Filter paper method of soil suction measurement

Método del papel de filtro para la medida de la succión del suelo

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ABSTRACT

The capillary pressure of the soil (i.e., the pressure difference between air and water components in soil voids) is a key variable in the analysis of the hydro-mechanical behavior of unsaturated soils. Therefore a simple and economical laboratory method for the measurement of the capillary pressure of the soil (also known as soil matric suction, the reference being the atmospheric pressure), even if a degree of approximation is involved, is of considerable value. The filter paper method calculates soil suction indirectly by measuring the gravimetric water content of the filter paper at equilibrium that is related to soil suction through a predetermined calibration curve. The advantages of the method are simplicity, economy and reasonable accuracy. It can be used to measure suctions from 10 to 30000 kPa. In this paper, the authors use the contact filter paper method for matric suction measurements of an unsaturated compacted silty sand (formed by the weathering of granite) which has been used as a building material for a road in the north of Portugal. The matric suctions inferred from filter paper measurements depend on the calibration between the water content of the filter paper and suction. Therefore, three calibration curves proposed at the literature (Chandler et al. 1992; ASTM D 5298; and Oliveira & Marinho 2006) for the Whatman 42 filter paper are used to interpret the measured filter paper gravimetric water contents. The results of these tests are compared to other techniques (i.e., tensiometers, and the osmotic technique) used to measure or control the negative pore water pressure in the compacted soil specimens and the results obtained are reasonably accurate.

RESUMEN

La presión capilar del suelo (es decir, la diferencia de la presión entre el aire y los componentes del agua en vacíos del suelo) es una variable llave en el análisis del comportamiento hidromecánico de suelos no saturados. Un método por lo tanto simple y económico del laboratorio para la medida de la presión capilar del suelo (también conocido como la succión matrica del suelo, la referencia que es la presión atmosférica), mesmo si un grado de aproximación está implicado, es de valor considerable. El método del papel de filtro calcula la succión indirectamente utilizando curvas de calibración. Las ventajas del método son simplicidad, economía y exactitud razonable. El método del papel de filtro se puede utilizar para medir succiones a partir del 10 al 30000 kPa. En este artículo, los autores utilizan el método del papel de filtro para la medida de la succión matric de una arena limosa compactada no saturada (formada por la meteorización del granito) que se ha utilizado como material de construcción para un camino en el norte de Portugal. Las succiones matric deducidas de medidas del papel de filtro dependen de una calibración entre el humedade del papel de filtro y la succión. Por lo tanto, tres curvas de calibración propuestas en la literatura (Chandler et al. 1992; ASTM D 5298; y Oliveira & Marinho 2006) para el papel de filtro de Whatman 42 se utilizan para interpretar lãs humedades gravimétricas medidas del papel de filtro. Los resultados de los ensayos se comparan a otras técnicas (es decir, tensiómetros, y la técnica osmótica) usadas para medir o controlar la presión negativa en lãs muestras compactadas del suelo y los resultados obtenidos sea razonablemente exacto.

Keywords: laboratory tests, unsaturated soils, pore pressures, water retention curves

1 INTRODUCTION

A significant portion, if not the majority, of the problems encountered in geo-environmental engineering practice involve unsaturated soils in the vadose zone (i.e., the unsaturated soil zone above the water table). It is accepted that the matric suction, which is commonly associated with the capillary pressure (i.e., the pressure difference between air and water components in soil voids, u_a - u_w), is a key variable in the analysis of the hydro-mechanical behavior of unsaturated soils.

A comprehensive description of the experimental techniques commonly used for measuring or controlling matric suction can be found in many references (Fredlund & Rahardjo 1993; Lee & Wray 1995; Ridley & Wray 1996; Lu & Likos 2004). The techniques vary widely in terms of cost, complexity, and measurement range. The matric suction can be determined from previous calibration or can be measured directly. Because of the various difficulties involved in the direct measurements of the matric suction, a simple and economical laboratory method for the measurement of the capillary pressure of the soil (also known as soil matric suction, the reference being the atmospheric pressure), even if a degree of approximation is involved, is of considerable value.

In this paper, the authors use the contact filter paper method for matric suction measurement of an unsaturated compacted silty sand (formed by the weathering of granite) which has been used as a building material for a road in the north of Portugal. The matric suctions inferred from filter paper measurements depend on a calibration between the water content of the filter paper and suction. Therefore, three calibration curves proposed at the literature (Chandler et al. 1992; ASTM D 5298; and Oliveira & Marinho 2006) for the Whatman 42 filter paper are used to interpret the measured filter paper gravimetric water contents. The results of these tests are compared to other techniques (i.e., tensiometers, and the osmotic technique) used to measure or control the negative pressure in the compacted soil specimens.

