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Subsurface hydrology related to soil displacement and subsequent shallow landslide initiation induced by rainfalls

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Understanding mechanisms of precursors to shallow landslides that commonly occur prior to landslide initiation, such as small soil displacements (soil creep), can improve the accuracy of predictions of shallow landslide initiation and mitigate subsequent sediment disasters. We focused on these displacements, empirically well known as a precursor to shallow landslide initiation, to understand the effect of subsurface hydrology on shallow landslide occurrence and to contribute for creating prediction methods and preventive measures of sediment disasters. We measured soil displacement and pore-water pressures occurring prior to shallow landslides in two flume experiments (Runs 1 and 2) using an artificial sandy slope of 32? that was 9 m long, 1 m wide, and 0.7 m deep, with rainfall intensities of 100 and 80 mm/h. In addition, we conducted the direct shear box test of the sandy soils under the compression and undrained condition to obtain the weakest soil strength, and got failure envelopes as that the soils were cohesionless and their internal friction angles were 34.1 and 32.6 degree for the soils of Runs 1 and 2, respectively. From the experiments, we found that 1) prior to shallow landslides, soil compression was mostly provided around the slopes which occurred shallow landslides, 2) unsaturated areas had been widely expanded in the collapsed slopes, 3) the direction of subsurface flow in the deep part of the slopes began to parallel the slope about 30 min before shallow landslides, which timing coincided closely with onset of soil displacement, 4) stress paths calculated by the modified Fellenius method which was based on the change in total stress without considering seepage force exceeded the failure envelopes just 1 sec before shallow landslides, 5) stress paths based on the change in effective soil weight by rainfall infiltration did not exceed the failure envelopes before shallow landslides. In contrast, we also found that 6) by adding seepage forces calculated from the hydraulic gradient in the slopes to the effective normal and shear stresses which were derived from the changes in effective soil weight, stress paths exceeded the failure envelopes at mostly the same timings of onset of soil displacement, 7) The calculations based on changes in seepage force provided the better prediction accuracy for both onset of soil displacement and landslide initiation than the case based on the change in total stress without considering seepage force and the change in effective soil weight by rainfall infiltration. These things reveal that soil displacement and shallow landslides could not be simply induced by the change in soil weight accompanied with rainfall infiltration. That is, seepage forces controlled by changes in direction and magnitude of subsurface flow under unsaturated and/or saturated conditions caused changes in normal and shear stresses. Thus, the combination of changes both in the apparent soil cohesion and internal friction angle and in seepage force and soil weight, which controlled by changes in soil water content and finally affect the change in effective stresses in soils, could be one of the main causes of soil displacement and subsequent shallow landslide initiation.

Keywords: shallow landslide, seepage force, soil displacement, flow direction, flume experiment