes the steady-state propagation of collapse in a cohesive-granular weak layer. The aim is to properly understand the process of fracture propagation afar from the trigger point.

2. FIELD EXPERIMENT

Position markers are apposed to the lateral surface of a field sample which is brought to failure by saw-cutting (Fig.1). The motion of the markers is recorded on high-speed video and analyzed with particle image velocimetry. For details see van Herwijnen et al., (in press).

3. MODEL CALCULATION

The mathematical model takes into account the forced subsidence of the layers above the fracture plane, caused by the volumetric collapse of the previously supporting weak layer. The main ingredients for the calculation are: (i) plane strain deformation, (ii) uniform, linear-elastic slab material, (iii) fully brittle weak layer material, (iv) a rigid substrate, (v) negligible resistance to collapse (van Herwijnen and Heierli, 2009). Except for the elastic modulus of the slab, all necessary material properties and geometrical characteristics were measured in the field. The elastic modulus was determined using a phenomenological model obtained for strain rates comparable to those of the collapse waves (Sigrist, 2006).

4. DISCUSSION AND CONCLUSION

Besides the simplifying assumptions of a uniform slab material, plane-strain deformation and a linear material model, the important assumptions of the physical model are i) brittle failure and ii) crack propagation by mixed-mode anticracking of the instant crack tip.

We find that fracture is propagated by a stable, kink-shaped wave travelling with sub-shear velocity through the snowpack. We also find that the fracture energy, despite being a crucial factor that determines whether fracture can be triggered or not, has often negligible influence on the propagation of fracture after a supercritical crack has been formed.

We conclude:

1. For a highly heterogeneous and variable material such as snow, the accordance between theory and experiment is remarkable. Comparison with other field data show similar agreement.

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2. The essential features of steady-state fracture propagation through collapsible snowpack layers are captured by the mathematical model.
3. According to the model, fracture energies on the order of 0.1 Jm^{-2} or below have negligible influence on steady-state fracture propagation.
4. The new knowledge can be used to search for criteria whether the current snowpack conditions are favorable or unfavorable for fracture propagation over large areas and, consequently, propitious for slab avalanches.

6. ACKNOWLEDGEMENTS

Financial support by the DFG project Gu367/30 is gratefully acknowledged.

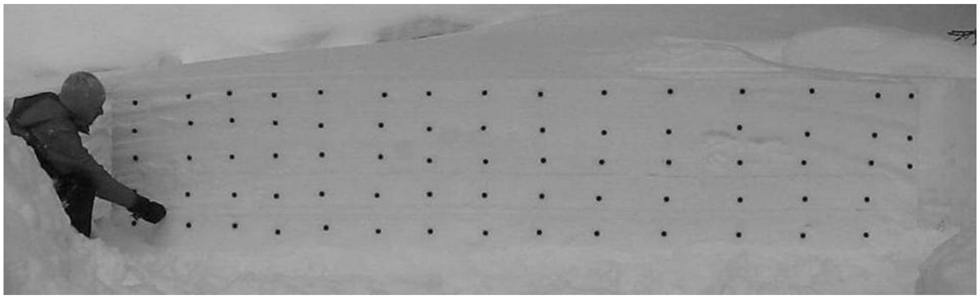

Figure 1. Field experiment: Fracture is about to propagate at one go through the sample.

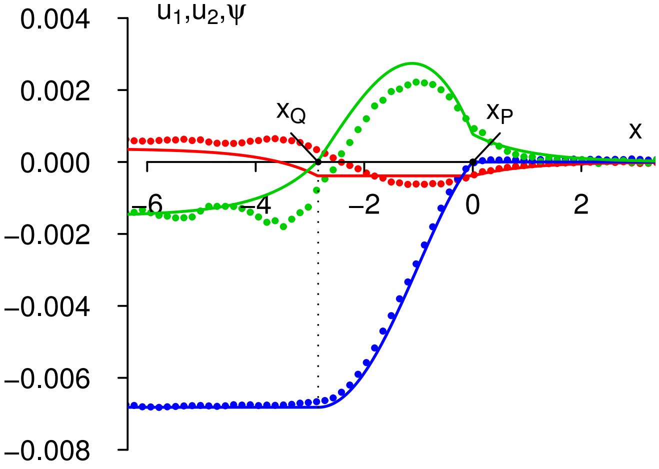

Figure 2. Deformation profiles during passage of collapse wave (calculated: solid lines, versus measured: points). Red: slope-parallel displacement of a point on the center line* (u_1). Blue: slope-normal displacement of a point on the center line* (u_2). Green: average rotation angle of cross-section (Ψ, rad). x : instant position with respect to crack tip*, x_P : instant position of crack tip, x_Q : instant position of wave tail.

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* expressed in units of slab thickness.

Table 1. Field data for Figs. 1 and 2.

slab density	slab thickness	E-Modulus	Slope angle	Collapse amplitude	Wave velocity
150 kg/m^3	0.66 m	10 MPa	0	5 mm ± 2 mm	30 m/s±2 m/s

6. REFERENCES

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