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A proposal of structural models for colluvial and lateritic soil profile from southwestern Brazil on the basis of their collapsible behavior

J.C.B. Benatti *, M.G. Miguel

State University of Campinas, Campinas, São Paulo, Brazil

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ABSTRACT

This paper aims to propose structural models for understanding the collapsibility of a colluvial and lateritic soil by conducting oedometric tests with controlled suction executed in laboratory. The undisturbed soil samples submitted to experiments were collected by opening a trial pit in Experimental Field for Soil Mechanics and Foundations situated at the State University of Campinas, São Paulo, Brazil. The soil samples were characterized by means of standard geotechnical tests, chemical and mineralogical tests and mercury intrusion porosimetry. Oedometric tests with controlled suction showed the influence of matric suction on the compressibility of the soil samples. It was also observed that the higher the values of matric suction, the higher the Laboratory Collapse Potential — CP. The mineralogical chemical tests indicated the presence of oxides and hydroxides of iron in the samples, compounds usually associated with cementation. The presence of mineral, such as kaolinite, gibbsite, hematite and goethite, was also observed. The impregnated thin-layer plates of the soil samples, as well as the grain-size distribution curves and mercury intrusion porosimetry, indicated the presence of a structure formed by microaggregates. Structural models for soil collapse were proposed basing on the results obtained. There were behavioral differences in each soil sample collected at different depths. The behavior of the sample collected at a 1.5 m depth was basically influenced by matric suction. As for the samples collected at 4.5 m and 6.5 m, besides being both influenced by matric suction they were also influenced by the presence of cementing agents (samples collected at 4.5 m) and by the presence of more angular grains of quartz (samples collected at 6.5 m).

1. Introduction

Some soils under constant stress present volume decrease related to the increase in moisture content. This strain induced by moisture is a typical behavior of the so-called collapsible soils, which are characterized by having an unstable structure (Dudley, 1970).

Collapse behavior has been observed in different parts of the world, especially in tropical regions where a wide variety of soils, regarding texture chemical composition and genesis are present; but it is characterized primarily by presenting unstable and porous structure, and moisture content lower than the necessary one for its complete saturation (Houston et al., 2001; Rao and Revanasiddappa, 2002; Pereira et al., 2005; Zeng and Meng, 2006; Zorlu and Kasapoglu, 2009).

Tropical soils have certain peculiarities that differ from soils originating from temperate climates. The typical climatic conditions of tropical regions lead to the formation of soils such as lateritic soils, which are characterized in their formation by the intense migration of particles under the action of filtration and evaporation in unsaturated zone, resulting in a porous superficial horizon, where the most stable minerals such as quartz, magnetite, ilmelite and kaolinite almost exclusively remain. Clay and silt particle aggregation is common in these soils due to the action of iron and aluminum oxides and hydroxides. These microaggregations give to the lateritic soil a peculiar mechanical and hydraulic behavior (Gidigasu, 1976; Committee on Tropical Soils of ISSMFE, 1985; Nogami and Villibor, 1995).

The lateritic soils often present collapsibility resulting from its metastable structure, which is guaranteed by cementations of iron oxides and matric suction, since they are typically unsaturated soils.

Collapse study in tropical soils is usually carried out using single or double conventional oedometer tests, without taking into account the influence of matric suction on soil (Jennings and Knight, 1957, 1975; Medero et al., 2009; Zorlu and Kasapoglu, 2009). The use of oedometer tests with suction control is vitally important for collapse study in unsaturated soils (Villar, 1999; Rao and Revanasiddappa, 2000; Rodrigues and Vilar, 2006; Jotisankasa et al., 2007). By using this technique, it is possible to predict soil behavior for known values of matric suction, eliminating the problem of not knowing the initial moisture content of the specimen, which is a value that significantly influences the increase in the collapse of the specimen.

Many elastoplastic constitutive models for unsaturated soils have been proposed over the past years (Alonso et al., 1987, 1990; Wheeler and Karube, 1996; Schinaid et al., 2004; Costa et al., 2008; Zhang and Lytton, 2009). These models include the suction as additional variable stress. The model proposed by Alonso et al. (1990) is the most widely

* Corresponding author. Tel.: +55 19 3521 2393.
E-mail address: jcbbenatti@gmail.com (J.C.B. Benatti).

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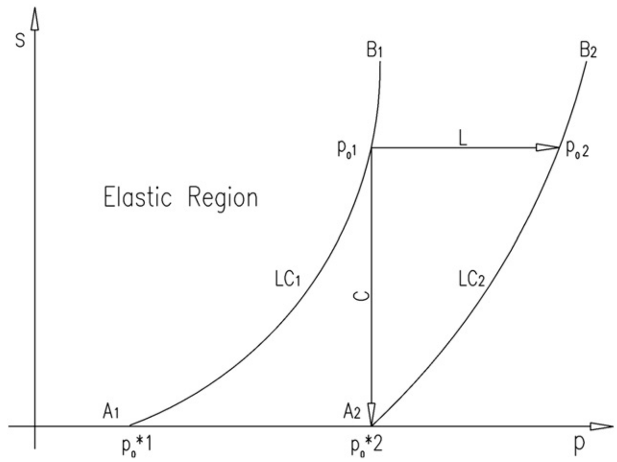

Fig. 1. Loading and wetting stress path in the plane (*p*,*s*) (Alonso et al., 1987).

