Permeability changes induced by microfissure closure and opening in tectonized materials.
Effect on slope pore pressure regime

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ABSTRACT*:*

Tectonized clays are complex materials characterized by several levels of structures that may evolve during load and wetting/drying processes. Some mesostructural patterns, as fissures, have a particular influence on the value of permeability which is one of the main factors controlling pore pressure regime in slopes.
In this work, the pore pressure regime measured in a real slope of tectonized clay in Southern Italy is analyzed by a numerical model that considers changes in permeability induced by fissure closure and opening during the wetting and drying processes resulting from climatic actions.
Permeability model accounts for the changes in Pore Size Distribution (PSD) observed by Mercury Intrusion Porosimetry.

STUDY CASE

Pisciolo hill-slope is located in a tectonized clayey formation on the right side of the Ofanto River valley in the Lucanian Apennines (Melfi, Italy). The low resistance of the fissured tectonized clays and the high level of pore pressures provide the conditions for the development of a complex landslide zone composed by up to 14 landslide bodies over the whole hill-slope (Cotecchia et al. 2014a).

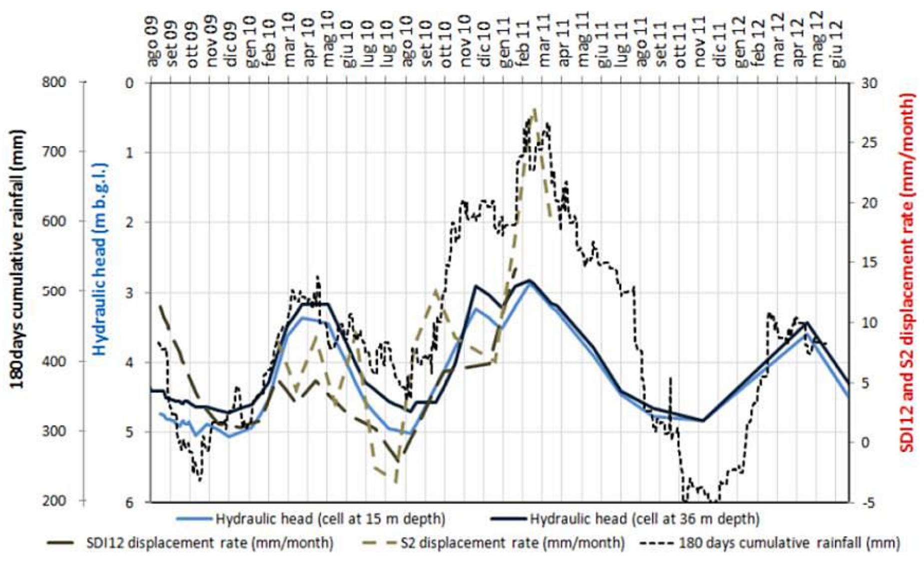


Figure 1: Monitoring data - *180 days cumulated rainfalls, piezometric heads and displacement velocities measured in the most hazardous zone of the Pisciolo hill-slope. (Pedone 2014).*

It is worth noting the significant variations in water pressure at a depth of 15-36 meters and their almost instantaneous temporal correlation with precipitation at ground level. Such a response is unusual in most of clayey soils.

Comparison between monitored pore pressures and rainfall records (Fig.1) evidences a hydrogeological response controlled by relatively high permeability values, resulting from fissuring at the different scales of observations. They are one of the key controlling mechanism for the stability of the Pisciolo landslide complex (Cotecchia et al. 2014b).

SOIL MICROSTRUCTURAL ANALYSIS

Mercury Intrusion Porosimetry technique is used in this investigation for the microstructural analysis of Pisciolo clay (Fig. 4). MIP tests are performed on representative undisturbed samples (Fig. 2 & 3) for initial (field porosity and humidity) and final conditions (flooded sample under *in situ* vertical stress in order to reproduce soil saturation during heavy rainfalls).

