Geophysical Research Abstracts,
Vol. 11, EGU2009-11014, 2009
EGU General Assembly 2009

Discrete element simulations to assess controls on landslide size in heterogeneous slopes: The roles of fractures and mechanical stratigraphy

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Landslides of different sizes, from different locations around the globe, triggered by different mechanisms, all seem to follow similar size-distributions, consisting of a maximum frequency at the small landslide side of the distribution and a power-law tail toward the large landslide side. Here we carry out numerical simulations using the discrete element method (DEM) to better understand the physics behind this distinctive landslide size distribution, and in particular, to determine what controls the shape of the power law tail. Previous studies have suggested that the power-law tail is a result of large, deep seated landslides that occur in the fractured and layered deep part of the slope.

We modeled 2D slopes constructed of numerous spheres simulating material with friction and cohesion. The simulated slope length is 2500 m with height (H) range of 500 m-1000 m; slope angle is fixed at 70 degrees. To determine landslide size, we measured the landslide surface length from the scarp to the toe, and the landslide thickness as the maximum distance from the slope surface to the sliding surface. Failure in mechanically homogeneous slopes initiates at the slope-foot and propagates to slope-crest forming a discrete sliding plane. Landslides (slumps) developed encompass the entire slope height (i.e. maximum size) with size dependent on H and a self-similar shape, producing a constant ratio of landslide thickness to surface length. Slumps developed in slopes containing 500 randomly distributed and oriented fractures produce landslides that are smaller than maximum size (as fracture length increases from 10 m to 100 m, landslide size increases from 0.75 of maximum size to the maximum size.). The sliding surface uses the preexisting fractures to propagate from slope-foot to crest. Landslides developed in slopes with a weak dipping layer are of rock-slide type and have geometries and dimensions reflecting the layer depth relative to the slope height.

The above observations highlight the importance of fractures and stratigraphy in determining the size distribution of large, deep-seated landslides. Longer fractures in otherwise homogeneous slopes readily coalesce to form continuous, through-going failure surfaces, thereby producing larger landslides than observed in slopes containing short, distributed fractures or no fractures. Heterogeneous mechanical layering also promotes large deep-seated landslides, by defining weak slip surfaces that cut the entire slope. These results confirm the importance of slope heterogeneity in defining the power-law tail of landslide size distributions.