Engineering Geology 195 (2015) 70–84

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

The hydro-mechanical behaviour of unsaturated pyroclastic soils: An experimental investigation

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ARTICLE INFO

Article history:
Received 19 July 2014
Received in revised form 18 February 2015
Accepted 19 May 2015
Available online 27 May 2015

Keywords:
Partial saturation
Shear strength
Compressibility
Suction
Landslides
Laboratory tests

ABSTRACT

An experimental investigation into the hydro-mechanical behaviour of a pyroclastic silty sand was carried out in the framework of a research project on flowslides in pyroclastic soils in the Campania region (Italy). Undisturbed soil samples were taken from the subsoil layers of a test site on a limestone relief mantled by a pyroclastic unsaturated soil cover. The lab investigation was focused on the hydro-mechanical behaviour of a pyroclastic silty sand originated from the *Ottaviano* eruption of the *Somma–Vesuvius* volcano some 8000 years ago. The main features of the hydraulic hysteresis domain were evaluated and the matric suction range showing the peak saturation rate with respect to suction was identified using water retention data obtained by means of evaporation and soaking tests. The mechanical behaviour of *Ottaviano pozzolana* emerged from stress-path controlled triaxial tests on saturated specimens and stress-path and suction controlled triaxial tests on unsaturated specimens. Average soil skeleton stress and matric suction were adopted as stress variables to present and interpret the experimental results. The effects of the unsaturated state on isotropic compressibility and on critical state shear strength are presented and discussed.

1. Introduction

Rainfall-induced flowslides have occurred repeatedly in the shallow pyroclastic soil deposits produced by the explosive activity of the various volcanic systems in the Campania region (e.g. Calcaterra et al., 2003; Di Crescenzo and Santo, 2005). Flowslides mainly affect the pyroclastic cover resting on the limestone massif in the region. Rainwater infiltration is the likely mechanism that leads or predisposes slopes to failure by reducing matric suction in the unsaturated pyroclastic soils, thereby reducing their shear strength.

Analysis of the phenomena obviously requires accurate description of the hydro-mechanical behaviour of the soils involved. Many authors have thus tackled this complex issue starting from the tragic events of Sarno in 1998 (Cascini, 2004). For instance, Olivares and Picarelli (2003) and Olivares and Damiano (2007) analysed the mechanical behaviour of pyroclastic soils involved in a typical flowslide. Bilotta et al. (2005) collected extensive experimental data about the hydraulic and mechanical properties of ashy soils from the source area of the May 1998 event. Picarelli et al. (2007) analysed the main mechanical properties of pyroclastic soils in Campania and tentatively organised their classification. Comparison of a number of experimental results led the above authors to identify some common features of the mechanical behaviour of the pyroclastic ashy soils affected by flowslides in Campania. It resulted that grain size, void ratio and structure are associated with the physical phenomena behind the generation and formation of the deposits. In particular, Picarelli et al. (2007) showed that volcanic ashes involved in flowslides are highly uniform concerning grain-size distribution (such volcanic ashes display a high sandy component and a significant amount of non-plastic silt) and present high porosity, ranging from 65% to 75%.

The experimental data presented in the papers mentioned above were interpreted in terms of net stresses and matric suction in accordance with one of the theoretical paradigms prevailing in unsaturated soil mechanics (e.g. Gens, 1996). All these contributions thus benefited from the simplicity of the stress variable set adopted, but at the same time suffered from its limitations. In particular, rather cumbersome procedures are required for modelling, in terms of net stresses and matric suction, the transition between saturated and unsaturated states and the mechanical effects of hydraulic hysteresis. More recently, Buscarnera and Nova (2009) proposed a constitutive model, conceived in terms of average skeleton stress and "modified suction", defined as the product of porosity and matric suction, that simulates mechanical responses similar to those observed by Bilotta et al. (2005). The stress variable set adopted by Buscarnera and Nova (2009) overcomes the main limitations of the approach in terms of net stress and matric suction, providing a smooth transition from unsaturated to saturated states (Alonso et al., 2010). Furthermore, Buscarnera and Nova (2009, 2011) showed that their model was suitable to reproduce the same kinds of constitutive instabilities upon

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http://dx.doi.org/10.1016/j.enggeo.2015.05.023
0013-7952/

wetting paths experimentally observed by Nicotera (2000), Olivares and Picarelli (2003) and Olivares and Damiano (2007).

During the past decade extensive experimental data from laboratory tests and from the monitoring of climatic conditions, matric suction and water content in the subsoil have been collected within the framework of a long-term research on flowslides (Papa, 2007; Papa et al., 2008, 2013; Evangelista et al., 2008; Nicotera et al., 2010; Papa and Nicotera, 2011; Pirone, 2010; Pirone et al., 2011). The test site used to obtain the above data is situated on a limestone relief about 30 km northwest of the volcano *Somma–Vesuvius*. In this site the limestone massif has a pyroclastic unsaturated soil cover several metres thick constituted by alternating layers of pumiceous soils and ashy soils originating from a series of eruptions of Somma–Vesuvius (Fig. 1). Although the mechanical and hydraulic behaviours of all the pyroclastic soils covering the limestone massif were investigated in the laboratory, herein we primarily focus on the hydro-mechanical behaviour of one of the ashy layers identified in situ that in the following is termed *Ottaviano pozzolana* (Op). This ashy soil was recovered at about 1.50 m depth and consists of a 1.00 m thick palaeosol covering a pumiceous layer from the *Ottaviano* eruption (8000 years ago) and is found commonly in the area involved in catastrophic flowslides. However, this unsaturated pyroclastic soil has the same origin and similar grain-size distribution and physical properties to those investigated by Olivares and Picarelli (2003) and Bilotta et al. (2005), as observed elsewhere by Sorbino and Nicotera (2013). For this reason, scientific interest in the hydro-mechanical behaviour of *Ottaviano pozzolana* is not only based on its intrinsic importance but also on its representativeness of quite an extensive class of pyroclastic ashy soils in Campania.