Figure 2: Sample of unaltered Pisciolo soil. *(M. De La Fuente 2014).*

Figure 3: Cubic sample for MIP tests. *(M. De La Fuente 2014).*

Figure 4: Record of incremental intrusion pressures during low pressure steps in the MIP test. *(M. De La Fuente 2014).*

MIP measurements allow for the characterization of the pore size distribution of the natural and flooded soil. They lead to the identification of soils dominant pores families and their evolution during wetting (Fig.5). Data particularly evidence the sealing of the largest pores (identified as fissures by fractal analysis) during sample saturation.

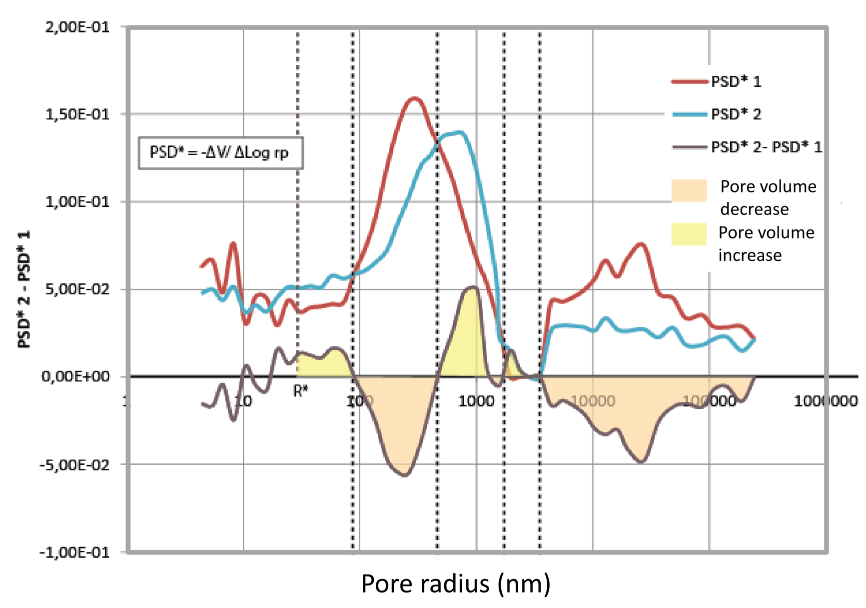


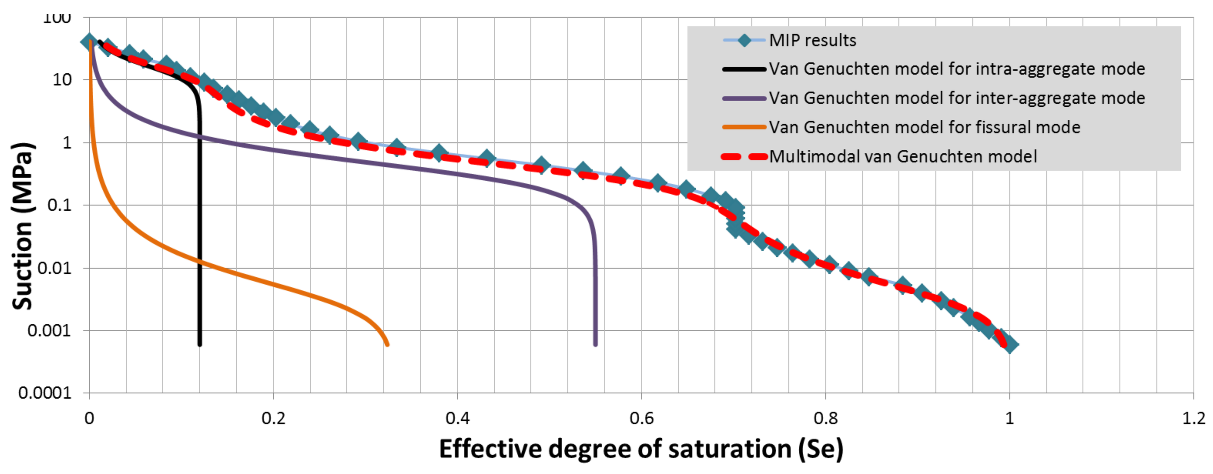
Figure 5: Pore size distribution (expressed in terms of volume change) for the natural (PSD*1) and the flooded soils (PSD* 2).

