Landslide Rupture and Length-Depth Scaling

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Introduction

Landslides are often assumed to exhibit self-similarity in their failure geometry and a linear scaling between slip depth and rupture length. Such an assumption has important implications for the prediction of large landslide volumes and for the estimation of erosion budgets by mass-wasting. However, some field data indicate a break from selfsimilarity and imply that in some circumstances landslide depth may scale non-linearly with length. Here we test the simple scaling hypothesis by numerical experiment.

Hypothesis

In the absence of material and topographic complexity, **the maximum depth of landslide rupture scales linearly with rupture length**:

$$z_{\mathrm{m}} = \eta\, L \qquad (1)$$

where z_{m} is the maximum rupture depth (measured vertically), L is the planform rupture length (measured horizontally). This is derived from the following simple scaling of mobilized debris volume V and rupture area A: $V \sim A^{3/2}$ and $V \sim A z_{\mathrm{m}}$. Since $A \sim L^2$,

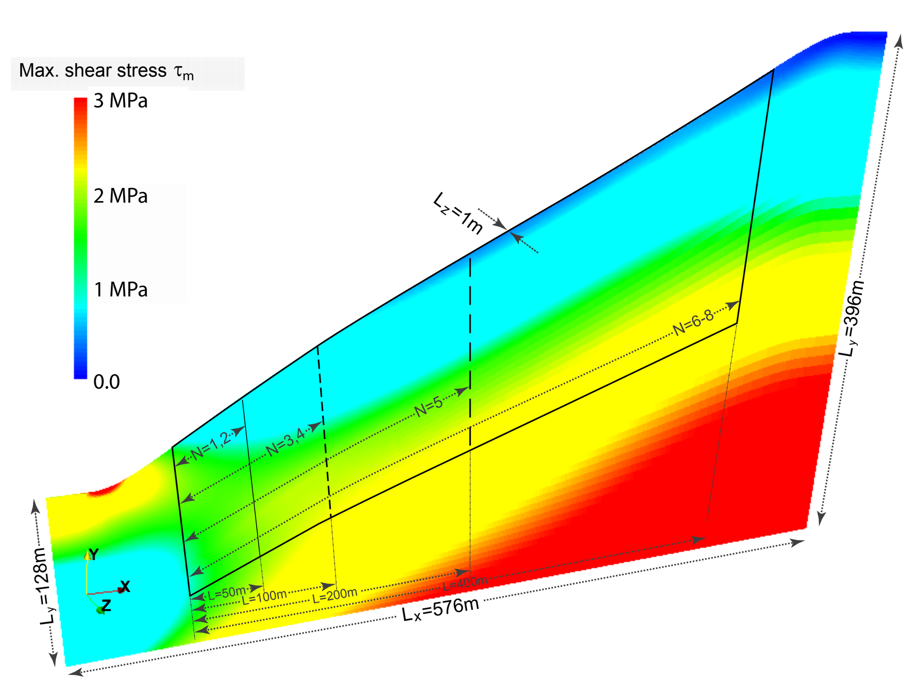
$$z_{\mathrm{m}} \sim A^{\frac{1}{2}} \sim L\,.$$

Previous Studies

The self-similar length-depth scaling hypothesis was first made in the context of landslide area-volume distributions and sediment budget estimation by Hovius et al. (1997) and has been used on several occasions since (e.g., Guzzetti et al., 2009; Lavé and Burbank, 2004; Malamud et al., 2004b). It is often implicit in engineering assessments of slope failure, particularly in modeling treatments that impose an anticipated slip plane in the assessment of a safety factor (e.g., Morgenstern and Price, 1965; Wyllie and Mah, 2004). Linear scaling is also broadly consistent with geotechnical modeling where the plane of failure it not predetermined, for example in studies using commercial codes such as FLAC, FLAC-3D, ELFEN, PFC, Tochnog and UDEC (Barla, 2008; Brideau et al., 2006; Commend et al., 2004; Crosta et al., 2003; Crosta and Clague, 2006; Evans et al., 2006; Li et al., 2006; Pasculli and Sciarra, 2006; Poisel et al., 2009; Stead et al., 2006).

