Earth Surf. Dynam. Discuss.,
https://doi.org/10.5194/esurf-2020-70-AC1, 2020

Interactive comment on "Stability assessment of degrading permafrost rock slopes based on a coupled thermo-mechanical model" *by* Philipp Mamot et al.

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Received and published: 27 December 2020

We thank the two anonymous referees for reviewing our submitted manuscript and writing helpful and interesting comments. However, we would like to shortly respond to some comments of the evaluation of the second referee. While doing so, we will focus on those modelling assumptions which we think are essential:

(i) Saturated frozen condition: We assumed the summit crest to be saturated for the following reasons: Sass (2005, ESPL) and Rode et al. (2016) show that the rock moisture in depths greater than 15 cm does not fluctuate (which occurs near the rock surface due to meteorological influences like precipitation, wind or insulation). Deeper than 15

cm, the rock saturation ranges between approximately 75 and 90 % dependent on the rock type and its porosity. In addition, water saturated rock samples have to be used to calibrate the electrical resistivity of rocks for ERT in rock walls (Krautblatter et al., 2010). The DC conductivity of porous or fractured subsurface matter highly depends on saturation of the pore space and conductivity of the pore fluid (Supper et al., 2014). Only saturated rock samples show a significant difference in conductivity/electrical resistivity when switching from the unfrozen to the frozen state, or vice versa (see also Mellor, 1973). The ER inversions of the presented study or many others in permafrost bedrock confirm that the rock mass under investigation is saturated, since big differences in the ER-values are detected.

(ii) Coupled modelling approach: We interpret the term "coupled thermo-mechanical model" differently. We refer to the fact that we for the first time include frozen and unfrozen bedrock material properties which are assigned to specific regions in the model and changed due to warming. However, we suggest to rename the title into "A temperature-dependent mechanical stability model for degrading permafrost rock slopes", and to adjust the wording in the text.

(iii) General approach: The presented general approach for the set-up of the model and the modelling procedure (Fig. 1) is formulated very generally. It can be easily applied to any degrading permafrost rock wall (if considering the model is temperature-dependent and not a coupled one, and hence, does not require numerical thermal modelling). We proposed one specific way how the set-up of the model and the modelling procedure can be applied to the Zugspitze summit crest. For instance, the conversion of the intact rock properties to those of the rock mass can also be performed by other techniques, like the Q-value.

(iv) Failure mechanism: Planar sliding is clearly the dominant failure mechanism at the site, though it is a combination with a wedge failure. In addition, the transects for the geophysical measurements and the profile for the numerical model run through the stepped planar failure part of the unstable rock mass (shear zones SZ1, SZ4, SZ5; left part in Fig. S2). We can make this clear by adding a comment in the text.

(v) Modelling domain: The numerical analysis was applied to a locally constrained section of the rock slope for the following reasons: (i) The selected model domain fully incorporates the unstable rock mass under investigation. (ii) It perfectly accounts for the spatial conditions of the rock-ice-mechanical processes we want to simulate. (iii) The upper and middle sections of the Zugspitze south slope do not contain significantly lower gradients as in the model domain. In contrast, the talus slope is flatter. However, it starts approximately 200 m below (at 2650 m a.s.l.), and ends in the Zugspitzplatt at ca. 2500 m a.s.l. We expect no big differences in the model results for a bigger size of the model domain, since the slope gradient downslope does not change significantly. However, we will test the potential effect of a bigger model domain size due to additional model test runs.

(vi) Elastic properties: It is true they are not the most important values for the presented numerical calculation, but as we had laboratory values for them we decided to better include them.

(vii) Disturbance factor: The disturbance factor D is set to values higher than 0 if the slope under investigation is affected by significant blast damage. To our knowledge, a standardised recommendation of how to set D for an unstable rock slope without blast damage does not exist so far. Such as recommendation should be numerically validated and include a classification of various degrees of instability. As a consequence, we decided to stick to D = 0, as any other value seems to be arbitrary.

(viii) Fracture displacements: No major openings have been observed along the fractures, so the major measured elongation of crackmeters went into displacements.

The presented model is the first numerical attempt to assess the mechanical response of a permafrost-affected rock slope to warming/thawing. As a consequence, it is impossible to account for all relevant input parameters and possible influences in the first study/article. It is certainly necessary to include hydrostatic pressures or a heat flow

model, and to perform more laboratory tests on mechanical properties in the future.

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