The chart discriminates pores families suffering volume increase (swelling) or decrease (shrinkage) during wetting. Fractal analysis allows to associate the first ones to bulk porosity and the second ones to fissure-like voids. Pores with radius less than 30 nm (R*) are not considered as participating in soil volumetric deformation. *(M. De La Fuente 2014).*

MODEL FOR PORE SIZE DISTRIBUTION AND PERMEABILITY EVOLUTIONS

According to Romero et al. (1999), Mercury Intrusion Porosimetry and soil water retention curves can be linked together provided that a correction is applied to switch from soil/air/mercury to soil/water/air interface effects. Consequently, under the assumption of undeformable soil skeleton, there is a direct relationship between degree of saturation at a target suction and the pore volume non intruded at the same value of mercury intrusion pressure. This similarity is exploited in this study to relate permeability and Pore Size Distribution through relationships classically used between permeability and degree of saturation in unsaturated materials.

To that aim, the Cumulated Pore Size Distributions of the natural and flooded samples are expressed into the form of a water retention curves and modelled by overlapping several van Genuchten's expressions, each one corresponding to one pore size distribution mode. Fig. 6 shows the fit obtained for the natural sample.



$$Se = \sum_{i=1}^{k} wi\left[1+\left(\frac{Pg-Pl}{P}\right)^{\frac{1}{1-\lambda}}\right]^{-\lambda}$$

Figure 6: Model of the retention curve obtained from the MIP of the natural soil sample. using a trimodal retention model defined by different subcurves of Van Genuchten adjusted to the effective saturation values corresponding to the domain of each modal pore families identified by MIP. *(M. De La Fuente 2014).*

In a second step, the soil water retention curve is derived for any microstructural arrangement between the natural and flooded states by setting an adequate description of PSD change. It is based on the definition of coupling parameter (χ), equal to the change of water content (or non intruded pore volume) over the change in porosity (or total pore volume) (Casini et al., 2014).

$$\text{WRC (Final)}: \quad Se_f = Se_i \cdot \frac{Vmax\ int_i}{Vmax\ int_f} + \chi \cdot \left(1-\frac{Vmax\ int_i}{Vmax\ int_f}\right)$$

$$\chi = \frac{d\theta_w}{d\theta_w + d\theta_a}$$

Figure 7: Computation of the current WRC from the initial WRC curve, obtained by MIP, and the knowledge of χ parameter, defined as the ratio of variation in water and void content in the sample. *(M. De La Fuente 2014).*

Finally, the permeability for a given microstructural state is inferred from a pore series model and Mualem closed form relationship.

$$k_{rl} = \sqrt{S_e}\left(1-\left(1-S_e^{1/\lambda}\right)^{\lambda}\right)^2$$

Figure 8: Equation of the permeability for one pore family. It is based on the effective saturation values derived from the multimodal Van Genuchten curve updated for a given microstructural state by application of χ parameter. *(M. De La Fuente 2014).*

FINITE ELEMENT MODEL AND RESULTS

Permeability model has been implemented in a thermo-hydro-mechanical code provided with a special boundary condition for climatic actions (Code_bright, 2014). Tool is used to analyze pore pressure measurements obtained in the tectonized clay slope. Results indicate that a correct reproduction of pore pressure at depth requires consideration of permeability values partly governed by clay fissures. Work is ongoing about the modelling of the effect of fissure evolution on slope pore pressure regime.

