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Technical Note

Saturated anisotropic hydraulic conductivity of a compacted lateritic soil

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ABSTRACT

This study focuses on the saturated anisotropic hydraulic conductivity of a compacted lateritic clayey sandy soil. The effects of the molding water content and the confining stress on the anisotropic hydraulic conductivity are investigated. The hydraulic conductivity is measured with a flexible-wall permeameter. Samples are dynamically compacted into the three compaction states of a standard Proctor compaction curve: the dry branch, optimum water content and wet branch. Depending on the molding water content and confining stress, the hydraulic conductivity may increase or decrease. In addition, the results indicate that, when the samples are compacted to the optimum water content, lower hydraulic conductivity is obtained, except at a confining stress equal to 50 kPa. The increase of the confining stress decreases the hydraulic conductivity for each of the evaluated compaction states. In the wet branch, horizontal hydraulic conductivity is about 8 times higher than the vertical value. The anisotropic hydraulic conductivities of the dry and wet branches decrease when the confining stress increases, and the opposite is observed in the optimum water content state.

1. Introduction

Soil hydraulic conductivity is an important parameter in the evaluation of the water flow in porous media (Wang et al., 2012). Frequently, numerical water flow models consider soil as a homogeneous and isotropic material (Selim and Dabney, 1986). However, the flow parallel to the layers is usually greater than that in the orthogonal direction. This can be explained by the presence of imperfections in the interface between layers or by the particle orientation caused by compaction loads (Witt and Brauns, 1983; Kim, 1996). Thus, the hydraulic conductivity is usually higher in the horizontal direction compared to the vertical direction (Boynton and Daniel, 1985; Chen, 2000).

In compacted soils, changes in compaction effort (Kim, 1996), confining stress (Shafiee, 2008) and dry density (Qiu and Wang, 2015) interfere significantly in anisotropic hydraulic conductivity. However, the influence of the soil compaction procedure on anisotropic hydraulic conductivity is still poorly understood. The standard compaction test results in significant variation in the vertical pore profile of the samples (Fener and Yesiller, 2013), which interferes with pore connectivity and, consequently, the anisotropic hydraulic conductivity along the compacted soil sample (Qiu and Wang, 2015).

In compacted soil used for the construction of earth-fill dams, it is possible to measure anisotropic hydraulic conductivity. In large dams constructed in Brazil using compacted tropical soils, the anisotropic hydraulic conductivity increases with the increase in confining stress (Cruz, 2004). The anisotropic hydraulic conductivity of earth dam core varies with its stress state and can be accurately measured with a flexible-wall permeameter (Zhu, 1989).

The anisotropic hydraulic conductivity has been evaluated in some soil types. These evaluations have been performed in compacted clay (Kim, 1996), bog peat (Beckwith et al., 2003), granule-clay mixtures (Shafiee, 2008), and sandstone-mudstone particle mixtures (Qiu and Wang, 2015). However, the evaluation of anisotropic hydraulic conductivity in compacted fine-grained lateritic soil has not been reported.

Recently, several studies have investigated the effect of water content on the hydraulic and mechanical properties of compacted lateritic soils (Osinubi and Nwaiwu, 2002, 2005, 2006). When suitably compacted, the lateritic soils may display low hydraulic conductivity, which makes them an interesting alternative for contaminant retention barriers in sanitary landfills (Osinubi and Nwaiwu, 2006). Landfill soils have been traditionally compacted using the water content-density criteria for compacted soil (Daniel

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and Benson, 1990). However, some aspects related to mechanical and hydraulic responses of compacted lateritic soils are still poorly understood (Crispim et al., 2011).

Through hydraulic conductivity tests performed using a flexible-wall permeameter, this study aimed to evaluate the influences of confining stress and molding water content on the anisotropic hydraulic conductivity of a compacted lateritic sandy soil. To prevent variation of the hydraulic properties of the sample due to uneven porosity distribution, some procedures were adopted to obtain homogenous compacted samples.

2. Experimental design

2.1. Tested materials

A highly weathered lateritic soil collected in São Carlos (Brazil) was evaluated. This type of soil, widespread in tropical areas and subtropical climates, normally displays high porosity and collapsible behavior. This soil shows liquid and plastic limits and solid specific gravity of 33%, 22% and 2.68, respectively. The plasticity index and liquid limit of studied soil are plotted on a plasticity chart, as shown in Fig. 1. In this figure, A-line is a line that splits the chart between clays (C) above A-line and silts (M) below A-line. The vertical line (B-line) separates high-plasticity fine-grained soils (H) from low-plasticity fine-grained soils (L).

The particle-size distribution curve presents the following soil fractions: sand (59%), silt (9%) and clay (32%) (Fig. 2). Thus, this material can be classified as a clayey sand (SC), according to the unified soil classification system (USCS).

