Influence of the Organic Matter Content on the soil water retention characteristics of a reconstituted kaolinitic clay

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ABSTRACT

An experimental study using kaolinitic clay was performed in order to understand the unsaturated behavior of soils with high organic matter content (OMC). Reconstituted samples of kaolinitic clay were prepared with different OMC. Soil Water Retention Curves (SWRC) were obtained after drying and wetting processes and volume changes were also measured. Matrix suction was measured by the filter paper technique. Results show that for a constant value of suction, the higher the OMC the higher the water content. The higher the OMC, the lower the Air Entry Value and the slope of the SWRC. OMC showed to have a different influence in the Volume Change behaviour (VC) in the drying and wetting process. Experimental results suggest possible engineering applications for the evaluation of volume change due to suction changes on kaolinitic soils with relatively high OMC.

Keywords: Organic Material Content, Suction, Volume change, kaolinitic clay

1 INTRODUCTION

Soils with relatively high Organic Matter Content (OMC) occur naturally in the majority of lacustrine sedimentary environments, such as the Bogotá high plateau where it is possible to find soil layers with OMC ranging between 1% in some sand lenses and around 75% in peat layers.

OMC strongly influences the engineering behaviour of natural soil, having a direct impact in the design of foundations, implying additional and challenging physical and mechanical characterization (Huang et al, 2009; O’Kelly, 2015), and usually demanding previous stabilization (Hwang et al, 2005; Kalantari and Prasad, 2014). The OMC influence on the mechanical behavior of soils is not well understood, being especially true for the unsaturated soil behavior. There is a lack of information about experimental unsaturated behavior of high OMC soils. Although there are some data bases available about different soils properties, such as soil-water retention curves (SWRC), they do not include clays with a high OMC.

It has been well documented that nowadays the ground water level of the soil deposits of Bogotá has been reducing, probably to climatic changes, represented by unusual dry periods (Pineda-Jaimes, 2005; Pineda-Jaimes et al, 2013). This fact, combined with evapotranspiration processes, may induce high suctions enough to dry some soil pores. Partial saturation on the shallow layers of the soil deposit may occur, affecting the soil-structure interaction on buildings and other structures. Excessive total or differential deformations, in unsaturated conditions under constant loads, can lead to severe damages in buildings and road infrastructure.

The influence of the OMC in the SWRC and the Volume Change behaviour (VC) was studied. Results show that an increase in the OMC moves the SWRC up and to the left resulting in higher the water contents for the same value of matrix suction. The Higher the OMC, the lower the Air Entry Value and the slope of the SWRC. Experimental results suggest possible engineering applications for the evaluation of volume change due to suction changes on kaolinitic soils with relatively high OMC.

2 GENERAL BACKGROUND

2.1 Geology

Bogotá City is located in a high plateau at 2550 m above sea level, over a lacustrine deposit, which was formed by the tectonic uplift of Los Andes between 5 and 3 million years ago in the Late Pliocene (Helmens & van der Hammen, 1994; van der Hammen & Hooghiemstra, 1997). After this moment, 2.5 million years ago, a great lake was formed in this area. This lake began to dry 65 to 28 thousand years ago, being completely dry around 32 to 27 thousand years ago (van der Hammen, 1986). However, the drying process was not constant in time.
In this process, depending on the water level, there were 11 different facies associated to different energy regimes and vegetation resulting in a great variability of the OMC with depth (Torres et al., 2005).

The upper 80 m of the Sabana Formation (lacustrine deposit) were consolidated during the last 250,000 years and they contain high proportions of organic matter. This deposit is mainly composed by clays named Bogota clay, which have a liquid limit in a wide range, ranging between 50 to 200% (Caicedo et al., 2018).

Bogota Clay is composed mainly by two minerals: vermiculite (5 to 15%) and kaolinite (as high as 50%) (Ávila Álvarez 2004; Betancourt Cardozo 1996; Romero y Berrio, 1997). Possibly, the mineral composition allows different electro-chemical and physical properties, such as Cation Exchange Capacity and Atterberg limits. It also allows the formation of several complexes with organic molecules, each one with a different surface chemistry (Chilom and Rice, 2009).

2.2 Organic Matter in soils

Organic soils are composed by a wide range of particles with different size, shape and mineralogical composition. There are also amorphous substances like organic matter attached to mineral grains which may have a direct influence in soil behavior (Hillel 2004).

Soils with high organic matter content are often regarded as atypical, with properties in its own range of values (water content, porosity and compressibility of organic solids). Therefore, they have their own classification system (Leroueil and Hight, 2003; Zhang and O’Kelly, 2014; Landva and Pheeney, 1980). The engineering behaviour of organic soils often includes higher compressibility, swelling potential, creep-like response. Soils with high OMC have more pronounced differences with typical soil characteristics in water content, unit weight, void ratio and compression index (Duraisamy et al., 2007; Fox et al., 1992; Leroueil, 1996; Perrin, 1974).

