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Hydro-mechanical framework for early warning of rainfall-induced landslides

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Early warning of shallow rainstorm-driven landslides and debris flows requires an estimate of the location, timing, and magnitude of initial movement, and the change in volume and momentum of material as it travels down a slope or channel [1]. In some locations advance assessment of likely landslide location, volume, and momentum is possible, but prediction of landslide timing entails quantifying the evolution of rainfall and soil-water conditions, and consequent effects on slope stability. Existing schemes for landslide prediction generally rely on empirical relations between landslide occurrence and rainfall amount and duration, for example [2], however, these relations do not account for the variably saturated subsurface flow processes that control the hydro-mechanical response of hillside materials to rainfall infiltration. Although limited by the resolution and accuracy of rainfall forecasts and now-casts in complex terrain and by the inherent difficulty in adequately characterizing boundary conditions and subsurface materials, physics-based models provide a general means to quantitatively link rainfall and landslide occurrence.

Obtaining quantitative estimates of landslide potential from physics-based models using observed or forecasted rainfall requires explicit consideration of the changes in effective stress that result from changes in soil moisture and pore-water pressures [3]. The physics that control soil-water conditions are transient, nonlinear, hysteretic, and dependent on material composition and history. To examine the physical processes that control infiltration and effective stress in variably saturated materials, we use field and laboratory methods to determine intrinsic relations among soil water and mechanical properties of hillside materials. At the REV (representative elementary volume) scale, the interaction between pore fluids and solid grains can be effectively described by the relation between soil suction, soil water content, hydraulic conductivity, and suction stress. We obtain these relations independently from outflow, shear strength, and laboratory deformation tests for a wide range of earth materials [4]. Comparisons between laboratory results and measurements of pore water pressure and moisture content from landslide-prone settings demonstrate that laboratory results obtained for hillside materials are representative of field conditions. A case study from a monitored hillslope in western North Carolina, USA, is used to show these fundamental relations provide a basis to combine observed or forecasted rainfall with in-situ measurements of soil water conditions using hydro-mechanical models that simulate transient variably saturated flow and slope stability.

Early warning for shallow, storm-driven landslides using an approach in which in-situ observations are used to establish initial conditions for hydro-mechanical models is feasible where materials have been adequately characterized in the laboratory and accurate rainfall information can be obtained. Accurate practical application may entail combining in-situ observations, hydro-mechanical models, and empirical rainfall-intensity-duration thresholds. Analogous to weather and climate forecasting, information from these tools could then be applied in an ensemble fashion using observed or forecasted rainfall to obtain quantitative estimates of landslide probability and uncertainty. Accurate Application to broad regions would be facilitated by breakthroughs in the development of remotely sensed proxies for soil properties and subsurface moisture conditions.

References:

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