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論文の内容の要約

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Introduction

Climate change due to global warming is one of the most concerning issues. Heavy rainfall and floods due to tropical cyclones and irregular weather conditions have become common recently. Sedimentary disasters related to heavy rainfall like landslides, shallow slope failures, and surface erosion having become severe and recent in many countries, especially developing countries. Sediment disasters caused damages to the lives and properties or the deterioration of the environment through the large-scale movement of soils and rocks. The failure mechanisms of natural slopes frequently comprise a complex interaction related to topography, hydrological conditions, geotechnical properties, boundary conditions such as permeability, and the initial state of the slope. From a geotechnical engineering point of view, one of the main reasons for slope failure is the loss of matric suction, and hence a loss of effective stress as water continuously infiltrates into the soil. The infiltrated rainwater could not flow out from the surfaces of slopes during rainfall, and it accumulated at the slope toes. Many studies indicated that slope failures are always initiated when the vicinities of the slope toes are nearly saturated and are triggered by cracks that appear in those regions. Once the initial failure occurs, the significant failures progressed within a short time as there are no proper countermeasures are installed. Therefore, it is necessary to prevent the initial failures from inducing whole surface failures.

Methods

In order to reduce and delay the initial failures, more systematic disaster protection plans are needed. Many corrective measures for slope stabilization have been used in practice. In this study, a series of experiments using slope models with filter gabions and drainage pipe was conducted to investigate the effect of those measures against rainfall-induced failures. The models had similar conditions as the typical natural slopes. Thus they had a permeable residual layer on a relatively firm rock foundation. The slope model was composed of surface sand (Kasumigaura sand) layers and a silt (DL clay) foundation. Then, a filter gabion with a drainage pipe was placed at the slope toe to reinforce the slope and drain accumulated rainwater from the slope toe. Three cases of the model tests with different pipe diameters (inner diameter = 56 mm and 107 mm) and two different pipe insertion ratios R_p = 35% and 70%, where R_p is the ratio between the pipe insertion depth and the sand layer depth, were conducted. The rainfall intensity of I = 60 mm/h and the relative density: D_r = 25% for the sand layer were selected for the test conditions. Temporal changes in pore water pressures (PWPs), displacements, and the amount of drained water through the pipe were measured during the tests. Hence, many researchers have analyzed rainfall-induced slope failures due to different mechanisms that induced distinct changes in the pore water pressure, suction, shear strength within the soil, and slope stability. In this study, as a part of the disaster protection planning, the numerical analysis method developed by Kohgo was applied to evaluate the stability of slopes due to torrential rainfalls.

Results

The results indicated that the infiltrated rainwater slowly came to the slope toe in the cases with R_p = 70%. The amount of the positive PWPs at the slope toes significantly decreased in the cases with R_p = 70%. The displacements also significantly decreased as the pipe diameter R_p increased. Water did not discharge through the pipe until the PWPs around the pipe reached positive values. The drainage with R_p = 35% started earlier than the cases with R_p = 70%. This could be because the infiltrated rainwater came to slope toe quickly and the phreatic surface formed around the pipe faster with R_p = 35%. The failures always started when a phreatic surface appeared on the slope surface. Thus, it is crucial to prevent a phreatic surface from forming within the surface layer. In the case with the d_i = 107 mm and R_p = 70%, the phreatic surface did not appear on the slope surface and kept the slope stable compared to other cases. Thus, adequate arrangement of a filter gabion with a drainage pipe may increase the slope stability.

The model tests were then simulated using the saturated-unsaturated consolidation analysis method coupled with an elastoplastic model for unsaturated soil, considering two suction effects. The analytical model conditions were the same as those in the experimental tests. The simulated and observed results were then compared. In both experiment and simulation of slope model failures tests, the rainwater accumulated over time. The pore water pressures (PWPs) increased to be positive or larger than the surface soil's air entry value. As the positive PWPs increased with the elapsed time, the phreatic surface appeared on the slope surface. The initial failure or large displacement started in experiments and simulations once the phreatic surface reached the soil slope surface. Nevertheless, once the large initial displacement started in the simulations, large deformations followed quicker than the experiments.

Conclusions

The failures always started when the phreatic surface appeared on the slope surface. It is crucial to prevent the phreatic surface from being on the slope surface. This is the same as the critical point in the stability of fill dams for seepage that the phreatic surface never appears on the downstream slope surface. Adequate arrangements of filter gabion with pipe, which prevent the phreatic surface from being on the slope surface, may increase the potential of slope stability. Although the simulations results were quite similar to those in the experiments, further investigations are needed to simulate the cases with the drainage pipe. More material parameters investigations are needed to get effective simulated behaviours. Since the drainage pipes investigations are primarily done in the three-dimensional domains, 3D investigations may be an appropriate alternative method to investigate the effectiveness of the drainage pipe. More importantly, we found and concluded that the pipe diameter and the length of the pipe in the sand surface layer strongly affected to reduce the failure situations.