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Shear and compression strain development in sandy model slope under repeated rainfall

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Abstract

Repeated rainfall on natural slope may cause repeated loading and unloading of pore pressure in the slope. The deformation behavior and soil-water conditions in a model slope were monitored under repeated rainfall to examine the influence of repeated rainfall on the deformation of the slope. The results show that the shear and compression deformation of the soil layer developed not only during the wetting process but also during the drying process. The surface and vertical displacement of the slope increased as the groundwater level (G.W.L.) increased during the first wetting process and remained constant during the subsequent drying process. The displacements showed small progress until the maximum G.W.L. of the first wetting process and then increased significantly at the next wetting process. The shear and compression strain remained constant as the suction decreased during the wetting processes and increased with the increase of suction during the drying processes; the strains significantly increased with a small decrease in the suction and then significantly increased with the generation of the pore pressure at the final rainfall event. The relationship between the shear strain and the compression strain was not affected by the repeated loading and unloading of suction. The relationship between the surface displacement and the vertical displacement was also free from the variation of the suction due to the repeated rainfalls. Strain increased with the increase in the pore pressure and the maximum pore pressure at a deeper layer was larger than at a shallower layer. The increase in the vertical displacement to the increase of the surface displacement approaches zero with the increase in the shear strain at the soil layer, denoting a failure state of the soil layer.

Keywords: Rainfall-induced landslide; Shear strain; Compression strain; Groundwater level; Suction; Pore pressure

1. Introduction

Monitoring slope deformation is an effective tool for predicting the onset of landslides. Conventional tilt meters with Micro Electro Mechanical Systems (MEMS) or Global Positioning Systems (GPS) have recently been developed for the measurement of slope deformations. The development of new methods or instruments for monitoring slope deformation is expected to follow the development of Information and Communication Technology (ICT). However, the analysis methods currently used to examine the monitoring data for time prediction of an onset of a landslide are still relatively unsophisticated.

A soil creep theory was adopted for this data analysis to predict the onset of a landslide. The creep theory describes the time-displacement relationship before the failure of the soil. It can simulate an accelerative surface displacement just prior to the onset of slope failure. Many formulae for the time prediction of landslides have been established based on soil creep theories (Saito, 1965; Saito and

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Yamada, 1973; Varns, 1983; Fukuzono, 1985; Voight, 1988; Voight, 1989; Crosta and Agliardi, 2003; Xiao et al., 2009; Bozzano and Mazzanti, 2012). Although they have been able to predict the time of the onset of landslides in some cases, these formulae have failed in other cases. They might not have succeeded in predicting the onset of rainfall-induced landslides when the rainfall intensity suddenly decreased prior to the failure. This is because of the change in stress of the landslide body resulting from the change of rainfall intensity. The creep theory cannot describe the deformation generated by the change in stress because it only describes the time-strain (displacement) relationship under a constant stress condition of the soil. A stress-strain relationship is necessary to describe the onset of a landslide resulting from a change in stress. The authors (Sasahara and Tsunaki, 1996; Sasahara and Sakai, 2011, 2014) have reported the stress-strain relationship of the soil in the model slope. They examined the relationship of the volumetric water content (hereafter V.W.C.), the suction, and the groundwater level to the shear strain in a sandy model slope under artificial rainfalls. Although other reports also took the surface displacement and the pore pressure in the model slope or natural slope under artificial rainfall into consideration (Moriwaki et al., 2004; Ochiai et al., 2004), as well as the initiation condition of the failure of a model slope due to artificial rainfall in a flume (Orense et al., 2004; Reid et al., 2009; Wang and Sassa, 2001, 2003), very few studies have examined the influence of the variations in the stress in the slope.