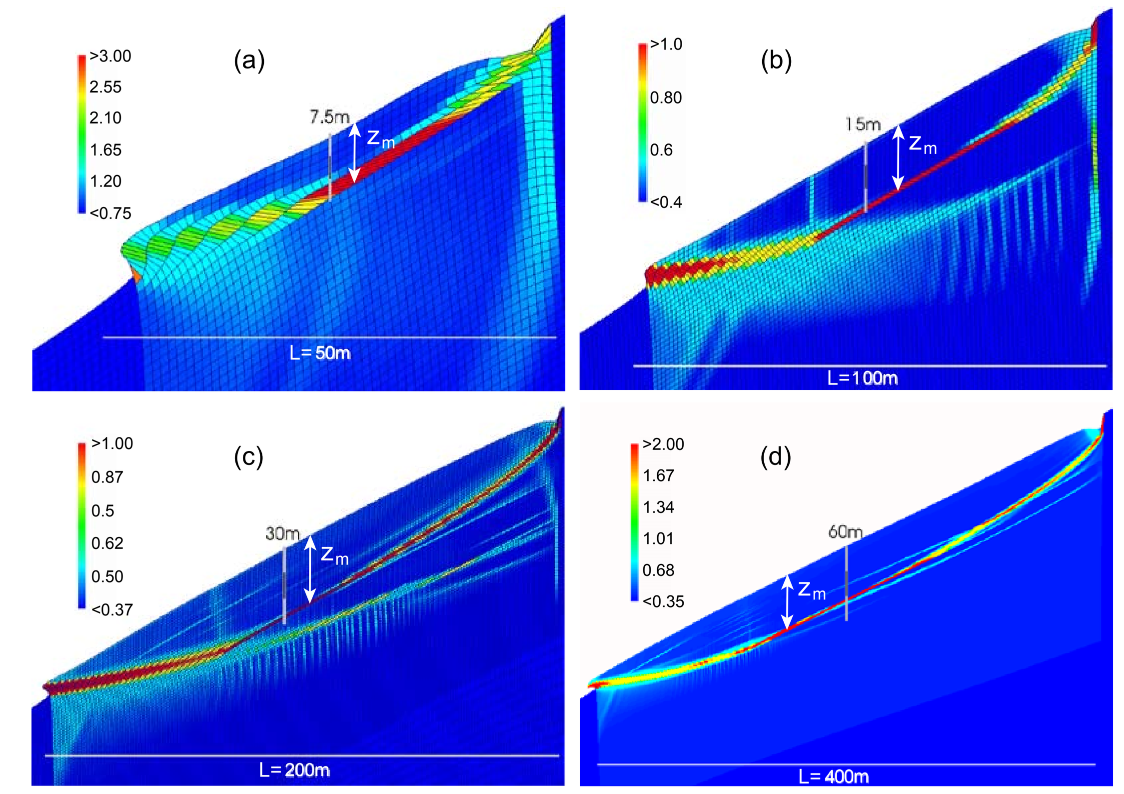
Model Setup

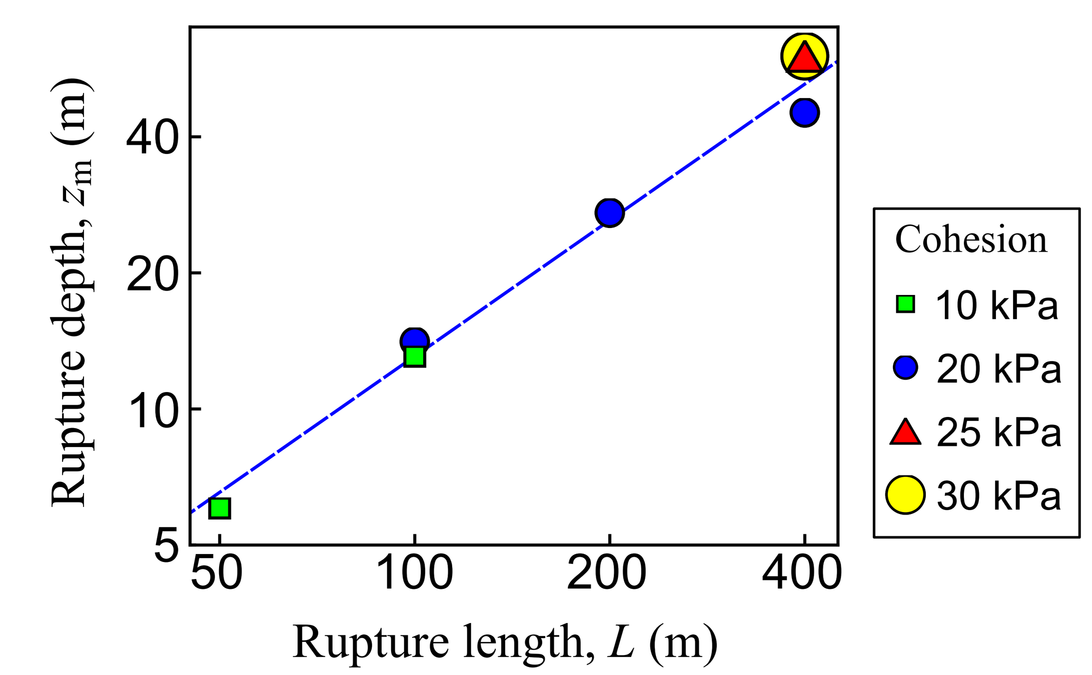
- Used SNAC (StGermaiN Analysis of Continua), a 3D community code originally designed to model elastoviscoplastic deformation on a crustal scale (Choi et al., 2008).
- Landslide rupture treated as emergent *shear localization* under *strain-weakening* Mohr-Coulomb plasticity.
- Only the initial slip and early motion of a landslide simulated.
- 2D simlulations of failures spanning 50, 100, 200, and 400 m.
- Density: 2500 kg/m^3; Lamé's constants: 30 GPa; friction angle: 25°; dilation angle: 5°; cohesion: 10 to 30 kPa, reduced to zero over plastic strain of 100 %.



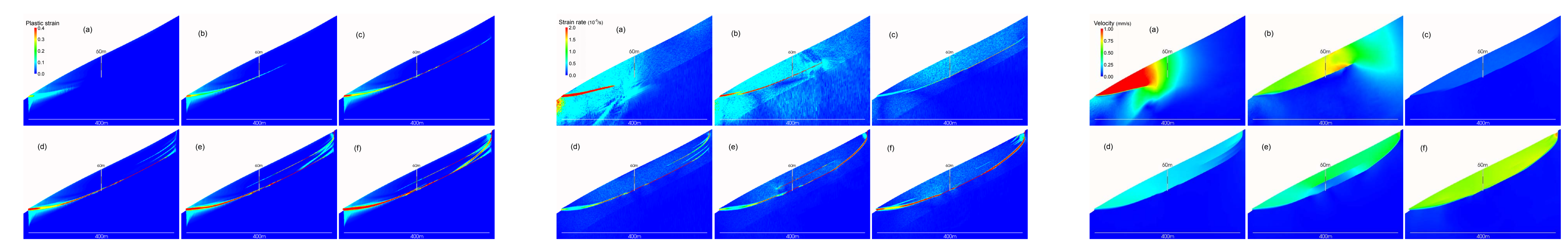
Results

Length-Depth Scaling





Detailed Rupture Process



< Plastic Strain > < Strain Rate > < Velocity Magnitude >

Summary

- A linear scaling confirmed over the tested values of L.
- A depth-length ratio of 11-15% is recorded.
- Interesting complexity in the evolution of the slip plane found: Failure initiates at the toe, propagates upslope, and asymptotically parallels the planar upper boundary.
- However, a connected failure surface is only achieved once a secondary rupture has propagated downwards into this slip plane from the upper breakaway zone.
- 3D continuum modeling of soil and rock-slope failure, and the study of their rich behavior, is now feasible using a non-commercial code on supercomputing platforms.

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