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Technical Communication

Influence of the wetting path on the mechanical response of shallow unsaturated sloping covers

Luca Comegna [a,*], Guido Rianna [b], Su-Gon Lee [c], Luciano Picarelli [a]

[a] Seconda Università degli Studi di Napoli, Department of Civil Engineering, Design, Building and Environment, via Roma 29, 81031 Aversa (CE), Italy
[b] CMCC Euro-Mediterranean Center on Climate Change, REMHI-CMCC Regional models and geo-hydrological impacts Division Euromediterranean Center on Climate Change, Via Maiorise, 81043 Capua (CE), Italy
[c] University of Seoul, Department of Civil Engineering, Seoul, South Korea

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ABSTRACT

Some Authors highlight the hysteretic response to wetting of unsaturated soils, showing that the operative SWCC may significantly diverge from the one usually adopted in conventional approaches. Accounting for the typical range of values covered by the suction–degree of saturation relationship for loose granular pyroclastic soils, the paper examines the influence of potential wetting paths on slope stability conditions.

1. Foreword

Some Authors [1–6] highlight the hysteretic nature of the relation between matric suction, s, and degree of saturation, S_r (known as *Soil Water Characteristic Curve*, SWCC) displayed by some unsaturated soils.

Fig. 1a depicts the typical response to drying and wetting cycles of an initially saturated sandy specimen. Upon drying, the soil maintains a full saturated condition until a threshold matric suction, s_b, called *air entry value*, is attained. As suction exceeds s_b, air starts penetrating. The finer is the soil the larger is the air entry value. As drying proceeds, the degree of saturation, S_r, decreases, while suction increases following the so-called *main drying curve* until the *residual* (minimum) *degree of saturation*, S_{res}. If at that point the specimen is wetted, the degree of saturation starts increasing along a path known as *main wetting curve*: the two curves do not coincide. If wetting along the main curve is extremely slow, full saturation could be attained at zero suction. In contrast, if wetting is relatively rapid, some air could be trapped in the soil and the main wetting curve would not reach a 100% saturation degree. If during the drying (wetting) stage the process is reversed and the soil is wetted (dried), it can follow a path, called *scanning curve*, internal to the zone comprised between the two main curves previously described. This suggests that the water content can assume any intermediate value within the zone individuated by the two main curves depending on the recent wetting/drying history.

Fig. 1b shows couples of values suction–degree of saturation obtained from both physical modelling [7] and field monitoring [8,9] on loose unsaturated pyroclastic soils widespread in Campania Region, Southern Italy, which are well known for being the seat of catastrophic rainfall-induced flowslides [10–12]. The wide range of values obtained in such cases seems a clear indication of the hysteretic soil behaviour [9,13]. The suction–degree of saturation relationship is then not univocal, but depends on the initial conditions.

Mathematical analyses of the hydraulic soil response to wetting (drying) often ignore this relevant issue, adopting a unique SWCC fitting all experimental data or passing through the point that represents the initial conditions. Through simple numerical analyses, the paper examines the influence of selected wetting paths on the mechanical response of a virtual slope consisting of pyroclastic soils, focusing on the influence on the safety factor and on the time to failure.

* Corresponding author. Tel.: +39 081 5010384; fax: +39 081 5037370.
E-mail address: luca.comegna@unina2.it (L. Comegna).

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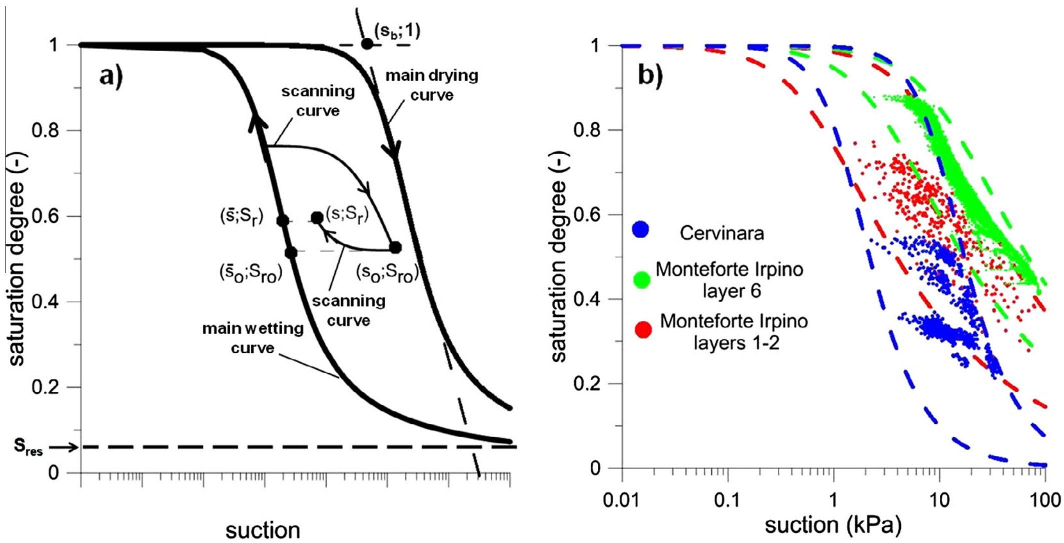

Fig. 1. Soil hydraulic response: (a) schematic response of a sample subjected to drying/wetting cycles; (b) data obtained from physical modelling (Monteforte Irpino layer 6 [7]) and field monitoring (Monteforte Irpino layers 1–2 [8], Cervinara [9]) on granular pyroclastic soils.