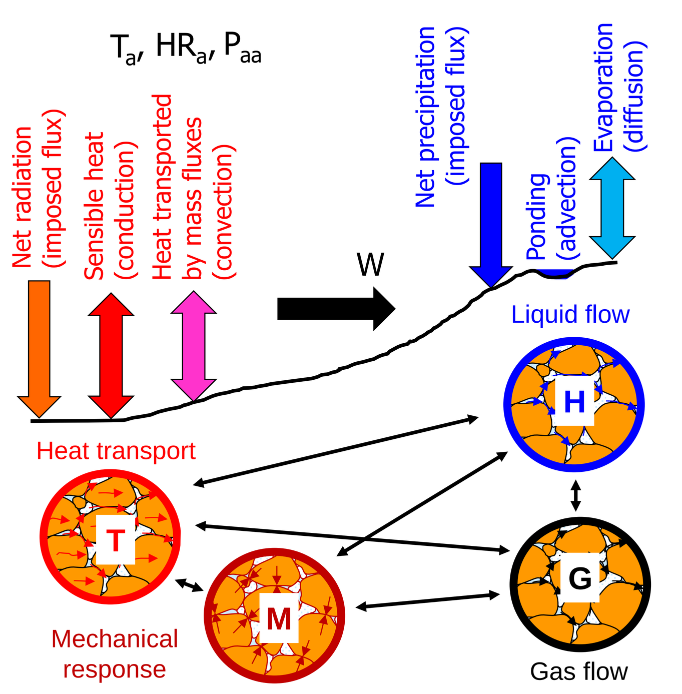


Figure 9: Processes accounting for in the numerical analysis

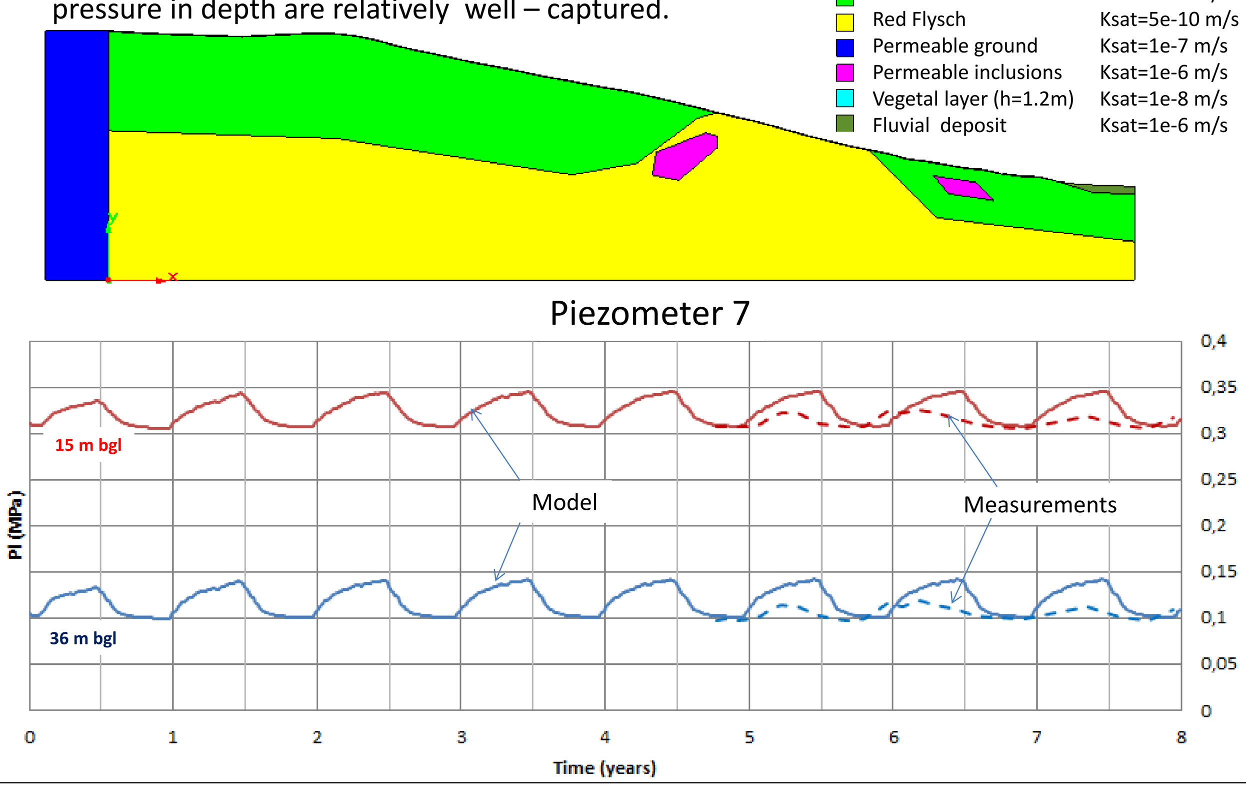


Figure 10: Model of Pisciolo slope. Pore water pressure in depth are relatively well – captured.

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