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Effects of anisotropy ofpreferential flow on the hydrology and stability of landslides

Elena Cristiano[a]*, Thom Bogaard[a], Stefano Barontini[b]

[a]*Delft University of Technology, Faculty of Civil Engineering and Geosciences, Water Management Department, Stevinweg 1, 2600 GA Delft, the Netherlands*

[b]*Università degli Studi di Brescia, Dipartimento di Ingegneria Civile, Architettura, Territorio e Ambiente, e di Matematica, Via Branze, 42, 25123 Brescia (BS), Italy*

Abstract

Infiltration is one of the most important landslides triggering mechanisms and it is controlled by the hydraulic characteristics of the soil, which depend on degree of saturation, existence of preferential flow paths and anisotropy. In order to account for preferential flow that can have place in macro-pores and fissures, it is common to represent the soil matrix by means of the superimposition of two different domains: a soil matrix domain, which mainly accounts for the flow in the porous matrix, and preferential flow domainrepresentingthe flow through macro-pores and fissures. There have been recentinvestigations on the influences of preferential flow on slope stability;however, the combined effects of anisotropy and preferential flow on infiltration processes and on rainfall induced landslide mechanisms havenot been studied yet, at our knowledge.Aiming at better understanding the effects that anisotropy combined with preferential flow has on the infiltration process, we investigated the stability of a hillslope using a numerical modelling approach. Results indicate that anisotropy affects the slope stability and its failure area.

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*Keywords:*Anisotropy, Hydraulic conductivity, Dual permwability model, slope stability

1. Introduction

Infiltration is recognized as one of the most important landslides triggering mechanisms. In fact, during the infiltration process a perched water table can onset and the positive pressure head reduces the effective stresses.

* Corresponding author. Tel.: +31 (0)15 2788578.
E-mail address: e.cristiano@tudelft.nl

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Both infiltration and soil water dynamics are strongly influenced by the profile of soil hydraulicconductivity[1,2]and by the anisotropy of the conductivity tensor.[3]Many soils,in nature, exhibit a certain degree of anisotropy due to stratification associated with sedimentation processes and consecutive soil forming process, such as illuviation and compaction. Recently, various authors investigated the effects of rainfall on layered soilsand on rainfall-triggered landslides, by means of experimental, theoretical, numerical and conceptual approaches,[4,5,6,7] but the combined influence of anisotropy and preferential flow on slope stability is still poorly investigated.

Shao and coauthors[7] studied the influence ofpreferential flow on slope stability using a numerical modelling approach. They showed that for a low intensity rainfall event, modelling a hillslope using a dual permeability model results in a smaller failure area compared to using the single permeability model. This is due to the fact that preferential flow facilitates the drainage of the hillslope. For great rainfall intensity, the preferential flow domain of the slope facilitated the infiltration and reduced significantly the stability. In that work the authors simulated low intensity and high intensity rainfall events, using a hypothetical hillslope modelled by means ofboth a single and a dual permeability model.

The aim of this research is to contribute to better understand the combined effects of anisotropy and preferential flow oninfiltration process and on landslide triggeringand failure size.In this work, we started from the approach proposed by Shao and coauthors[7]and on their presented numerical model.The paper is organized as follows: section (2) presents the theoretical background, focusing on the definition of anisotropy and on the interaction between soil water flow and slope stability; model, methodology and investigated scenarios are subsequently described in Section (3); section (4) presents the discussion of the results, considering both the hydrological results and the stability analysis.

2. Theory

2.1. Dual permeability model

A single permeability model consists in only one domain, made of soil, where the water can flow through it. A dual permeability model, instead, supposes that the soil is split into two overlapping flowing domains: a soil matrix domain (indicated by subscript *m*) and a preferential flow domain(indicated by subscript *f*), which represents the ensemble of preferential flow paths such as macro-pores and fractures in the soil.[8] The fractures and the matrix blocks have their own characteristic and properties (i.e. porosity, hydraulic conductivity function and soil water retention relationship), and water flow is allowed in both the domains.[7,9,10]These two domains co-exist in the same total volume V. The sum of the preferential flow domain and the soil matrix domain gives the total domain:

$$V_f + V_m = V \tag{1}$$

or in terms of ratios v between the partial and the total volumes:

$$v_f + v_m = 1. \tag{2}$$

This model does not need a pre-defined fracture network, but it considers only the fraction of fractures over the total volume V.

In the dual permeability model, the water flow is represented by two coupled Richards equations, one for each domain:

$$C_m(h_m)\frac{\partial h_m}{\partial t} = \nabla[\boldsymbol{K_m}(h_m)(\nabla h_m + 1)] + \frac{\Gamma_w}{v_m} \tag{3}$$

$$C_f(h_f)\frac{\partial h_f}{\partial t} = \nabla[\boldsymbol{K_f}(h_f)(\nabla h_f + 1)] - \frac{\Gamma_w}{v_f} \tag{4}$$

where C is the specific water capacity function,h is the tensiometerpressure head, t is the time, $\boldsymbol{K}$is the hydraulic conductivity tensor and Γ_w is the water exchange term. The tensiometerpressure potential is defined according to USS-ISSS[11]convention and accounting for all the interactions between the soil matrix, the water and the environmental pressure. The exchange of water between the matrix and the fracture pore systems is assumed to be proportional to thedifference between the tensiometerpressure head of the two systems.[8,12]

$$\Gamma_w = \alpha_w(h_f - h_m)K_a; \tag{5}$$

where α_w is the first order water transfer coefficient, and K_a is the apparent conductivity that is defined as:[7]