In comparison with mineral soils, it is well known that peat and organic soils are highly compressible if compared to mineral soils, with a longer consolidation process that can increase considerably when the ground water level decreases (Huat et al. 2014; Mesri & Ajlouni 2007).

2.3 SWRC for organic soils

Estimation procedures for the SWRC involving gravimetric or volumetric water content generally assume that a decrease in water content correspond to a decrease in the degree of saturation of the soil. As this may not always be the case, more realistic estimations can be made using the degree of saturation for the SWRC. This curve can be obtained together with a shrinkage curve of the material (Fredlund & Houston 2013).

It is well known that the pore size distribution, pore shape, pore angularity and pore continuity affect directly the SWRC (i.e. high angular shapes of pores as triangles, retain more water than low angular shapes as squares and hexagons (Tuller & Or 2005)).

Unimodal shaped SWRC can be related to a monomodal pore size distribution (PSD), and the bimodal shaped SWRC can be related to a bimodal PSD. Monomodal PSD is usually related with a sample initially in a fully hydrated state, and a unique class of intra-matrix voids. Bimodal PSD is usually related with aggregates formation of the smallest clay platelets which are larger entities separated by macropores different from intra-matrix micropores (Monroy 2005). This bimodal SWRC is thus associated to gap-graded grain size and PSD (Gitirana & Fredlund 2004). Changes between unimodal and bimodal behaviour may occur either with stress or hydraulic paths (Sheng et al. 2011).

Some efforts involving the OMC in the prediction of the parameters of the SWRC equations have been made with soils with OMC lower than 2% (Rajkai et al. 2004). However, the lack of information, in data bases which do not include soils with high OMC, prevent to verify the validity of those predictions.

2.4 Volume change for plastic soils

The potential of a soil to shrink and expand depends on the soil type, with principal influence of mineralogy and granulometric composition (Marinho 1994). Soils with expansive clay minerals are very sensitive to seasonal variation of moisture due to precipitation, evaporation from the soil surface, and evapotranspiration from vegetation. During long dry periods (without precipitation), an expansive soil would dry and shrink, leading to both recoverable and permanent volume changes. When an initially saturated soil is continuously dried, a reduction of volume (shrinkage) is observed up to a point after which the total volume remains constant. The process is related to the evaporation of pore water and it explains the reduction of volume (Ledesma 2016). There are some models (ie. Fredlund et al (2002), Marinho (1994)) for the prediction of the shrinkage curve. They can be used together with the SWRC to estimate the volume change potential of an unsaturated soil.

3 LABORATORY TESTING PROGRAM

3.1 Sample preparation

Reconstituted cylindric samples of kaolinitic clay were prepared from slurry using different OMC (0, 20, 50 and 75%), following the same stress history. Commercial Kaolin was chosen to prepare samples with a mineralogy similar to Bogota Clay. Gravimetric OMC was measured (ASTM D2974).

3.1.1 Materials used

Kaolinite minerals are the most abundant minerals
of the 1:1 silica to alumina structure minerals. There is no significant interlayer swelling with addition of water, due to the sufficiently strong bonding (Van der Waals forces and hydrogen bonds) (Mitchell & Soga 2005).

Commercial Humus was used to simulate the organic matter and peat present in the shallow layers of the Bogota high plateau.

The general physical characterization is presented in Table 1.

Table 1. Physical characterization of the material used to reconstitute soil samples.

| Material | Gs | Sand (%) | Clay (%) |
|----------|----|----------|----------|
| Kaolin   | 2.71 | 4.9     | 95.1     |
| OM       | 1.57 | 43.1    | 56.9     |

3.2 Suction measurement and SWRC estimation

Soil Water Retention Curves (SWRC) were obtained for drying and wetting processes. Suction was measured by the filter paper technique described in ASTM D5298-16. Drying and wetting paths were followed, and volume change was measured. Suction values for both drying and wetting paths were obtained for different equilibrium water contents.

Considering that one of the most common equations for the modelling of the SWRC is the proposed by Fredlund and Xing (1994), best-fitting parameters for drying SWRC were obtained using the equation (1). This equation involves the saturated water content, the residual suction, and has 3 adjustment parameters which relate to the air-entry value (\(a\)), the slope of the curve (\(n\)) and the properties at the high-suction range (\(m\)).

\[
w = w_s \left[ 1 - \exp \left( - \frac{1}{\ln \left( \frac{1}{W_s} \right)} \right) \right] - \ln \left( \frac{\psi}{\psi_r} \right) \left( 1 + \frac{1}{\ln (1 + \frac{\psi}{\psi_r})} \right) \left( 1 + \frac{1}{\ln (\frac{1}{W_s})} \right)
\]

Where \(w\) is the water content for a given suction (\(\psi\)), \(w_s\) is the saturation water content, and \(\psi_r\) is the suction for the residual water content.

