Soil Fabric of Compacted and Natural Swelling Soils Studied by Mercury Intrusion Porosimetry

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Abstract. This article compares the Pore Size Distribution (PSD) study of two different fine graded swelling soils, in natural state, and remoulded at the same initial state. The soil fabric of these clayey soils including the macropores, mesopores, and micropores was mainly studied by the mercury intrusion porosimetry (MIP) technique. For both soils, the results showed clearly that the soil fabric of the remoulded samples compacted in the laboratory are significantly different from the natural ones. Therefore, as the artificial compacted samples do not correctly represent the natural soil fabric, hydro-mechanical parameters measured on them would be different from those obtained on the intact natural samples.

Keywords: soil fabric, mercury intrusion porosimetry, clayey soils.

1 Introduction

Clay soils subjected to hydraulic solicitations can induce relative settlements that can affect the structures, including shallow foundations and drainage channels, as well as buffers in radioactive waste disposal sites. The complex hydromechanical behaviour of these expansive materials is connected to their fabric (Pusch, 1982; Gens & Alonso; 1992; Alonso et al., 1999), which have become the main subject of additional studies on their micro- and macrostructure (Delage & Lefevre 1984, Romero et al. 1999, Pusch & Yong, 2003; Lloret et al., 2003; Nowamooz 2007, Nowamooz & Masrouri 2008, 2009).

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Based on the classification of IUPAC (1997), the pores with widths exceeding about 0.05 µm or 50 nm are called macropores; those with widths not exceeding about 0.002 µm or 2 nm are called micropores and the pores of intermediate size are called mesopores. We consider in this article that the macrostructure is equivalent to macropores, the mesostructure to the mesopores and the microstructure to the micropores. A pore diameter of 0.150 µm was also proposed as the pore boundary between the inter- and intra-aggregate of the compacted swelling soils (Lloret *et al.,* 2003; Delage *et al.,* 2006). We take this value as a diameter size limit between macro- and mesopore as a simplifying hypothesis however we believe that this diameter size limit which is not constant depends highly to the soil initial state (Nowamooz & Masrouri, 2009).

The pore size distribution (PSD) obtained by the mercury intrusion porosimetry (MIP) test has been used as an essential method in soil fabric studies. It has been observed that the double structural level is much more evident on the dry side of the optimum point of the compaction curve than on the wet side which shows a homogeneous structure (Barden & Sides, 1970; Sridrahan *et al.,* 1971; Collins & McGown, 1974). It has been observed that mechanical loading significantly influences the macropores without producing important modifications in the meso- and micropores for compacted tills (Simms & Yanful, 2004) and for compacted bentonite (Hoffman *et al.,* 2007).

Most investigations on the swelling soils were done on the compacted samples artificially prepared in the laboratory. The important question is whether the soil fabric of these artificial swelling soils represents correctly the fabric of the natural swelling soils or not. To address this question, this article compares the Pore Size Distribution (PSD) of the natural samples with the remoulded samples (prepared exactly at the same initial states of the natural ones).

2 Soil Fabric Tests

MIP tests were performed to evaluate the pore size distribution of the studied materials. MIP tests were conducted using a porosimeter, where the mercury pressure was continuously raised from 0.007 to 450 MPa and the device was able to detect pore diameters ranging from 3 nm to 300 µm. The MIP tests required dehydrated samples with volumes less than 3000 mm^3 (limited by the sample holder and the cell stem volume). Starting with a prepared and compacted sample, the MIP specimens were carefully trimmed into cubes and subsequently freeze-dried to remove the pore water, and then placed in a desiccator until testing. One assumption is that the larger pores can be intruded from the outside without the mercury having to penetrate through smaller pores. However, it is possible that large pores with a small access diameter are not intruded until high pressures are reached; as a result, their volume appears to be associated with much finer pores. Therefore, in this article we prefer to use the term “pore access diameter” rather than “pore diameter.”

3 Soil Fabric of Natural Swelling Soils

The experimental results in literature were more frequently reported on the compacted samples in the laboratories rather than the natural samples.

