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Mechanics of progressive failures leading to rapid shallow landslides using the fiber bundle model

Denis Cohen (1), Massimiliano Schwarz (1,2), and Dani Or (1)

(1) ETH Zurich, Institute for Terrestrial Ecosystems, Environmental Sciences, Switzerland (denis.cohen@env.ethz.ch), (2) Swiss Federal Institute for Forest, Snow and Landscape Research, 8903, Birmensdorf, Switzerland

Shallow landslides are often sudden events caused by the rapid failure of a slip surface. Yet, such global failure is the culmination of a series of steps that begin with the initiation and growth of local cracks and failure planes that, with increased load eventually coalesce to form a continuous surface. The dynamics of such failure events is controlled, in part, by the rate of soil weakening during water infiltration and by distribution of tree roots that span across these failure zones. Conventional approaches rely on static limit-equilibrium analysis to compute the ratio of soil resistive strength to gravitational driving forces (factor of safety) to determine slope stability, often ignoring dynamics leading to failure as well as heterogeneities associated with land cover, subsurface material properties, hydrologic pathways, and presence of biological elements such as roots. Casting the problem in terms of stable or unstable slope does not describe the progressive formation of cracks in heterogeneous soils or the failure of roots that stretch across tension cracks or basal shear planes. Here we use the fiber bundle model (FBM) to describe soil and root failure focusing on landslide initiation. The FBM consists of a bundle of parallel, elastic-brittle fibers of identical length and stiffness stretched quasi-statically between two plates. Heterogeneity is introduced by fibers having finite threshold strength drawn randomly from a probability density function. Step-loading of the bundle causes weak fibers to break and load redistribution (either global or local) among surviving fibers can trigger secondary, tertiary, and so on, failures, a process known as an avalanche. We illustrate the potential utility of the FBM for two cases: (1) modeling of lateral root reinforcement where fibers represent roots of different sizes and strengths, and (2) modeling of progressive weakening of soils by water infiltration where fibers are analogs of bonds between soil aggregates whose strength distribution evolves with changes in water content. The main advantages of the fiber bundle model is its ability to account for progressive failure and heterogeneities of soils on slopes, to describe the complex rheological behavior of soils and soil elements such as roots using simple basic blocks (the fibers) whose properties can be directly related to the properties of the materials, and to represent physical processes of failure in soils and roots.