HYSTERESIS PROCESSES AND EFFECTIVE RAINFALL HISTORIES

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The research is aimed to investigate how accounting for (or not) hydraulic hysteresis could influence the prediction of pore water pressures in partially saturated pyroclastic soils of Campania Region. The issue is particularly interesting as, in last years, they have been frequently affected by rainfall induced landslides. The analysis is based on i) deep investigations performed on such soils through field monitoring, laboratory test and physical models allowing to calibrate and validate a widely adopted literature model and ii) numerical analysis designed to detect the main features distinguishing the predictions of pore water pressures carried out taken into account hydraulic hysteresis.

Keywords: pyroclastic covers, hysteresis, Soil-water characteristic curve, landslide triggering weather patterns

1. INTRODUCTION

In last years, weather-induced landslides largely affected pyroclastic covers of Campanian Region, Southern Italy (Sarno, 1998; Cervinara, 1999; Nocera, 1997 and 2005; Ischia, 2006). Under usual conditions, the partially saturated state of the soil and then the contribution provided by suction to soil tightening can significantly increase soil shear strength permitting them to be stable also on very steep relieves. Wetting phenomena (primarily precipitation), increasing soil water content, can remarkably reduce such contributions up to attain local slope failure conditions (Pagano et al., 2010).

Due to the complexity of the investigated issues, the investigations about hydraulic soil state conditions inducing the events require the adoption of numerical methods. To this aim, the soil hydraulic behavior of an unsaturated soil is usually modelled by assigning two main functions: i) soil–water characteristic curve (SWCC) and ii) hydraulic conductivity function. However, many researches proved how both relationships exhibit a hysteretic behavior (e.g. Poulovassilis, 1962) while different studies have widely demonstrated in the laboratory, field and numerical investigations the relevance of the hysteresis for both soil hydraulic (Lenhard and Parker, 1987b) and mechanical response (Likos et al., 2014). The main goal of our research is to deepen the role of hydraulic hysteresis on the triggering of landslide events involving silty pyroclastic soils. It is accomplished by first studying the hysteretic behavior of the soils in hand, basing it on experimental results coming from laboratory tests and a physical model (Rianna et al., 2014) interpreted by suitable hysteretic model. Subsequently, through numerical analysis aimed to evaluate the hydrological behavior of a silty pyroclastic cover under the action of virtual atmospheric conditions. Finally, by comparing these theoretical results with ones obtained in the hypothesis of non-hysteretic behavior.
2. METHODS AND DATA

Among the several approaches proposed in literature (Iwata et al., 1995), the Lenhard-Parker (LP) approach (1987a, b) is adopted. It predicts the wetting and drying scanning curves scaled from the respective main wetting ($w$) and drying ($d$) curves defined through the Mualem-van Genuchten approach (1980):

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = \theta = (1 + (a s)^n)^{-m}$$

$$k = k_s \theta^\lambda (1 - \theta^{1/m})^{m/2}$$

where $\theta_r$ represents residual (saturated) volumetric water content; $k_s$ hydraulic conductivity (saturated hydraulic conductivity); $n$, $m (=1 - 1/n)$, and $a$[kPa$^{-1}$] and $\lambda (=0.5)$ are empirical parameters. The definition of the functions for the two branches (subscript $d$ for drying and $w$ for wetting) entails the assessment of $5 \times 2$ parameters. However, the LP approach requires two simplifying assumptions: $\theta_r = \theta_r^d = \theta_r^w$ and $n = n^d = n^w$. Furthermore, it prevents the non-closure of moisture retention scanning loops in simulations of cyclic paths (artificial pumping errors, APE), and permits considering the air entrapment effects employing the algorithm proposed by Land (1968) also in terms of differences in relative permeability.

