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Compressibility and microstructure of compacted laterites

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ABSTRACT

Tropical soils are abundant in several equatorial South American countries. The laterites located in the high plain of central Brazil are one example of these tropical soils. This zone, dominated by the Tocantins complex, has metasedimentary rocks which are affected by the extreme environmental conditions produced by the region's two marked dry and wet seasons. This paper presents a laboratory study about the behaviour of this compacted lateritic soil that is currently used in Brasilia as a subgrade for roads and embankments. In their natural state, 65% of the mass of these soils is in the form of aggregates of smaller particles which exhibit great collapsibility. A total of 102 samples were compacted with different water contents and energies using the Proctor procedure, afterwards their microstructural and compressibility characteristics were studied. Microstructural states were studied using a mercury intrusion porosimeter, and oedometric compression tests were carried out under different conditions of suction and saturation using the osmotic technique. From the microstructural point of view, all the samples show a bimodal pore size distribution and the shape of the pore distribution curve changes during compression. The results show that the microstructure is strongly related to mechanical behaviour.

Introduction

Compacted soils are used as construction materials in numerous geotechnical works everywhere. Most studies about soil compaction are based on Proctor's studies, (Proctor, 1933a,b). This method tries to reproduce field compaction in the laboratory by applying controlled mechanical energy in order to remove the air within the soil. Proctor showed the influence of water content on the dry weight of compacted soils and linked the effect of water to lubrication due to the water within the soil.

In the last 20 years, abundant research devoted to explaining compaction curves have used the unsaturated theory of soil behaviour. This interpretation relates increased water content with a reduction in suction, and consequently to a reduction in friction between particles without using the earlier interpretation of the lubrication effect of water. This new way of thinking was demonstrated in various researchers that measures the post-compaction suction of compacted soils using oedometric paths (Li et al., 1995; Delage and Graham, 1996; Alonso, 1998; Fleureau et al., 2002). In addition, it is now the possible to follow the stress-suction and void ratio-water content paths during oedometric compaction because of the development of suction monitored (suction controlled) apparatuses (Blatz and Graham, 2000, 2003; Jotisankasa

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et al., 2007; Tarantino and Tombolato, 2008; Caicedo et al., 2014).

On the other hand, growing interest in the study of soil structure at multi-scale levels from micrometric to nanometric scales has resulted in the incorporation of structural effects into predictions of the macroscopic behaviour of compacted soils (Alonso et al., 1999, 2011; Airò-Farulla et al., 2010; Pham and Fredlund, 2011). Various techniques such as scanning electron microscopy (SEM) and mercury intrusion porosimetry are now commonly used for these characterizations (Diamond, 1970; Collins and McGown, 1974; Delage and Lefebvre, 1984; Mitchell and Soga, 2005; Romero and Simms, 2008).

Most previous studies have examined compacted clays derived from sedimentary processes, and little research exists on the behaviour of compacted lateritic soils that are common in many parts of the world especially in the subtropical and tropical climates of South America and Africa. In addition to their natural complexity, lateritic soils exhibit local-specific features. For instance, gneiss lateritic soils in Ouro Preto, Brazil are characterized by clay aggregations with two dominant pore sizes (Futai and Almeida, 2005), but lateritic soils in Campinas, Brazil exhibits two dominant pore size volumes separated by three orders of magnitude (Miguel and Bonder, 2012).

A better understanding of the properties of compacted lateritic soils requires characterization of their compositions and structural arrangements. Their structure has been defined by Mitchell and Soga (2005), as the combination of structural arrangement, or fabric, and bonding. In this paper, the structural behaviour of compacted lateritic soils was analysed based on the MIP technique, and the determination of the compressibility characteristics was investigated to assess the effect of the fabric and partial saturation on the mechanical behaviour of compacted lateritic soils.

Materials

The soil used for this study was collected in the Federal District of Brasilia at the city limits of Brasilia and Taguatinga, one of Brasilia's satellite cities. Fig. 1 shows the exact location of the sampling site. This soil is the main material for road subgrades in the region and is also currently used for embankments and bridge approaches. The Federal District of Brasilia has two marked seasons: a hot, rainy season between October and April and a cooler, dry season from May to September which has humidity that can be as low as 11%. Mean yearly precipitation varies between 1200 mm and 1700 mm.

Geologically, the sampling site is the result of intensive erosion from the tertiary age. Groups of meta-sedimentary rocks such as the "Grupo Canastra", "Grupo Paranoá", "Grupo Araxá" and "Grupo Bambui" are typical of the region (Freitas-Silva and Campos, 1998). The sample was obtained from the "Grupo Paranoá" which has a sequence of six lithological units the layers of which have thicknesses which vary in thickness from a few centimetres to a few decimetres.

The soil was characterized using physical and chemical techniques. Table 1 presents the results of this characterization. In addition, index tests such as Atterberg limits, specific gravity, and pH were repeated several times to identify the variability of the sample which is represented by the coefficient of variation CV that is defined as the ratio between the standard deviation and the mean value.

The grain size distribution of the soil was obtained using two techniques: a laser granulometer and sieve analysis. The laser technique was used because it provides results similar to those of sedimentation analysis (Di Stefano et al., 2010). However, for this study the laser method was chosen because this method can detect a larger range of particle sizes and has better accuracy in the micron and submicron range. The sedimentation technique is less accurate because its results for particle sizes less than 1 μm are unreliable due to the effect of Brownian motion on the rate of sedimentation (Di Stefano et al., 2010).

To assess aggregation of soil, these analyses were done under water using two fluids: distilled water, and water with sodium hexametaphosphate as a deflocculant. Fig. 2 presents the results of the analyses of grain size distribution. These results show a huge difference between the curves with and without deflocculant reflecting the aggregation of clay and silt sized particles into larger sand-sized particles. The degree of aggregation can be assessed by calculating the relationship between the areas of the grain size distribution curves using Eq. (1). Using this definition, the difference between the two grain size distribution curves indicates a degree of aggregation of 65% of the soil mass. Although both are unimodal grain size distribution curves, the aggregation of grains produces a bimodal pore size distribution as shown in the section that presents the porosimetry of the soil.

$$\text{Aggregation} = \frac{\sum \%\text{Ret}_{\text{without dispersant}} - \sum \%\text{Ret}_{\text{with dispersant}}}{\sum \%\text{Ret}_{\text{with dispersant}}} \tag{1}$$

Although the soil can be classified as ML in the Unified Soil Classification System (USCS) when the Atterberg limits and the grain size distribution with deflocculant are taken into consideration, the activity of this soil is less than 0.5 which is typical for soils having high kaolinite content and clays with low expansivity.

Measurements with an X-ray diffractometer (XRD) were carried out to assess the mineralogical composition of the soil. The shape of the XRD signal for each incident angle was obtained using an *ULTIMA IV RIGAKU* apparatus equipped with a copper tube and a nickel filter. Tests were carried out using a wave length of 1.54 Å and a scanning rate of 0.05°/min. Samples were prepared in dry state and then crushed in an agate mortar. Finally the soil was sieved through a 75 μm mesh. Fig. 3 presents the results of the XRD measurements showing quartz, haematite, goethite, gibbsite and kaolinite.

Chemical composition was measured using the X-ray fluorescence technique (XRF) from a sample prepared following the same procedure as for the DRX test. The procedure for this characterization was developed at the