Natural slopes are subject to many rainfall events over a long period of time. The stress history, or, more specifically, the repeated loading and unloading of the pore pressure and suction due to repeated rainfalls, may influence the deformation behavior of the slope. Very little research has examined the influence of repeated loading and unloading of the pore pressure or suction on the deformation of a slope. Uchimura et al. (2011) examined the shear deformation behavior of sandy soil in a direct shear apparatus with constant shear stress under the repeated supply (wetting) and drainage (drying) of water. According to the study, shear displacement developed with the increase of the V.W.C. during the first wetting process. The shear displacement remained almost constant until the V.W.C. increased to the maximum of the first wetting stage and then further developed with the increased V.W.C. at the subsequent wetting stage. Although the V.W.C. is not a stress variant in a strict sense, its variation may be closely related to the variation of the suction. Thus, the relationship between the V.W.C. and the shear displacement might be analogous to that between the suction and the shear strain in the direct shear condition.

In this study, the V.W.C., the pore pressure (including the suction), and the shear and compression deformation in a sandy model slope were automatically monitored under repeated rainfalls. Analyses were conducted on the relationship between the deformation and the soil-water condition under the repeated loading and unloading of pore pressure to seek the constitutive laws between the deformation and the soil-water conditions in the slope under repeated rainfall conditions.

2. Methodology

2.1. Model slope and monitoring equipment

Fig. 1 shows the longitudinal section of the model slope and the location of the monitoring devices. Photo 1 shows the model slope with dimensions of 300 cm in length, 150 cm in width, and 50 cm in depth in the gravitational direction at the horizontal section, and 600 cm in length, 150 cm in width, and 57.7 cm in depth at the slope section with an inclination of 30 degrees. The model is composed of granite soil (Fig. 2 and Table 1) and was made in a steel flume with vertical blades of 1 cm in height at every 50 cm in the longitudinal direction at the base of the slope to prevent slippage between the base of the model and the flume. The surface of the slope is parallel to the base of the slope. The inclination and the thickness of the model slope are based on the fact that most rainfall-induced landslides occur in a topsoil layer on slopes of 30 ~ 50 degrees, and the thicknesses of the topsoil layers are typically 0.5 ~ 1.5 m in Japan (Osanai et al., 2009). The steel base plate of the model slope models the impermeable surface of the base rock beneath the topsoil. The combination of a topsoil layer on an impermeable base rock is typical of collapsed

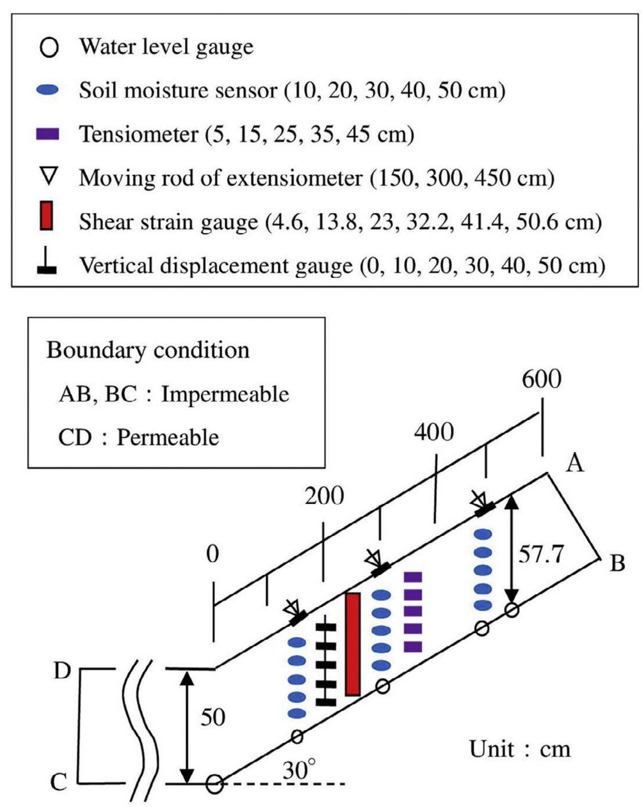

Fig. 1. The longitudinal section of the model slope and the arrangement of measurement devices.