降雨條件下各異向性邊坡多相耦合滲流及穩定性分析

Wu, L. Z., Zhang, L. M., Zhou, Y., & Li, B. E., 2017. Analysis of multi-phase coupled seepage and stability in anisotropic slopes under rainfall condition. *Environmental Earth Sciences*, **76**, 1-11.

報告者：吳昀容
指導教授：王士榮 董家鈞 老師
報告日期：2024/12/27

摘要

降雨對於邊坡滲流、變形及穩定性有顯著影響，可能導致嚴重災害，因此，降雨入滲條件下的非飽和土壤邊坡穩定性評估是大地工程的重要議題。本研究採用 COMSOL 有限元素法，以多相耦合理論為基礎，透過求解耦合偏微分方程式來探討降雨入滲條件下土壤邊坡的穩定問題。其中，滲透係數為三相耦合模型（固相、液相和氣相）中的變數。本研究主要探討降雨入滲如何影響土體邊坡的穩定性，包括評估入滲、氣體遷移、土體變形和邊坡穩定性；探討了土壤孔隙中的空氣遷移和土體變形引起濕潤鋒的影響，以及分析土壤異向性的影響。結果顯示，異向性對孔隙水壓力的影響和非飽和土壤邊坡的深度和位置有關。當邊坡橫向滲透係數大於垂向滲透係數時，部分飽和邊坡的安全係數較高，而安全係數為異向性程度之函數，也就是說，如果水更容易橫向流動而不是垂向流動，邊坡通常更穩定。

關鍵字：降雨入滲、非飽和土壤、異向性、多相耦合、邊坡穩定。

Environ Earth Sci (2017) 76:469
DOI 10.1007/s12665-017-6811-6

ORIGINAL ARTICLE

Analysis of multi-phase coupled seepage and stability in anisotropic slopes under rainfall condition

L. Z. Wu[1] · L. M. Zhang[2] · Y. Zhou[1] · B. E. Li[3]

Received: 19 August 2016 / Accepted: 6 July 2017 / Published online: 10 July 2017

Abstract The seepage, deformation and stability in unsaturated soil slopes under rainfall infiltration are important issues in geotechnical engineering. Based on multi-field coupling theory, a finite element code, COMSOL, is employed to solve the coupled partial differential equations for soil slopes under rainfall infiltration. The coefficient of permeability is a variable in the three-phase coupled model. The water seepage, air migration, deformation and stability in a soil slope due to precipitation are studied. The effect of the wetting front caused by the migration of pore-air and the deformation of soil are explored, and the impact of soil anisotropy is analysed. The results indicate that the effect of anisotropy on the pore-water pressure is related to the depth and position of the unsaturated soil slope. The factor of safety of the partially saturated slope is relatively high when the lateral coefficient of permeability of the slope is greater than the coefficient of permeability in the vertical direction. The factor of safety is a function of the degree of anisotropy.

Keywords Rainfall infiltration · Unsaturated soil · Anisotropy · Multi-field coupling · Slope stability

✉ L. Z. Wu
cewulz@gmail.com

[1] State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu, Sichuan 610059, People's Republic of China

[2] Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Kowloon, Hong Kong

[3] Nanjiang Hydrogeology and Engineering Geology Team, Chongqing Geological and Mineral Exploration and Development Burea, Chongqing 401121, China

Introduction

Heavy rainfall is a key factor that results in landslides. Rainfall infiltration into a slope causes migration of fluid and gas in the partially saturated porous media. The soil–water interaction causes changes in the effective stress state and weakening of the strength characteristics of the soil mass. The induced deformation of the unsaturated soil slope can give rise to variations in the micromechanism and permeability of the soils and changes in the route for fluid and air seepage. Thus, the rainfall seepage into an unsaturated soil slope touches off complicated responses among the soil particle, liquid and air phases of the soil mass and possibly slope instability.

Natural soil sediments are intrinsically anisotropic regarding different properties (Ward et al. 1959, 1965; Bishop 1966; Al-Karni and Al-Shamrani 2000; Rocca et al. 2006; Zhu and Zhang 2013). The primary geostresses at the earth's surface are anisotropic because the ratio of vertical stress to lateral stress is usually more than 1. Engineering activities including banking and cutting bring out stress anisotropy (Ling et al. 2002). The anisotropic behaviour mainly occurs during the deposition process (fabric anisotropy), e.g. loose fill slopes formed by end tipping and compacted slopes. Ignoring the anisotropy of soil behaviour may cause inaccurate evaluation of soil responses under loading (Zdravkovic et al. 2002).

The flow in unsaturated soil slopes and rainfall-induced instability have been examined by both experiments (Mein and Larson 1973; Terzariol et al. 2003; Ochiai et al. 2004; Zeballos et al. 2005; Wang et al. 2013; Wu et al. 2017) and numerical modelling (Ng and Shi 1998; Cho and Lee 2001; Cai and Ugai 2004; Collins and Znidarcic 2004). When the wetting front propagates in an unsaturated soil slope, the pore gas in the vadose region is constricted; thus, there is a kinetic