3.3 Volume change

Volume change was measured for both drying and wetting processes. The VC is the relation between the volume at a given water content and a reference volume. For the performed analysis, during the drying process the reference value is the fully saturated volume, while for the wetting process the reference volume is the minimum volume (completely dry sample).

4 RESULTS AND DISCUSSION

Fig. 1 to Fig. 4 show the SWRC for the kaolin with different values of OMC (0, 20, 50 and 75%). The experimental results for the drying and wetting processes correspond to the Primary Drying Curve (PDC) and the Primary Wetting Curve (PWC), which establish the boundaries of the hysteretic behavior (Luckner et al, 1989) thus showing the boundaries for maximum and minimum SWRC of soils with similar properties. As expected, for a given water content, a higher suction is found in the drying process than in the wetting process.

All drying curves have a unimodal shape, while wetting curves have a bimodal shape.
Fig. 4. SWRC in drying and wetting processes for kaolin with 75% OMC.

For comparison purposes, Fig. 6 presents the best-fit result for the drying process using the suction equation proposed by Fredlund and Xing (1994), presented in equation (1) showing the differential behavior from the different kaolin-OM mixtures, particularly in Air-Entry Value (AEV) and in the slope.

Fig. 5 shows the wetting process. Those experimental results were not fitted to any equation.

As water content varied from nearly 0 to 250%, SWRC were expressed in terms of degree of saturation, so that the minimum and maximum possible are 0 and 100%.

Kaolin has a higher AEV due to its high clay fraction, and has a steeper slope after the AEV, which would indicate a pore size distribution with a prevalent pore size. SWRC for kaolin is the only one that has a unimodal equation with one bending point.

Increasing OMC reduces the AEV and gives a less steep slope, due to a not uniform pore size distribution generated by the presence of both the sand and the fine fraction (see Table 1) which has a great relevance for each sample.

SWRC in drying for an OMC of 50 and 75% are almost overlapping. For this reason, it could be inferred that the OMC controls the unsaturated behaviour for values higher than 50%. A threshold of OMC influence must be between 20 and 50%, were a difference in the curves is still relevant.

Fig. 7 shows the experimental data for wetting SWRC in terms of the degree of saturation. There are some important features about the wetting curves: a) it is not evident a bimodal shape of the curves when they are drawn in function of the degree of saturation, b) similar as for drying process, kaolin shows a higher degree of saturation, for a given suction value, compared with the other materials, c) 20, 50 and 75% OMC curves are almost overlapping (or very near), and d) all curves have a similar value of suction for total saturation.

Volume change (VC) was measured for different samples in both drying and wetting process. Fig. 8 shows laboratory data of volume change related to the water content. For a water content range between 0-50%, there are relevant aspects to point out: a) 50% and 75% OMC data are not overlapping, b) all materials have a linear trend c) increasing OMC increases the slope of the VC-WC curves, d) at higher OMC there is a higher VC potential when drying, and d) residual water content is higher when OMC increases inhibiting a higher potential VC.

Fig. 9 shows laboratory data for wetting. Volume changes are related to the minimum volume of the samples. In the wetting process, all material tested have a similar behavior and show a general linear trend. The maximum swelling due to wetting is related with the maximum WC that can be reached after a full drying
and is inversely proportional to the OMC.

![Graph showing volume change in drying process.](image)

**Fig. 8.** Volume Change in drying process.

![Graph showing volume change in wetting process.](image)

**Fig. 9.** Volume Change in wetting process.

5 CONCLUSIONS

An experimental test program to understand the influence of OMC in SWRC and VC was developed with reconstituted kaolinitic with different OMC. The reconstitution followed the same stress path for all materials.

OMC controls the unsaturated behaviour for values higher than 50%. A threshold of OMC influence may be located between 20 and 50%, were a difference in the curves is still representative. For a given suction value, increasing OMC increases the water content. An increase in OMC reduces the AEV, and reduces the slope of the curve. This can be related with the high specific surface area of the OM, and the sand size particles from the OM.

Like SWRC, the curves of VC-WC present a hysteretic behavior in the drying-wetting process. This behavior is responsible for irreversible settlements due to desiccation.

Drying of soils with different OMC can cause differential settlements in buildings and other structures. At higher OMC there is a higher VC potential. However, wetting process after complete drying of the different soils, seems to have a similar VC potential regardless of the OMC. This may occur due to a similar internal structure generated after completely drying soil samples.

Appropriate identification and characterization of soils with high OMC may help in the estimation of problems related with soil-structure interaction of structures with shallow foundations located near the ground water level fluctuation.

Further research is needed to understand the interaction between minerals, organic particles and water in soils, and their relationships in unsaturated conditions, together with the thresholds of influence of the OMC.

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