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Towards a mechanical failure model for degrading permafrost rock slopes representing changes in rock toughness and infill

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The climate-induced degradation of permafrost in mountain areas can reduce the stability of rock slopes. An increasing number of rockfalls and rockslides originate from permafrost-affected rock faces. Discontinuity patterns and their geometrical and mechanical properties play a decisive role in controlling rock slope stability. Under thawing conditions the shear resistance of rock reduces due to lower friction along rock-rock contacts, decreasing fracture toughness of rock-ice contacts, diminishing fracture toughness of cohesive rock bridges and altered creep or fracture of the ice itself. Compressive strength is reduced by 20 to 50 % and tensile strength decreases by 15 to 70 % when intact saturated rock thaws (KRAUTBLATTER ET AL. 2013). Elevated water pressures in fractures can lead to reduced effective normal stresses and thus to lower shear strengths of fractures. However, the impact of degrading permafrost on the mechanical properties of intact or fractured rock still remains poorly understood.

In this study, we develop a new approach for modeling the influence of degrading permafrost on the stability of high mountain rock slopes. Hereby, we focus on the effect of rock- and ice-mechanical changes along striking discontinuities onto the whole rock slope. We aim at contributing to a better rock-ice mechanical process understanding of degrading permafrost rocks.
For parametrisation and subsequent calibration of our model, we chose a test site (2885 m a.s.l.) close by the Zugspitze summit in Germany. It reveals i) a potential rockslide at the south face involving 10E4m^3 of rock and ii) permafrost occurrence due to ice-filled caves and fractures.

Here we combine kinematic, geotechnical and thermal monitoring in the field with rock-mechanical laboratory tests and a 2D numerical failure modeling. Up to date, the following results underline the potential effects of thawing rock and fracture infill on the stability of steep rock slopes in theory and praxis:
i. ERT and SRT measurements confirm that the unstable area lies in a permafrost border zone. The south face of the Zugspitze crest is mainly thawed while the north face shows permanently frozen sections.
ii. High-accuracy movement measurements along discontinuities reveal maximum rates of 73.8 mm/year and an average of 10.26 mm/year (median: 4.01 mm/year).
iii. Brazilian lab tests on saturated Zugspitze limestone show that indirect tensile strength decreases by 30 % from frozen to unfrozen condition.
iv. Saturated Zugspitze limestone shows a decrease by 15 % in P-wave velocity from frozen to unfrozen state.
v. Shear tests on fill material of discontinuities at the Zugspitze crest reveal that shear strength in frozen state is higher than in unfrozen state. Fine grained soil decreases by 5-45 % and coarse grained soil by 35-65 % after thawing.

Krautblatter M, Funk D, Günzel FK. 2013. Why permafrost rocks become unstable: a rock-ice-mechanical model in time and space. Earth Surface Processes and Landforms 38: 876-887.