学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Wide-area geohazard risk assessment in snowy-cold regions by multiphase soil mechanics and multi-scale analysis

(高緯度寒冷地域の広域地盤災害リスク評価手法に関する研究)

In order to more accurately predict the occurrence of slope failure and improve the early warning system, this study attempts to give new insights into the failure mechanism, simulation technology, prediction criteria, etc. For these purposes, the new methodology and numerical approach are developed on different scales, i.e., local-scale, catchment-scale and regional-scale.

On the local-scale, this study proposes a local shear strength (LSS) method for determining the variable LSS with changes in matric suction (MS) for each soil material point within an unsaturated slope. By using the proposed LSS method, a FEM-MPM coupled model is proposed. Afterward, the effectiveness of the proposed LSS method-based FEM-MPM coupled model is validated based on a validation model. The results obtained from the LSS method-based FEM-MPM coupled model show good agreement with that obtained from the limit-equilibrium method (LEM) and shear strength reduction technique (SSRT). Finally, through the reproduction of the whole landslide process of a natural slope at Nissho Pass in Hokkaido, Japan in 2016, the LSS method-based FEM-MPM coupled model proposed in this study is proved to be effective for simulating landslide-related large-deformation problems subjected to rainfall infiltration in an unsaturated slope.

On the catchment-scale, this study attempts to simulate the runoff, infiltration, seepage, and instabilities of multi slopes on a catchment-scale range simultaneously in order to consider the effect of runoff on the slope instability. For this purpose, this study firstly proposes a coupled model of surface flow, subsurface flow, and soil mechanics based on shallow water equations, Richards’s equation, Green-Ampt infiltration capacity model, and local factor of safety (LFS) approach. Next, in order to make the proposed coupled model effective in the practical analysis of runoff, a diffusion wave approximation of shallow water equations is validated by numerical simulations, and then it is used to replace shallow water equations in the proposed coupled model. Finally, the proposed coupled model is verified by Abdul and Gillham system and applied to a natural slope in Hokkaido, Japan. The catchment-scale range multi slopes instabilities assessment approach proposed in this study provides an effective approach for simulating heavy rainfall induced runoff and multi slopes instabilities in the target region, and it has significant implications for precisely determining the dangerous spots (instead of areas) on a catchment-scale range and accurately releasing warning information to the dangerous spots.

On the regional-scale, this study attempts to propose a new determination method for setting an early warning criterion of rainfall and/or snowmelt induced slope failures in seasonally cold regions. For this purpose, this study firstly proposes a combination model for estimating snow density in order to incorporate hourly snowmelt water into the Japanese early warning system more accurately by using

meteorological monitoring data and modeled snow density. Next, based on case studies and parametric analyses for slope stability assessment, new early warning criteria are proposed for predicting three different patterns of slope failures under two typical types of precipitation (rainfall and snowmelt) conditions. Finally, a new determination method for setting the early warning criterion in seasonally cold regions is proposed by referring to the existing early warning criteria near the target area. This study propose an effective method for determining the early warning criterion and predicting the occurrence of rainfall and/or snowmelt induced slope failures in seasonally cold regions in the future. Furthermore, numerical simulations are also performed to semi-quantitatively evaluate the impact of uncertainty in climate factors on slope stability, and to evaluate the impact of climate change on the occurrence of slope failure and its probability distribution based on historical statistics and parametric analysis of slope failures. The climate prediction and instability assessment of an actual highway embankment slope are done based on dynamical downscaling techniques and the slope stability assessment approach.

Chapter 1 introduces the background, objective, main technical path, and organization of this study. Chapter 2 reviews several popular numerical methods (FEM, FDM, DEM, DDA, and MPM) and their comparisons, and several slope stability assessment approaches (LEM, SSRT, and LFS) and their comparisons. Chapter 3 introduces a LSS method-based FEM-MPM coupled model to solve rainfall induced landslide-related large-deformation problems in unsaturated soil slope on the local-scale. Chapter 4 introduces a coupled model of surface flow, subsurface flow, and soil mechanics to simulate the runoff, infiltration, seepage, and instabilities of multi slopes on the catchment-scale. Chapter 5 introduces a new determination method for setting an early warning criterion of rainfall and/or snowmelt induced slope failures on the regional-scale. Chapter 6 semi-quantitatively evaluates the impact of climate change on the occurrence of slope failure and its probability distribution based on historical statistics and parametric analysis of slope failures. Chapter 7 summarizes the conclusions and recommendations of the study.