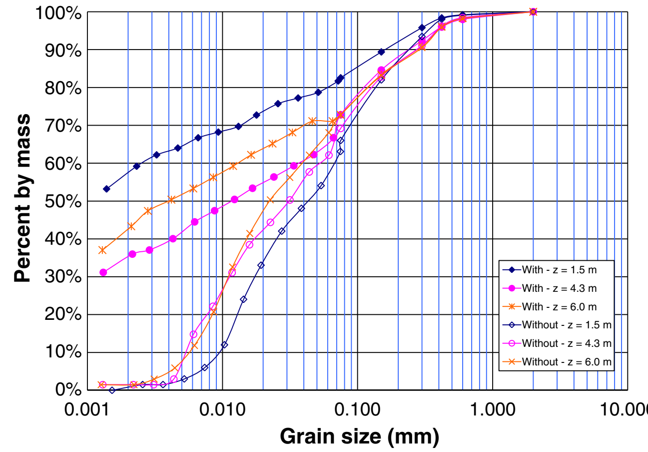

Fig. 2. Grain-size distribution curves obtained with and without the use of dispersant.

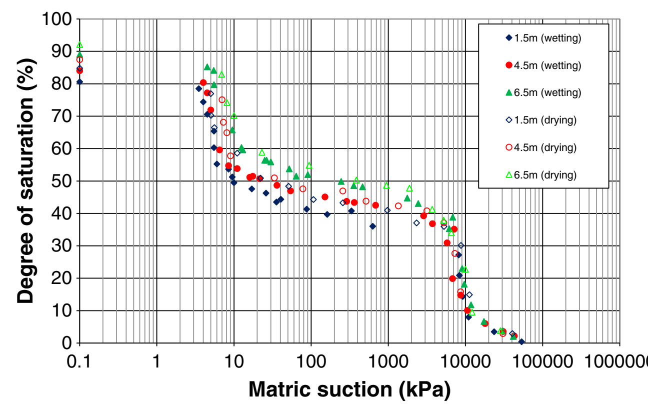

Fig. 3. Soil–water characteristic curves.

used, now called the Barcelona Basic Model (BBM) (Wheeler et al., 2002).

According to Alonso et al. (1987, 1990), when soil samples are subjected to increasing compressive stresses at a maintained matric suction, the resulting stress–deformation curves allow the determination of their current pre-consolidation or yield stress. The values of these pre-consolidation stresses, once united on the plane (*p*, *s*), – where *p* is stress and *s* is suction – resulted in points which, when interpolated, will generate a curve as shown in Fig. 1. The points $(p_0^*)1$ $(p_0^*)2$ and $(p_0)1$ and $(p_0)2$, represent the pre-consolidation stresses *1* and *2*, for the saturated and unsaturated soils, respectively. The A_1B_1 and A_2B_2 curves are called plastification or LC (*loading-collapse*) yield curves, because they represent irreversible volumetric paths for L and C, i.e. for *loading* and *collapse*.

Understanding the mechanisms that control the collapse in tropical soils is of vital importance for studying their behavior. Because of their very endogenous characteristics of formation, their behavior varies greatly depending on the region where it is and usually is not consistent with the soils of temperate climates, whose study is already well developed.

This paper analyzes the results of oedometer tests carried out with suction control for the superficial layer of the colluvial and lateritic soil profile at the Experimental Field of Soil Mechanics and Foundations — EFSMF, Unicamp, located in Campinas, São Paulo State, Brazil, and aims to assess the influence of matric suction in the hydro-mechanical behavior of this soil through analysis of its structure and chemical–mineralogical composition taking into account its formation processes.

From this analysis, structural models are proposed to represent the collapse mechanism acting on this soil. For the proposal of structural models presented here, the concepts proposed by Alonso et al. (1987, 1990) have been used.

2. Materials and methods

2.1. Studied soil

The studied soil was removed from a colluvial and lateritic soil profile, 6.5 m thick, situated at the Experimental Field of Soil Mechanics and Foundations (EFSMF) of the State University of Campinas (Unicamp), São Paulo State, Brazil.

Undisturbed soil samples were collected at 1.5 m, 4.5 m and 6.5 m depth, by opening a 7.0 m deep trial pit. These soil samples were chosen because they present different hydro-mechanical behavior, which was already pointed out by Miguel et al. (2007) and Miguel and Vilar (2009).

Table 1 shows the values of physical indexes of the undisturbed samples tested: natural unit weight (ρ), particle unit weight (ρ_s), natural or field moisture content (w), void ratio (e), porosity (n), degree of saturation (Sr) and saturation moisture content (w_{sat}). Furthermore, Table 1 shows the liquid limits (LL) and plasticity index (PI) of the soil samples according to ASTM (1998a).

Observing the data presented, it appears that the soil samples have high void ratios and low degree of saturation, which are typical of tropical lateritic and collapsible soils. The particle unit weight values of the soil samples are relatively high, indicating the possible presence of oxides and hydroxides of iron, typical cementing agents of lateritic soils.

Table 1
Values of physical indices of the undisturbed samples.

Depth (m)	ρ (kN/m^3)	ρ_s (kN/m^3)	w (%)	e (—)	n (%)	S_r (%)	w_{sat} (%)	LL (%)	PI (—)
1.5	11.8	29.9	24.2	2.14	68.2	33.7	71.6	48.0	10.7
4.5	14.4	30.8	27.2	1.72	63.3	48.6	55.9	49.6	11.2
6.5	14.7	30.6	22.4	1.55	60.8	44.2	50.6	49.2	14.1