In this section, we studied natural swelling soils taken from an experimental site in the Mignaloux-Beauvoir region, near Le Deffend, about 4 km south-east of Poitiers (France). Two in-situ boreholes were performed in the same season to a depth of 7 meters for geological and geotechnical investigations within the framework of the ANR ARGIC project (Vincent et al., 2006), including one in the pasture (site E1) and the second in the forest (site E2). The studied clayey layer is located between 6.20 and 6.80 m depth in the E1 core. The second soil comes from between 5.20 and 5.70 m in the E2 core. We call the first soil E1 and the second one E2. The physical and geotechnical properties respectively for soils E1 and E2 are the liquid limit of 86% and 65%, the plasticity index of 32 and 25%, the specific gravity (Gs) of 2.60 and 2.62 and the clay size content of 72% and 52%. The mineralogical composition of both natural soils, as determined by X-ray diffraction, shows that smectite minerals are dominant.

In parallel, the samples were remoulded by static compaction to the initial states very close to natural states in the laboratory: a water content of 43% and 14%, an initial dry density of 1.21 and 1.84 Mg/m^3 corresponding to a void ratio of 1.15 and 0.42 respectively for soils E1 and E2. In other words, the soils were initially prepared at the indicated initial water contents and then compacted at the initial dry densities very close to their initial in-situ states.

To analyse the influence of the compaction process on the soil fabric of the studied samples, two series of MIP tests were performed on the natural soil and on the remoulded samples (compacted to their initial natural state) for both soils E1 and E2. Fig. 1 and 2 present the variation of Pore Size Distribution (PSD) function (= Δ void ratio / Δlog pore diameter) as well as the cumulative void ratio versus the pore access diameter.

The distributions showed two distinct structural levels for soil E1: meso- and macropore (Fig. 1-a). The dominant diameter of about 50 µm, corresponding to the macropores of this natural soil, decreased to 10 µm after compaction. However, the macropores were absent for soil E2 (Fig. 2-a). The compaction decreased the mesopores significantly without modifying their peak at 0.011 µm for soil E1 and 0.02 µm for soil E2.

A same boundary limit value of 0.150 µm was taken between the meso- and macropore for both soils E1 and E2. The void ratios corresponding to an average pore size of to 0.150 µm (Fig. 1-b) allowed the estimation of the macrostructural void ratio (e_M). The residual space starting from the e_M and ending at the final intruded void ratio (maximum void ratio obtained by the MIP test) can be considered as the meso-structural void ratio (e_m). This residual space corresponds also to the micropores not intruded by porosimeter. Tables 1 and 2 summarize these values for both samples compacted at the same initial total void ratio (e_T) for both soils E1 and E2.

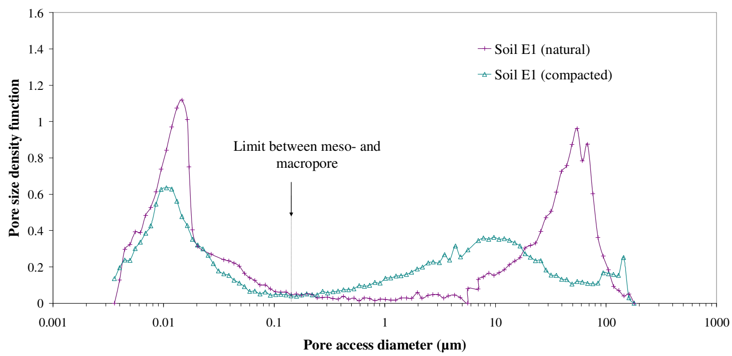
Table 1. Soil fabric variation for the natural and compacted soil E1.

Soil E1	Natural	Compacted
Total void ratio (e_T)	1.15	1.15
Void ratio of macropore (e_M)	0.59	0.54
Void ratio of mesopore (e_m)	0.56	0.42
Void ratio of micropore (e_n)	---	0.19

Table 2. Soil fabric variation for the natural and compacted soil E2.