2 CONTACT FILTER PAPER TECHNIQUE

Filter paper technique was established for measuring soil suction by soil scientists and agronomists (e.g., Gardner 1937; Fawcett & Collis-George 1967; Al-Khafaf & Hanks 1974; and Hamblin 1981). In geotechnical engineering fields, many researchers have also used the technique as a routine method for suction measurement (e.g., McKeen 1980; Chandler & Gutierez 1986; Greacen et al. 1989; Chandler et al. 1992; Ridley 1993; Marinho 1994; Houston et al. 1994; and Marinho & Oliveira 2006).

The filter paper method calculates the soil suction indirectly from previous calibration. Basically, the filter paper comes to equilibrium with the soil either through vapor (total suction measurement) or liquid (matric suction measurement) flow. At equilibrium, the filter paper and the soil will have the same suction value. After equilibrium is established between the filter paper and the soil, the gravimetric water content of the filter paper disc is measured. The gravimetric water content of filter paper is converted to suction using a calibration curve for the type of paper used. This is the basic approach suggested by the American Society for Testing and Materials (ASTM) standard D5298 for the measurement of either matric suction using the contact filter paper technique or total suction using the non-contact filter paper technique. The ASTM D 5298 employs a single calibration curve that has been used to infer both total and matric suction measurements and recommends the filter papers to be initially oven-dried (16 h or overnight) and then allowed to cool to room temperature in a desiccator. The ASTM D 5298 calibration curve is a combination of both wetting and drying curves. However, because of the marked hysteresis on wetting and drying of the filter paper, the calibration curve for initially dry filter paper is different from that of the initially wet filter paper. Some publications presents calibration for the wetting path, with the paper initially air dry (Chandler & Gutierez 1986; Chandler et al. 1992; Ridley 1993; and Marinho 1994). Marinho & Oliveira (2006) show that the calibration for the particular type of paper is unique in relation to the type of suction (i.e., total or matric).

The contact filter paper technique is used for measuring matric suction of soils. In the contact filter paper technique, water content of an initially dry filter paper increases due to a flow of water in liquid form from the soil to the filter paper until both come into equilibrium. Therefore, a good contact between the filter paper and the soil has to be established. The contact filter paper method becomes inaccurate in high matric suction range since water transport is dominated by vapour transport (Fredlund et al., 1995). The calibration curve for the filter paper matric suction measurement is commonly established using a pressure plate apparatus (e.g., Al-Khafaf & Hanks 1974; Hamblin 1981; Greacen et al. 1989).

It is important to note that only ash-less filter papers should be used in the filter paper technique. Although there are a number of ash-less filter papers available, only Whatman 42 and Sleicher and Schuell 59 (or SS 59) filter papers are commonly used. Table 1 lists some calibrations presented in the literature for the filter paper Whatman. 42. Most of the curves are bilinear with an inflection point occurring at a filter paper gravimetric water content value somewhere between 30 and 50 %. Figure 1 shows calibrations curves for Whatman 42 proposed by Chandler et al. (1992), ASTM D 5298 and Oliveira & Marinho (2006) for filter paper gravimetric water content (w) values ranging from 30 to 60 %. It should be noted the suction deviation between Chandler et al. (1992), ASTM D 5298 and Oliveira & Marinho (2006) increases for 30 % < w < 47 % and the use of Chandler et al. (1992)'s equation results in high suction values for these water content values.

Likos & Lu (2002) conducted an analysis to evaluate the accuracy and precision of total suction measurement using the noncontact filter paper technique. They conclude that the filter paper calibration curves can significantly vary among the same type of filter paper from one "batch" or "lot" to another. Therefore, they recommend batch-specific calibrations. It is important to mention that the non-contact filter paper technique must be performed with extra cares to avoid suction errors induced by temperature gradient and relative humidity error. Figure 2 presents the results obtained by Likos & Lu (2002) for seven different batches of Whatman 42 and the calibration curves proposed by Chandler et al. (1992) and ASTM D 5298 for filter paper gravimetric water content (w) values ranging from 0 to 40 %. The results indicate that the measurement deviation generally increases as w increases (i.e., as suction decreases) for w < 40 %. At relatively high values of soil suction the use of Chandler et al (1992)'s equation yields underestimated suction.

Marinho & Oliveira (2006) suggest that whenever the filter paper method is used as suction quantifier, one should check for the possibility of been using a "batch" presenting a calibration curve that differ from those frequently used in the scientific community. It is suggested to make the calibration of at least one point, verifying if that point is coherent with the calibrations proposed in literature.

