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Effects of wetting and drying cycles on mechanical properties of pyroclastic soils

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ABSTRACT

Pumice, a component of pyroclastic soils, undergoes a grain crushing process, even at lower stress level, with the resulting decreasing in shear strength in such material. According to the content already discussed in Esposito et al. 2013, this paper is focused on the attempt to further correlate the in situ measures acquired on these kinds of soils, in particular about suction, humidity and saturation, to the mechanical behavior observed in laboratory. The data collected in situ during 19 months, to cover both dry and wet cycles, supported the evidence that the wetting and drying conditions of such soils, due to the analyzed meteoric precipitations, fulfilled the required conditions that may induce the phenomenon of grains crushing. Hence, we have further explored the connection of these kinds of phenomena introducing new elements of discussion such as the decay of the mechanical characteristics, in situ measurements of the hysteretic relation between the suction and the soil water content, investigation about the occurrence conditions of static liquefaction and more. The research was developed by selecting, as test case, a wide area around Naples and the Vesuvius (Italy), affected, in particular, by frequent landslide phenomena, due to the instability of the pyroclastic cover, such as the events occurred at Monte Faito, Nocera Inferiore, Coroglio and Monte di Procida Ridges. Evidence of a marked influence of the wetting-drying cycles on the pumice crushing and on the resulting structural collapse phenomena, was observed during laboratory tests. The issues and the related discussion addressed in this paper could be useful in order to identify the triggering phenomena of shallow collapses, fast landslides, flow liquefaction and more, where pyroclastic covers, similar to those coming from the selected areas, are located.

1. Introduction

This paper deals with the particular behavior of pyroclastic soils under a wetting and drying process which lowers the specific strength of this kind of soils. The selected samples come from a wide area around Naples (Phlegrean soils, P) and the Vesuvius volcano (Vesuvian soils, V) (Italy).

Many papers dealt with the collapse and the shear strength of unsaturated pyroclastic soils (among many others Guadagno et al., 1999; Bilotta et al., 2005; Picarelli et al., 2006; Cascini et al., 2013). Nevertheless, in the following sections a further contribution about these kinds of issues, including infiltrometric site tests discussion and a sort of soils classification by means of Seed's plot are given.

Results regarding both in situ and laboratory tests conducted on samples coming from the Camaldoli Hill (P site), from which infiltrometric and pluviometric data were also obtained and described, Pizzo D'Alvano (V site), Gragnano (V site), Giugliano Settecainati (P site) and some other ones were compared to each others. The laboratory tests, which have already been in part discussed in Esposito et al. (2013), were performed at the laboratory of 'Geologia Applicata e Geotecnica', University of Federico II, Naples, Italy.

Pumice, a pyroclastic soil component, during wetting and drying cycles, undergoes a grain crushing process, even at low stress levels. In Mazzarella (1999), an ongoing phenomenon of rains clustering in Italy was discussed. From this research it resulted that the total amount of rain falling in a given zone within a year is the same on average, but the number of rainy days have diminished. This is to mean that periods of heavy rains alternate with long periods characterized by a total absence of rain. The rainfall measurements at Camaldoli Hill, during 19 months, show that even for this site the phenomenon of clustering of the rain occurs. Accordingly, in order to study the soil mechanical consequences of this weather variabilities, we have performed some in situ and laboratory tests aimed at acquiring the water content and suction versus time at different depths, volumetric water content versus mean pressure invariant, suction and rainfall intensity versus time at different depth, shear strength versus normal and horizontal displacements and suction.

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The evaluation of the physical, mechanical and hydrological parameters acquired by this kind of investigations is the necessary step in order to employ mathematical-numerical tools aimed at studying wet debris flow (Minatti and Pasculli, 2010, 2011; Pasculli et al., 2013, Pasculli et al., 2014), local erosion (Pasculli and Sciarra, 2006; Pasculli, 2008), river embankments erosion by Cellular Automata (Pasculli et al., 2010; Audisio et al., 2015; Pasculli and Audisio, 2015, applied to Piedmont basins, but suitable to be applied for basins located in Pyroclastic area), landslides and landslides mapping (Calista et al., 2015a, b; Calista et al., 2016; Audisio et al., 2017).

This paper is organized as follows. Hydraulic hysteresis is briefly introduced in order to give just a brief sketch of important phenomena influencing the results discussed in the paper (Section 2). In Section 3 the selected samples description, where they were taken from and the instruments used, are dealt with. Then, the measured data in the site of Camaldoli Hill, in particular suction vs water content, acquired by infiltrometric and pluviometric tests, briefly described in order to give the reliability of the obtained measures, are reported (Section 4). The wetting and drying cycles effects from laboratory tests conducted on samples coming from different sites are discussed in the next section (Section 5). In Section 6 the impact on the shear strength of selected samples, due to wet and dry cycles are analyzed. The discussion of the results and the related implications are summarized in Sections 7 and 8.

