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ANALYSIS OF THE HYDRAULIC PARAMETERS MOSTLY AFFECTING THE HYDROLOGICAL RESPONSE OF SHALLOW PYROCLASTIC COVERS

ROBERTO GRECO[1], PASQUALE MARINO[1] and GIOVANNI F. SANTONASTASO[1]

[1]Dipartimento di Ingegneria, Università degli Studi della Campania "L. Vanvitelli", via Roma 9, 81031 Aversa (CE), Italy.
E-mail: roberto.greco@unicampania.it

Slopes covered with shallow deposits of loose pyroclastic materials, lying upon a fractured limestone bedrock, are common in the mountainous areas surrounding the city of Naples (southern Italy). The equilibrium of the soil cover along such slopes is ensured, up to inclination angles of 50°, by the contribution of unsaturated soil suction to shear strength (Lu et al., 2010; Greco and Gargano, 2015). Wetting of the soil cover during rainfall infiltration causes reduction of suction and, consequently, of the effective shear strength. This process sometimes leads to the triggering of shallow landslides, which often develop in the form of fast and destructive flows (Olivares and Picarelli, 2003). While the vanishing of suction is unanimously recognized as the triggering mechanism of landslides along such slopes, there is still debate about the hydrological processes causing the establishment of the conditions predisposing to landslides. In fact, within the layered soil profile typically characterizing these slopes, layers of loose volcanic ashes (i.e. loamy sands) are always found (Damiano et al., 2012). Such pyroclastic materials usually exhibit extremely high porosity (even up to 75%) and saturated hydraulic conductivity (in the order of 10^{-4}m/s). During the rainy season, from late autumn to early winter, the mean water content of the cover is around 35-40%, implying that the vanishing of suction requires a great storage of water within the cover (e.g. up to 700-800mm for 2m of soil cover). Even during the maximum ever observed rainy periods, such an amount of rain falls during several weeks (the mean annual rainfall in the area is around 1500mm), a time interval long enough to let the cover drain out most of the infiltrating water. Nonetheless, in soil covers with thickness around 2m, landslides have been triggered by rainfall events characterized by 250-350mm falling in 36-72hours. This highlights the importance and the dynamic nature of the hydraulic conditions at the boundaries of the soil cover (i.e. at the foot of the slope and at the interface between the soil cover and the underlying bedrock). The fractured and sometimes deeply karstified bedrock is in fact pervious (Celico et al., 2006) and allows significant water recharge to the aquifers hosted in the underlying carbonate rock (Fusco et al., 2017), which supply springs often gushing at the foot of the slopes (e.g. Petrella et al., 2009). A model capable of reproducing the dynamics of the hydrological processes filling (i.e. infiltration) and draining (i.e. hydraulic boundary conditions) is therefore necessary to reliably model the storing of water in the cover and, so, the establishment of landslide triggering conditions (e.g. Bogaard and Greco, 2015).
In this study, a sensitivity analysis is carried out, to quantify the effects on slope equilibrium of the hydraulic properties of the soil cover and of the permeability of the soil-bedrock interface. In particular, the sensitivity analysis refers to the slope of Cervinara, around 40 km northeast of Naples (Italy), covered by a pyroclastic deposit with an average thickness around 2.0 m, and characterized by an average slope angle of 40°. For the sake of simplicity, the analysis is carried out for a slope of constant inclination angle, α, covered with a homogeneous pyroclastic deposit of constant thickness, for which friction angle ϕ'=38° and cohesion c'=0kPa have been assumed.

The physically-based model of the hydrological response of the slope, under the hypothesis of rigid soil skeleton, isothermal conditions and neglecting the flux of the gas phase, consists of the 2D Richards' equation, written in the space coordinates (*s*,*n*), respectively parallel and orthogonal to the slope:

$$\frac{d\theta}{dh}\frac{\partial h}{\partial t} = \frac{\partial}{\partial s}\left[k(h)\left(\sin\alpha + \frac{\partial h}{\partial s}\right)\right] + \frac{\partial}{\partial n}\left[k(h)\left(\cos\alpha + \frac{\partial h}{\partial n}\right)\right] \quad (1)$$

In equation (1), θ represents the volumetric water content of the soil, h is the matric potential. The hydraulic conductivity function, $k(h)$, and the water retention curve, $\theta(h)$, of the soil have been expressed with the van Genuchten-Mualem model (van Genuchten, 1980).
The boundary condition at the interface between soil and bedrock has been written by assuming gravity driven leakage from the soil cover towards a perched aquifer developing in the upper weathered part of the carbonate rock (*epikarst*). Darcy equation has been used to model storage and drainage of aquifer water. The fractured rock containing it has been hydraulically characterized by means of its effective porosity and saturated hydraulic conductivity.
The sensitivity analysis has been carried out to investigate the effects, on the minimum factor of safety at the base of the cover, evaluated under the hypothesis of infinite slope, of variations of the following parameters: two shape parameters of the van Genuchten-Mualem model of the hydraulic characteristic curves; the saturated hydraulic conductivity of the soil cover; the saturated hydraulic conductivity and the effective porosity of the fractured bedrock. The obtained results point out that the equilibrium of the slope during rainfall infiltration is affected not only by the hydraulic characteristics of the soil cover, but a major role is played by the permeability of the soil-bedrock interface.

Keywords: Sensitivity analysis, perched aquifer, hydrological budget, factor of safety.

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