3 MATERIAL AND TEST PROCEDURES

3.1 *Test material*

Tests were performed on a residual silty sand, hereafter called Perafita sand, resulting from weathered granite, which has been used as a building material for a road in the north of Portugal. Its grain size distribution is indicated in Figure 3. It contains about 20% of grains smaller than 80 μm, with a layered structure similar to that of clay particles. The liquid limit of the Perafita sand is 32.6 %, the plastic limit is 25 %, clay fraction is 2.5%, specific gravity is 2.66, standard Proctor optimum water content is 17.6% and the corresponding dry density is 16.8 kN/m^3, modified Proctor optimum water content is 13.2% and the corresponding dry density is 18.6 kN/m^3.

Table 1. Calibrations curves for Whatman 42 filter paper

Reference	*Suction*	*W (%) range*	*Log_{10} (suction) (kPa)*
ASTM D5298	Total and Matric	W < 45.3	5.327 -0.0779 w
ASTM D5298	Total and Matric	W > 45.3	2.412 -0.0135 w
Chandler & Gutierrez (1986)	Matric	(*)	2.85 -0.0622 w
Chandler et al. (1992)	Matric	W < 47	4.842-0.0622 w
Chandler et al. (1992)	Matric	W > 47	6.050-2.48 Log w
Oliveira & Marinho (2006)	Matric and Total	W < 33	4.83 – 0.0839w
Oliveira & Marinho (2006)	Matric and Total	W > 33	2.57 – 0.0154w

Note: w = Gravimetric water content
(*) suction range (80-6000 kPa)

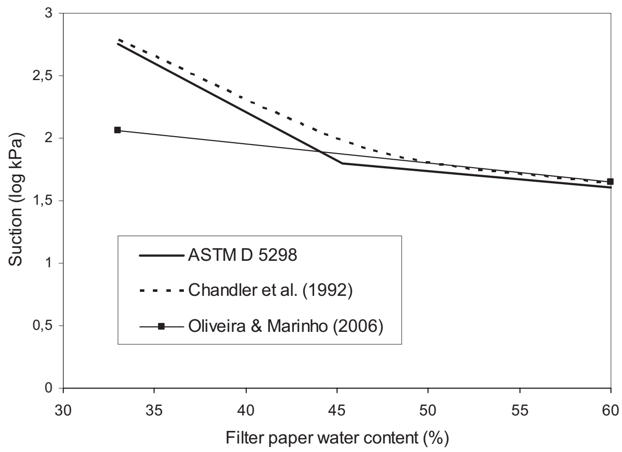

Figure 1. Calibrations curves for Whatman 42 filter paper for w (%) values ranging from 30 to 60 %.

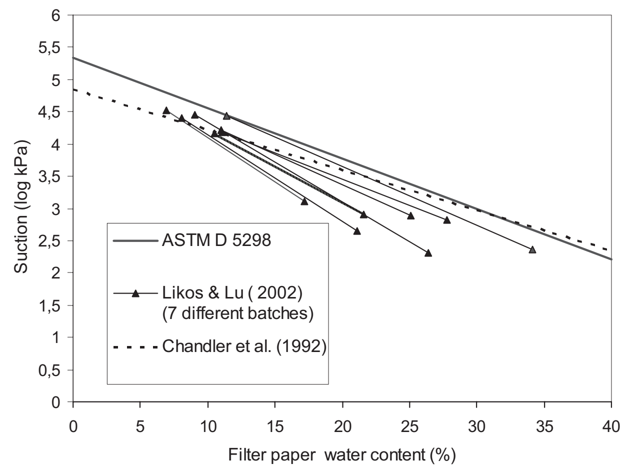

Figure 2. Calibrations curves for w (%) values ranging from 0 to 40 % for seven batches of Whatman 42 filter paper.

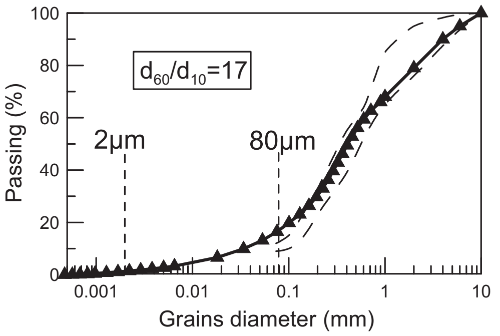

Figure 3. Grain size distribution of Perafita sand (Fleureau et al. 2002)

3.2 *Test program*

The preparation procedure of samples is the same for all the tests: the soil is sieved to avoid the presence of coarse grains (maximum size 4.75 mm), then it is mixed up with the right quantity of water; after that, it is placed in a sealed plastic bag for 24 hours to allow the hydric equilibrium to establish. The contact filter paper tests were carried out on soil specimens compacted to the Modified Proctor Optimum water content (13.2%) and nearly maximum density (18.6 kN/m^3). The compacted soil specimen sizes were 102 mm in diameter and 23.35 mm high.