2. Methods and data

Rainfall-induced landslides in unsaturated soils are usually triggered by intense and persistent precipitations. In particular, the characteristics of the critical rainfall event (intensity and duration) depend on slope morphology, on soil stratigraphy, on hydro-mechanical properties and on initial and boundary conditions. The analysed case reproduces a typical situation in Campania, where rock slopes having an angle, α, up to 45° and more, are covered by layered deposits of essentially loose pyroclastic soils whose total thickness typically reaches 2–3 m [14,15].

Slope stability analyses have been carried out in the assumption that failure is caused by a 1D vertical unit flux induced by a continuous rainfall of constant intensity, whose projection normal to the sloping ground surface is equal to the hydraulic saturated permeability of the soil, k_{sat}. This is an extreme (but not unlikely) condition that allows to assess the response of a real slope to intense precipitations leading possibly to rupture. Of course, the effective infiltration rate and consequent runoff depend on the actual surficial hydraulic conditions, i.e. on the hydraulic gradient and conductivity. This last in turn depends on the current saturation degree. The seepage process has been simulated by the finite element code SEEP/W [16], that takes into account the well known Richards equation [17]:

$$-\frac{\partial}{\partial z}\left\{k(S_r)\cdot\left[1+\frac{1}{\gamma_w}\frac{\partial s(S_r)}{\partial z}\right]\right\} = n\cdot\frac{\partial S_r}{\partial t}, \quad (1)$$

where z is the depth, k the hydraulic conductivity, γ_w the unit weight of the water, t the time, n the soil porosity that has been assumed constant (thus neglecting any change induced by changing suction, s).

The current value of k has been related to the degree of saturation (Fig. 2) through the simplified van Genuchten equation [18]

$$k = \Theta^{0.5}\cdot\left[1-\left(1-\Theta^{\frac{1}{m}}\right)^m\right]^2\cdot k_{sat} \quad (2)$$

where $\Theta = \frac{S_r - S_{res}}{1-S_{res}}$ is the dimensionless volumetric water content (also known as the effective degree of saturation), while m is a shape parameter.

The shear strength of the soil has been determined by the extension to unsaturated soils of the Mohr–Coulomb strength criterion [19]:

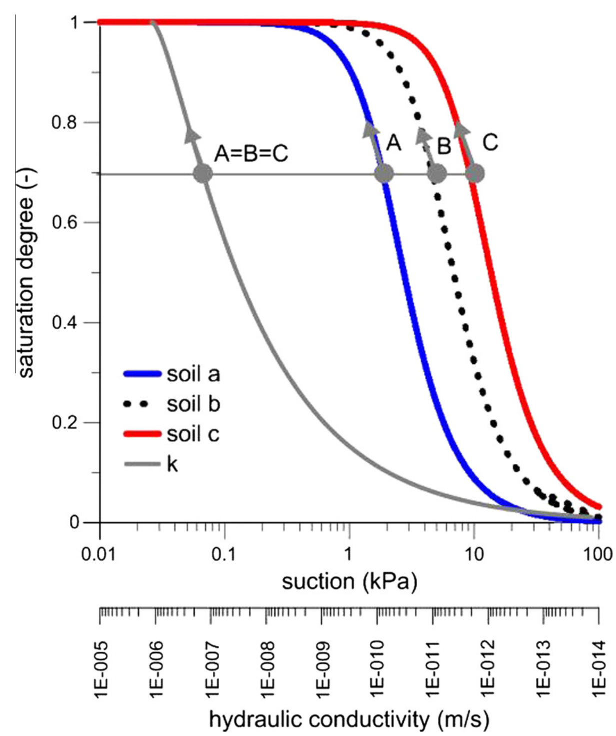

Fig. 2. Soil water characteristic curves and hydraulic conductivity curve considered in the analyses.

$$\tau_{\lim} = c' + s\cdot\Theta\cdot\tan\varphi' + (\sigma - u_a)\tan\varphi' \quad (3)$$

where c' is the effective cohesion, φ' the effective friction angle, σ the total normal stress, u_a the air pressure in the pores (assumed nil in the analyses). The Eq. (3) relates the shear strength, $\tau_{\lim}$, to suction, s, and effective saturation degree, Θ, through the "apparent cohesion" of the soil represented by the term $s\cdot\Theta\cdot\tan\varphi'$. Usually the friction angle is considered constant while the other two parameters, s and Θ, vary with the saturation degree. Therefore, the overall effect of wetting is a strength reduction, driven by the decrease in the apparent cohesion due to the change in suction and volumetric water content caused by rainwater infiltration.