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Analysing the influence of preferential flow on pressure transmission and landslide triggering

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Rainfall-induced shallow landslides are the most frequent natural hazards in mountainous areas. As a result of rainfall, an increase in pore water pressure reduces the effective stress and shear strength of a slope, which could further trigger the occurrence of slope failure. Recognizably, such landslides are characterized by thresholds of rainfall magnitude and intensity, which are commonly evaluated in hydro-mechanical models via integration of a hydrological and a soil mechanics model. Mechanisms of slope instability and water pressure transmission in a natural subsurface hydrological system are very complex, because the soil hydraulic behaviours in the saturated and the unsaturated zones are rather different. Regarding the pressure transmission mechanism, in the saturated zone the pressure wave propagation is nearly instant, while, in the unsaturated zone the pressure fluctuates due to the variability of soil moisture content and the existence of preferential flow. However, the diffusion wave model has been derived to quantify the celerity of pressure waves in a near-saturated soil and also been applied in the landslide triggering analysis. Yet, the functionality of the preferential flow in landslide-triggering mechanisms under the high-intensity rainstorm is rarely quantified, and its role in pressure wave propagation is not well studied. The pore water pressure is still calculated based on a single-permeability assumption in most hydro-mechanical models. The dual-permeability approach, however, couples the matrix flow and preferential flow with two Richards equations, which has a great potential to investigate the influence of preferential flow on pressure transmission and slope stability in a heterogeneous hillslope.

In this study, a hydro-mechanical model was developed that couples a 1D dual-permeability model with an infinite slope stability analysis. A series of synthetic experiments simulates and quantifies the rainfall amount, intensity, and duration for the occurrence of shallow landslides in a predefined heterogeneous hillslope, which is parameterized with typical soil hydraulic and mechanics properties. The results highlight the soil hydrological condition which controls water and pressure wave propagation in case of a dual permeability subsurface, and will further detail on the importance of preferential flow in pressure wave propagation and thus slope stability assessment. The theoretical results will also be confronted with published case study data of the Rocca Pitigliana landslide consisting of 2-4m weathered clay overlying a clay-shale bedrock and located roughly 50 km south of Bologna. Three-year field data of pore pressure provide a reliable understanding of the dynamic hydrological response to the transient rainfall intensity. The Rocca Pitigliana landslide has been successfully modelled using a diffusion wave approach. Our study shows that fast pressure response due to preferential flow is important for landslide triggering and highlights the difference between a single domain diffusive wave approach and a dual-permeability approach.