The test procedure involves placing a piece of initially air dry filter paper against the compacted soil specimen whose matric suction is required and sealing the whole to prevent evaporation. The filter paper then wets up to a water content in equilibrium with the magnitude of the soil matric suction, and careful measurement of the water content of the filter-paper enables the soil matric suction to be obtained from a previously established correlation. This provides a measure of the matric suction, which is assumed to be the same numerically as the capillary pressure (the reference being the atmospheric pressure).The Whatman 42 filter paper was used in all tests.

The other techniques (i.e., tensiometers, and the osmotic technique) used to measure or control the negative pore water pressure in the compacted soil specimens are not discussed in this paper since the purpose herein is to discuss the filter paper technique only. Details of the experimental techniques are given in Fleureau et al. (2002).

4 TEST RESULTS AND ANALYSIS

The measured matric suction values of compacted Perafita sand specimens resulting from several methods used by Fleureau et al. (2002) to control or measure the matric suction and contact filter paper tests investigated in this paper are plotted versus volumetric water content in Figure 4. The term matric suction is used to indicate the negative pressure of water relative to atmospheric air pressure, i.e. -(u_w - u_{atm}). The volumetric water content is defined as the soil porosity times the degree of saturation.

In order to verify the effect of the filter paper calibration curves on the contact filter paper method for matric suction measurement, the authors have used three calibration curves proposed at the literature (Chandler et al. 1992; ASTM D 5298; and Oliveira & Marinho 2006) to interpret the measured contact filter paper gravimetric water contents (43 % $< w < 57\%$). It can be seen from Figure 4 that the matric suctions inferred from filter paper measurements depend on a calibration between the water content of the filter paper and suction and the use of ASTM D 5298's equation underestimated suction values for $w > 45.5$ %. As observed in Figure 1, the difference in matric suction values based on either Chandler et al. (1992)'s equation or Oliveira & Marinho (2006)'s equation is small for $47\% < w < 60\%$.

Based on the data in Figure 4 the matric suction values inferred from filter paper measurements depend on the calibration between the water content of the particular type of paper used and suction. The results suggest that the matric suction values based on Chandler et al. (1992) and Oliveira & Marinho (2006) calibration equations are reasonably well located on the drying-wetting path defined by the other techniques (i.e., tensiometers, and the osmotic technique) used by Fleureau et al. (2002) to measure or control the negative pore water pressure in the compacted Perafita sand specimens.

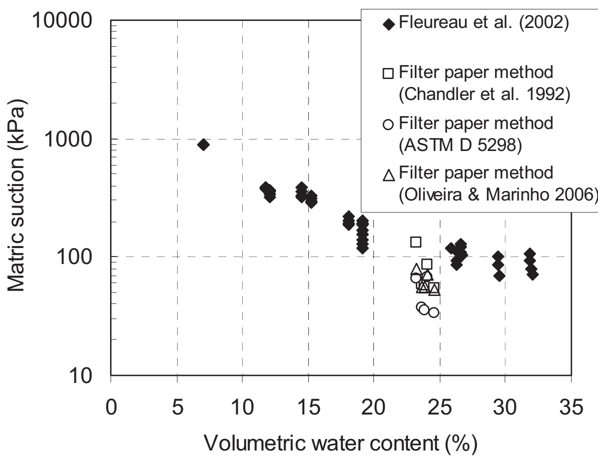

Figure 4. The measured matric suction values versus volumetric water content for compacted Perafita sand specimens.

5 CONCLUSIONS

Matric suction measurements of unsaturated compacted silty sand specimens using the contact filter paper method have been presented. The matric suctions inferred from filter paper measurements depend on a calibration between the water content of the filter paper and suction. Experimental errors induced by using a calibration curve that differ from those frequently used in the scientific community that may influence the experimental results have been discussed.

There is a general agreement between the measured matric suction values of compacted Perafita sand specimens resulting from several methods used by Fleureau et al. (2002) to control or measure the matric suction (i.e., tensiometers, and the osmotic technique) and contact filter paper tests investigated in this paper.

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