In this work, the approach has been calibrated and validated for a pyroclastic soil (Table 1), a silty sand part of stratigraphic series found on Monteforte Irpino (Avellino Province, Campania Region) relieves and deeply investigated through laboratory tests (Nicotera et al., 2010) and field monitoring by Pirone et al. (2015). The main drying curve ($\theta_r, n, \theta_r^d, \alpha^d$) is obtained from $k u$-pF apparatus while the remaining parameters are estimated through an inverse analysis (Hopmans et al., 2002) carried out using suction and volumetric water content measurements collected during an entire hydrological year through the physical model developed by Rianna et al. (2014).

In Figure 1a, the values, observed and returned after calibration and the related estimated main wetting curve are reported. The matching appears quite satisfying on the entire range. Nevertheless, also for validation periods (Figure 1b-c), the paths are recognized well reproduced by the LP approach. The parameters are listed in Table 1.

![Fig. 1](image)

**Fig. 1** Experimental (grey) and findings (black) returned on calibration hydrological year period 2010-2011 (a) and validation: 2011-2012 (b); 2012-2013 (c). Main drying (red) and wetting (blue) curves are also reported.

<table>
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<th>Tab. 1 Main soil parameters for investigated pyroclastic soil</th>
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<td>Field average thickness</td>
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<td>Field porosity</td>
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<td>$G_s$</td>
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<td>$n$</td>
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<td>$\alpha^w/\alpha^d$</td>
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<td>$\theta_r/\theta_r^d$</td>
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<td>$k_s$</td>
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3. RESULTS

The evaluation on the effects of accounting (or not) hysteretic dynamics for landslide triggering in pyroclastic soils is carried out investigating how they can impact the prediction of pore water pressures, on short time scale, under the effect of heavy rainfall events (potential triggering event) and on longer time scales (seasonal) to provide a frame of differences in terms of potential antecedent conditions.

In this perspective, several sets of numerical analysis have been carried out in Hydrus 1D code (Simunek et al., 2005) on a homogeneous soil column 2m long. At the bottom, a capillary barrier condition is used (consistently with field conditions usually retrieved on field) while at the ground surface soil atmosphere dynamics are reproduced following the Feddes et al. (1974) approach. By way of example, the results concerning the application at ground surface of a constant ingoing flux equal to saturated permeability are displayed. Four different SWCC sand related permeability functions are considered: i) hysteretic, taking into account (HAE) or not (H) air entrapment; ii) non-hysteretic main drying (D); iii) non-hysteretic mean curve (M).

In this perspective, it is worth noting that, if air entrapment is taken into account, the van Genuchten parameters regulating a hypothetical “non-hysteretic” wetting curve cannot be analytically retrieved.

Three initial hydrostatic conditions are assumed with water table respectively posed at 2.5, 3.5 and 4.5 m below the ground surface. A reference depth of 1.5m is considered. For HAE and H, the paths start from point located on main drying curve. For the lower initial suction value (10kPa at 1.5m), HAE approach permits firstly reaching the zero suction condition (slightly
more than 2 days), after drying and mean curve, finally hysteretic not considering air entrapment approach (H) require longer times to attain the condition (about 3.5 days). The behavior appears mainly regulated by the required variation in volumetric water content (from about 0.04 for HAE to 0.12 for M); indeed, according to the assumptions, D, H and M are required to attain $\theta_s^d$ while HAE reaches an intermediate water content value (about 0.65). Such dynamics significantly change for higher initial suction values. Indeed, for both 20 and 30 kPa, the D and H paths reach the target suction with a substantial advance respect to the other ones. However, in these cases, the higher mean values of hydraulic conductivity (more than $\Delta \theta$) regulate the processes: therefore, for D and H, around twice values are retrievable.

4. CONCLUSIONS

Under the availability of field and laboratory data, a framework to calibrate and validate the widely adopted approach proposed by Parker and Lenhard (1987) is provided. The results, for a typical pyroclastic soil present on Campanian slopes (South Italy), are then employed to assess how the different approaches for estimating soil hydraulic behavior could influence the prediction of pore water pressures under persistent rainfall histories, recognized in wet season as trigger for slope instability phenomena. An example clearly displays how arisen differences could be particularly significant and they should be considered, for example, in developing predictive approaches for early warning systems.

REFERENCES


