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3 failure limits to relief

Anne Voigtländer¹, Rachel C. Glade², and Jens M. Turowski¹

¹GFZ German Research Center for Geosciences, Potsdam, Germany (anne.voigtlaender@gfz-potsdam.de)

²Los Alamos National Laboratory, Los Alamos, New Mexico, United States of America

Reaching the top of a high mountain is a great experience, yet there seem to be several limits. One is the relief of the mountain itself, which constitutes the driving stress consisting of the height, h , and density, ρ of the mass, accelerated by gravity, g and modulated by the slope, α . The material strength required to balance this stress defines the limit to relief. There are three failure modes in which the material strength can be surpassed: shear, compression, and tension. Failure criteria established for shear and compression have been demonstrated to be useful in certain settings, but don't hold in steep (50-90°), hard and rocky landscapes. For those, we propose a tensile strength limit criterion (TSL). Due to the Poisson effect of normal stress (σ_n), indirect tensile stresses (σ_t) arise near free surfaces. The magnitude of these stresses is defined by the Poisson's ratio (ν) of the lithology and the relief. First-order estimates of different lithologies and their material properties are in good agreement with the height of cliffs and slopes of the same lithology. Similar to the approach by Schmidt and Montgomery (1995) predicting bulk, slope scale material properties from relief, we can invert the tensile strength limit criterion. By this, we can infer material tensile strength and Poisson's ratio from the maximum slope heights and angle on Earth, and beyond!

In terms of dynamics, the tensile strength limit criterion (TSL) predicts critical yielding at the foot of the slope, causing surface parallel fractures that would lead to further critical yielding and failure slope upward. This pattern of progressive rock failure has been observed in steep rock walls, like El Capitan or Half Dome in Yosemite National Park.

We propose this solely geometrically and stress-controlled criterion not contrary but in addition to existing limit criteria. Implications of the three failure limits to relief are that, (i) over-steepening doesn't necessarily exist, as there is not only a threshold slope angle but also a threshold height, (ii) there is a transition from one dominant limit and failure mechanism to the other, shifting from shear failure and sliding to toppling and fall, and (iii) internal material property changes, due to chemical and/or mechanical weathering, and subcritical crack growth can evoke a progressive reorganisation of yielding and potential rock failure without external triggering events.