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Stress analysis during slope failure from DEM simulations

O. Katz (1,2) and J.K. Morgan (2)

(1) Geological Survey of Israel, Jerusalem, Israel (odedk@gsi.gov.il), (2) Department of Earth Science, Rice University, Houston, TX (morganj@rice.edu)

We used Discrete Element Method (DEM) simulations to study the initiation and evolution of landsliding, with a focus on the development and propagation of the sliding plane, and on the effects of material strength on the behavior of the slope material during landsliding. Our simulated slopes were constructed of homogeneous materials, settled under gravity, bonded, and excavated to produce 70 deg slopes of 1050 m in height. Nine simulations were carried out, each using a different value of cohesions, ranging from 0.7 to 4.2 MPa (quantified through DEM direct shear simulations on representative materials).

In each of our simulations, failure initiated at the foot of the slope, accompanied by disintegration of the slope material. Failure then propagated upward to the slope crest with further material disintegration. A discrete detachment surface formed below the disintegrated material. Downslope movement of the failed material (i.e. landsliding) occurred only after the failure plane intersected the upper slope face. By the end of landsliding, the disintegrated slope material formed a talus like deposit at the foot of the slope. The value of initial material cohesion influenced the nature of the landslide deposit and its dimension. Higher material strengths produced smaller landslides, as well as the occurrence of discrete landslide blocks, which originated from the shallow slopes, and became entrained within the finer talus.

Stress analysis of the slope failure process clarifies how failure initiates and landsliding evolves, and further constrains the limiting failure criteria that define each simulated material. The local proximity to failure throughout the slope can be tracked during the simulation, revealing that high failure potential (high shear stress relative to mean stress) exists at the toe of the slope immediately following excavation. As material disintegrates near the toe of the slope, high tensile stresses develop in the overlying mass, causing the break-up of the shallower slope materials. The detachment surface defines the boundary between the mobile material undergoing disintegration and the coherent material below. With increased cohesion within the slope, less material reaches this failure condition, and the detachment surface shallows, causing a decrease in the in-slope extent of the landslide, the volume of the final deposit and type of failure (slump vs. rock-slide). These numerical simulations provide important insights into the stress evolution within a failing slope, and an understanding of how these control the final type, geometry and size of landlides.