Soil E2	Natural	Compacted
Total void ratio (e_T)	0.42	0.42
Void ratio of macropore (e_M)	0.10	0.06
Void ratio of mesopore (e_m)	0.32	0.18
Void ratio of micropore (e_n)	---	0.18

a)



b)

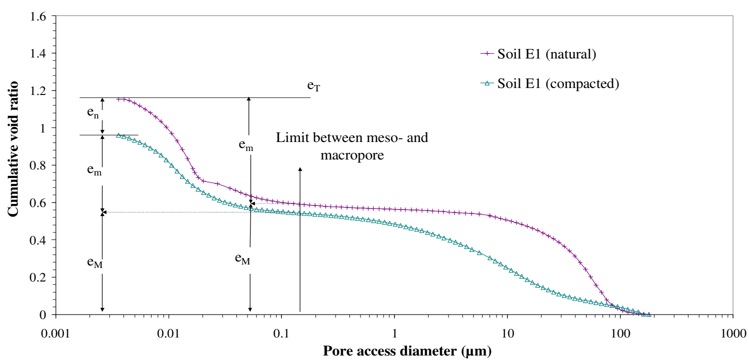
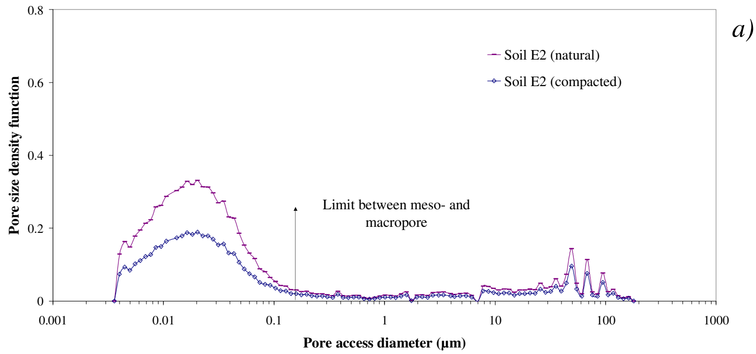


Fig. 1. Results of MIP tests on the natural and compacted soil E1, a) Pore size distribution function, b) Cumulative void ratio versus pore size.



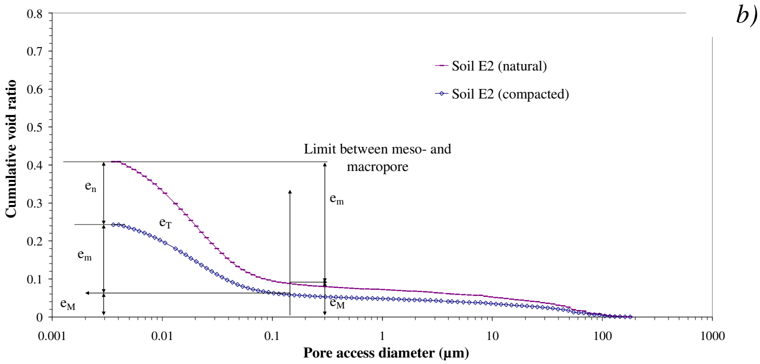


Fig. 2. Results of MIP tests on the natural and compacted soil E2, a) Pore size distribution function, b) Cumulative void ratio versus pore size.

The same boundary limit value of 0.150 µm was taken between the meso- and macropore for both soils E1 and E2. This diameter size limit which is not constant depends extremely to the soil initial state. For example, when the macropores are absent in the dense soil structure, a higher discriminating diameter can be taken between macro- and mesopores. The different limits modify the estimated void ratio of macro-, meso- and micropore.

4 Conclusion

The experimental study focused on the evolution of the soil fabric of the clayey soils including the macropore, mesopore, and micropore mainly studied by the mercury intrusion porosimetry (MIP) technique. We compared the Pore Size Distribution (PSD) of the natural samples with the remoulded samples (prepared exactly at the same initial states of the natural ones). The results showed that the soil fabric of the remoulded samples compacted in the laboratory can be significantly different from the natural ones. This point would directly impact the hydro-mechanical parameters obtained in laboratory conditions on remoulded samples such as the Soil Water Retention Curve (SWRC), the compression curves at the constant imposed suctions and the swelling/shrinkage strain accumulation during the wetting and drying cycles.

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