2. Hysteresis phenomenon relating to wetting and drying cycles

The interaction of water with a porous media and in particular with a pyroclastic soil was quantitatively expressed through the concept of hydraulic potentials, which we refer to in this paper. The curves of hydraulic potentials are the expression of the link between the energy necessary to extract water from the soil and the volumetric water content Θ_w (Bonn et al., 2009). If the soil is partially saturated, the water pressure is smaller than the atmospheric, and it is indicated as a 'negative pore pressure' or 'suction'. The studied pyroclastic soil is usually in a partial saturated condition. The negative pore pressure contributes to increase the shear strength of the soil. Thus, rainwater infiltration, increasing the degree of saturation and, consequently, lowering the stabilizing effect of the negative pore pressure, could be one of the triggering causes of soil failure. The phenomenology, however, is complex because the soil in place was subject to seasonal wetting and drying cycles. These cycles generated phenomena which, undoubtedly, induced effects on the pyroclastic soil, not so easy to identify. For both undisturbed and reconstructed laboratory samples, the curves relative to Θ_w versus p'_m (mean effective pressure invariant) could be determined through both wetting and drying transients. Furthermore, for each Θ_w, two or more pore pressure values could correspond, determining a hysteresis phenomenon. The variation of matric energy for a water-soil system, can cover 7–8 orders of magnitude. For this reason Schofield (1935) introduced the $pF = \log_{10}(u_{cm\ H_2O})$ parameter, defined as the logarithm in base 10 of the pore pressure u, expressed in centimetres of water column. Thus $pF = 1$, corresponds to a negative pressure of 1 kPa (10 cm) of water, while $pF = 3$ corresponds to a negative pressure of 100 kPa (1000 cm). The hysteresis loop implies energy dissipation due to the difficulty of the fluid to flow freely through the porous medium. Some of the reasons of such phenomenon are: irregularity of the cross sections of the ducts that connect the pores (bottleneck effect), higher contact angles of the fluid-solid menisci during the wetting phase with respect to drying, thixotropic recovery and/or the aging of the soil due to multiple wetting-drying cycles (Crassous and Charlaix, 1994; Robbins and Joanny, 1987). The diagram of the negative pore pressure represents the functional link between pore pressure and moisture contents. There is equivalence between the depression, which acts on the water, controlling its behavior, and the effects of the isotropic pressure. In the case in which a sample is consolidated under an effective pressure p'_m and then if this is removed, a pore pressure equal to p'_m, just as for capillary potential, is generated. It is evident that the isotropic consolidation curve and suction curve are actually exchangeable. The coincidence between pF-Θ_w curve and the consolidation curve seems to derive from the same hysteresis phenomenon, between the loading and unloading phase (drying and wetting). The existence of the hysteresis, also for consolidation, implies that, to an assigned value of pressure p'_m, more values of the void ratio 'e' can correspond and vice versa. The difficulty to face when hysteresis phenomenon occurs is that the functional relation between the two involved parameters is not unique, however this difficulty can be resolved by thermodynamic considerations (Gray and Hassanizadeh, 1998; Beliaev and Hassanizadeh, 2001). The hysteresis concept, in fact, involves system energy dissipation in order to gain the necessary forces opposing to soil volume lowering. It is worth noting that the capillarity, one of the main phenomena involved in the filtration through unsaturated porous media, could also affect the stability of slopes (Mancarella et al., 2012; Galeandro et al., 2013).

3. Selected samples and measuring instruments

The samples analyzed in this paper come from Vallone S. Rocco (NA): samples S3C2 and S3C3; Pizzo D'Alvano (SA): sample PA2; Gragnano (NA): sample PB5; Giugliano Settecainati (NA): sample P2; Vesuvian samples (NA); Soccavo (NA); Pianura (NA); S. Felice a Cancello (CE); Avella (AV) (3 samples) and Camaldoli Hill. Table 1 shows some useful informations about the principal samples utilized, where they come from, the main material of which they are made and the tests to which they were submitted.

The cylindrical samples had a diameter of 10 cm and a length of 4 cm and were partially remoulded. The samples were taken at the same depth of the porous tip of tensiometers. A summary of the geological features of many of the sites from which the samples analyzed come and the instrumentations used in performing laboratory and in situ tests, are reported following. The analyzed samples are constituted by pumice materials and come from an area located around the Phlegrean fields in the district of Naples (Fig. 1). The geological features are characterized, essentially, by successions of Mesozoic carbonate platform (Unit Alburno Cervati, D'Argenio et al., 1973) covered with late Quaternary pyroclastic layering, acquiring more thickness in the shelves summit and at the base of the slopes that are

Table 1
Sampling sites, type of material (P: Phlegrean soils; V: Vesuvian soils), samples main material, type of tests carried out and where (in situ or in the laboratory).

Tested samples	Sample location (see also Fig. 1)	Site	Material	Test type
S3C2	Vallone S. Rocco (NA)	P	Pozzolana	a, b
S3C3	Vallone S. Rocco (NA)	P	Pozzolana	a, b, I
PA2	Pizzo D'Alvano (SA)	V	Pumice	a, b
PB5	Gragnano (NA)	V	Pumice	a, c, d, I
P2	Giugliano Settecainati (NA)	P	Pozzolana	a, b, c
AP3	Giugliano Settecainati (NA)	P	Pozzolana (without pumice)	a, b, I
	Vesuvian samples (NA)	V	Pumice	a, b, d
	Soccavo (NA)	P	Pozzolana	a, d
	Pianura (NA)	P	Pozzolana	a, c
	S. Felice a Cancello (CE)	V	Pumice	a, d, I
1	Avella (AV)	V	Pumice	a, c, I
2	Avella (AV)	V	Pumice	a, c, d
3	Avella (AV)	V	Pumice	a, c
Tensiometer point	Camaldoli Hill	P	Pozzolana	a, I
P3C3	Camaldoli Hill	P	Pozzolana	a, b

Legend: a) classification, b) oedometer tests; c) direct shear test; d) triaxial test; I) in situ test.