2.2. Sample preparation

The effect of fabric on the behavior of compacted soils can be of great significance (Toll, 1990). Compacted clays do not exist as a uniform mass of clay particles, but as a set of particle aggregations (Croney et al., 1958). Toll (2000) studied the effects of the compactive effort and degree of saturation on the degree of aggregation of a lateritic gravel from Kenya. This author noted that the degree of saturation of a compacted soil could indicate the amount of aggregation presented. Clod size has significant influence on the hydraulic conductivity of compacted soils (Daniel and Benson, 1990). Therefore, samples used to obtain the compaction curve display different degrees of aggregation and pore structures. This typical compacted soil behavior justifies the choice of different compaction states to evaluate soil hydraulic properties.

Fig. 3 displays the compaction curve of the target samples and trimmed samples, obtained from standard Proctor tests performed with 9 samples. In this figure, S represents the degree of saturation.

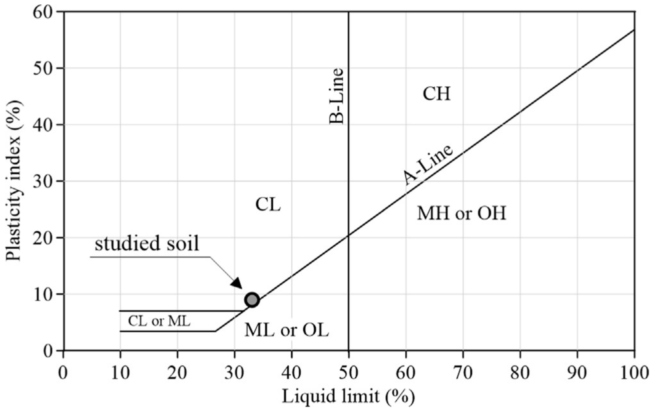

Fig. 1. Plasticity chart of the soil used in this study.

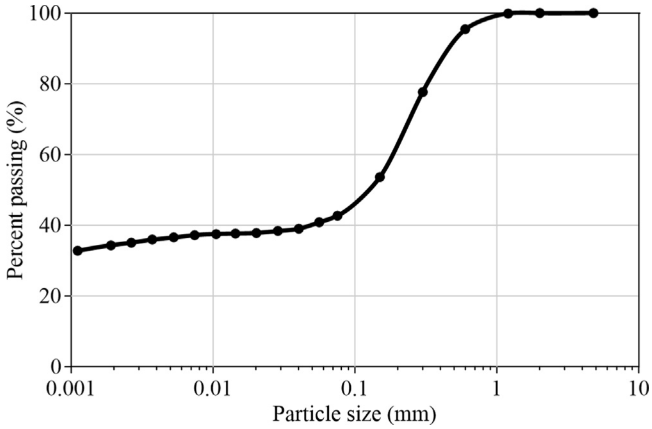

Fig. 2. Particle-size distribution curve of the soil used in the present study.

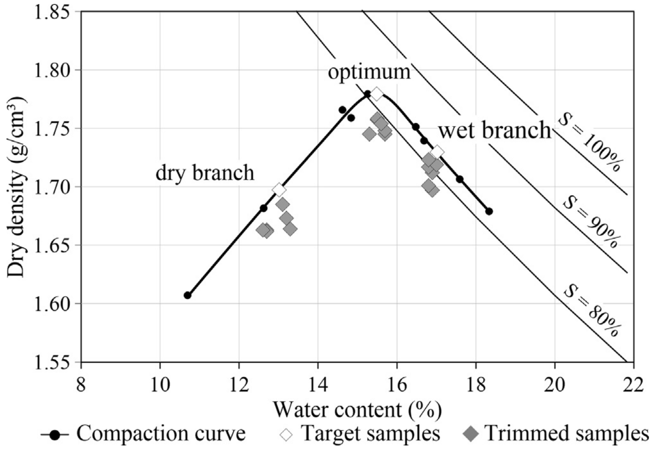

Fig. 3. Compaction curve and samples used in the hydraulic conductivity tests.

From compaction curve, the maximum dry density (ρ_{dmax}) of 1.78 g/cm^3 and optimum water content (w_{ot}) of 15.5% were calculated. Fig. 3 also displays the target samples, which are associated with the target compaction state. The three compaction states used in this research were the dry branch, optimum water content and wet branch. Each of these points was determined from the pre-determined compaction curve.

To represent the conditions corresponding to the dry branch, optimum water content and wet branch, two target samples of each compaction state were compacted, at compaction degrees (ratio of compacted to maximum dry densities) of 95%, 100% and 97% and molding water contents of 13%, 15.5% and 17%, respectively. After compaction, samples were trimmed in vertical and horizontal directions (trimmed samples). A good agreement between the data of trimmed samples and the compaction curve was observed.

Each target sample was compacted in a metallic cylindrical mold with a diameter of 15.59 cm and a height of 12.72 cm. The samples were prepared through 7 layers of compaction. For better bonding with the next layer, each layer was scored after compaction. The molding water content of the soil and the height of each compacted layer were controlled to ensure that the target dry density was reached. To prevent excessive densification of the lowest layers, each layer was compacted at different heights. During sample compaction, the wet soil mass was the same for all compacted layers, thus the target dry density was obtained by controlling the height of each layer. The first layer was compacted at dry density 3.31% lower than the target one, while the last layer was compacted at dry density 3.31% greater

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