2. *Ottaviano pozzolana*

Ottaviano pozzolana exhibited apparent cohesion such as to extract an undisturbed sample by means of a thin wall sampler both in drill holes and in trenches. As regards the possible presence of some cementation resulting in an "effective cohesion" three features of the *Ottaviano pozzolana* suggests that this is not the case: 1) it was originated by air ash falls resulting in a low concentration of volatiles, a rather low emplacement temperature and a quite fast cooling rate (mainly due the small thickness of the deposit); 2) it is a very young deposit (about 8000 years) and likely post emplacement diagenetic phenomena have not enough time to develop; and 3) it was preserved in a sort of "sealed environment" by the emplacement of deposits from subsequent eruptions (e.g. Avellino eruption 3700 years before present). The grain-size distribution of *Ottaviano pozzolana* is reported in Fig. 2. The grain-size envelope (obtained from 12 different samples) exhibits limited scatter, demonstrating the uniformity of the deposit. The soil is well-graded, ranging from sand to silt with a small clay fraction constituted by non-plastic fines (a number of tests showed that the value of the plasticity index for those fines is practically nil). Importantly, the single particles have a vesicular nature due to the complex processes of magma fragmentation and subsequent modification during transport and deposition.

Mean values of specific gravity, dry unit weight and gravimetric water content are reported in Table 1. The specific weight G_s measured with conventional procedures varies within quite a wide range ($G_s = 2.46–2.76$). This variability is due to two main reasons (Picarelli et al., 2007): 1) external and internal voids of the single particles cannot be completely destroyed by even intense crushing and hence they randomly affect pycnometer measurements; and 2) the specific gravity of particles depends on their size because a significant crystal fraction, with a higher specific weight, may be present only in a particular granulometric class. The soil is extremely porous (mean porosity $n = 0.73$ and void ratio $e = 2.704$) and partially saturated (mean degree of saturation $S_r = 0.67$). However, in situ monitoring of the soil water content confirmed that the saturation condition varies on a seasonal basis (Papa et al., 2013). The porosity and grain-size

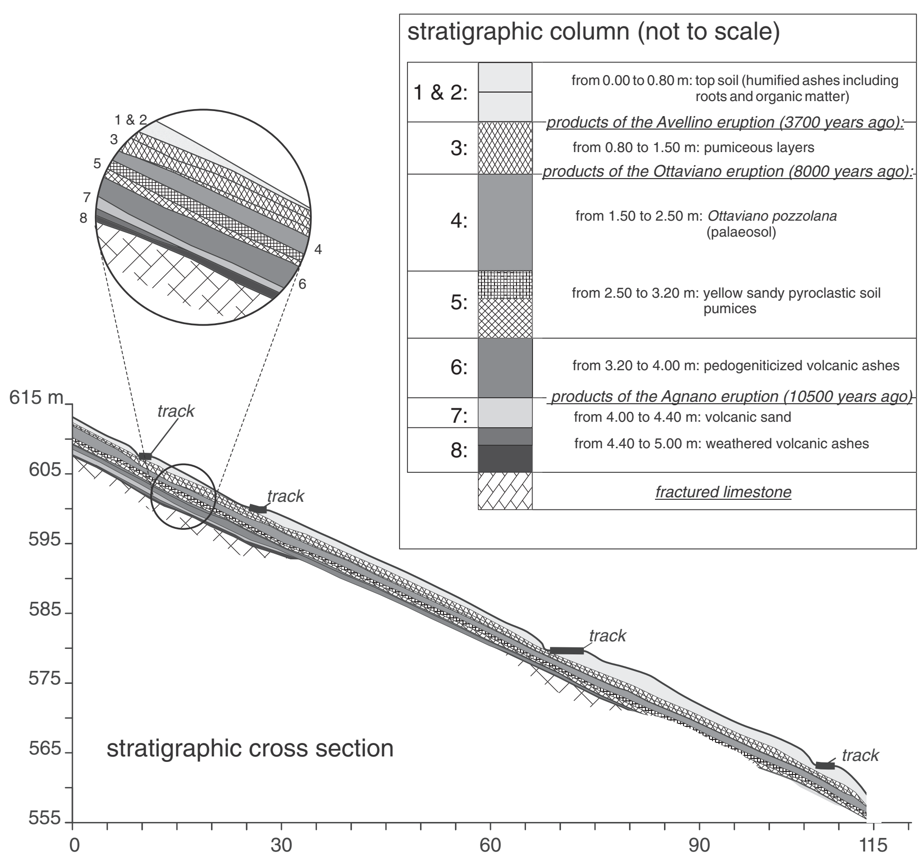

Fig. 1. Stratigraphic setting of the test site.