國立台灣科技大學

營建工程系

博士學位論文

學號：D10305813

Hydro-Mechanical Coupled Analyses of Unsaturated Natural and Reinforced Soil Slopes

研 究 生：Joseph Nganga Thuo-喬瑟夫

指導教授：Prof. Yang, Kuo-Hsin-楊國鑫 博士

中華民國一〇六年七月

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Department : Department of Civil and Construction Engineering

Student's Name: JOSEPH NGANGA THUO

Dissertation title: Hydro-Mechanical Coupled Analyses of Unsaturated Natural and Reinforced Soil Slopes

This is to certify that the dissertation submitted by the student named above, has been written under my supervision. I hereby approve this dissertation to be applied for examination.

Advisor:FU-CHEN TENG

Co_advisor: Kuo-Hsin Yang

Advisor's Signature: Fu-chen Teng Kuo-Hsin Yang

Date: 2017 / 07 / 11 (yyyy/mm/dd)

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Dissertation Advisor:FU-CHE TENG

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Department:Department of Civil and Construction Engineering

Student's Name:JOSEPH NGANGA THUO

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HYDRO-MECHANICAL COUPLED ANALYSES OF UNSATURATED NATURAL AND REINFORCED SOIL SLOPES

by

Joseph Nganga Thuo

Dissertation

Submitted to the Faculty of the Graduate School of the

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HYDRO-MECHANICAL COUPLED ANALYSES OF UNSATURATED NATURAL AND REINFORCED SOIL SLOPES

Graduate student: Thuo, Joseph Nganga
National Taiwan University of Science and Technology

Supervisor: Professor Yang, Kuo-Hsin

ABSTRACT

Assessment of rainfall-induced slope failures is important in reducing damage to infrastructures as well as guarantee safety of people living close to hazardous areas. This study presents case studies and numerical investigations of three unstable unsaturated slopes. The studied slopes are two natural slopes (Slopes T16 and T2) along the Taipei Maokong Gondola (Cable Transit) system and one unstable 26 m high multi-tier geosynthetic-reinforced soil (GRS) slope with marginal backfill in Taichung County, Taiwan.

Slope T16 collapsed during torrential rainfall during Typhoon Jangmi in September 2008, and another nearby slope (T2) developed excessive deformation under consecutive wetting and drying cycles. The GRS slope first experienced excessive deformation after seasons of typhoon and heavy rainfall from 2010-2012. The measured settlement and horizontal deflection at slope crest were 140 and 80 cm respectively from June to December 2012. Although an immediate remediation had been conducted for the slope excessive deformation, the slope final collapse was caused by two sequential typhoon events with total accumulated rainfall over 600 mm in August 2013.

Recorded rainfall, measured soil parameters, site geology, and slope geometry were used in coupled hydro-mechanical finite element analyses to investigate the failure and deformation mechanisms of these three slopes. The numerical results demonstrated that the coupled hydro-mechanical analysis based on the framework of unsaturated soil mechanics satisfactorily predicted deformation characteristics and failure timing of unsaturated soil slopes during rainfall. The slopes' failure was attributed to a decrease in soil shear strength when the matric suction gradually decreased as rainfall progressed.

Examination of the relationships between the slope factor of safety and the corresponding hydrological data (i.e., rainfall and soil PWP) revealed that coupled hydro-mechanical analysis combined with detailed site investigation could be performed to establish factor of safety (FS) versus accumulated rainfall relationship for slopes to act as reference in

disaster mitigation (forecasting) strategies. Findings of this study implies that continuous assessment of slope stability during wetting and drying cycles is significant in order to circumvent catastrophic slope failures. In addition, it is crucial to pay special attention to unstable rock or soil layers (such as weathered sandstone interbedded with shale layers) prior to design or construction of the GRS slope as well as to drainage installations to ensure that they remain intact and efficient if slope deforms. Lessons learned from this study are discussed, and remedial measures to improve the slope stability are proposed and evaluated. The significance of this study is to provide means for assessing and predicting slope stability (deformation and failure timing) using recorded rainfall, measured soil parameters, site geology, and slope geometry in order to mitigate the catastrophic damage and failure caused by natural and reinforced slopes failure during heavy rainfall.

Keywords: Hydro-mechanical analyses, Geo-disaster prevention, Unsaturated soil, Finite element analyses, Slope stability, Rainfall infiltration, Geosynthetics, Marginal backfill.