EFFECT OF THE FILTER PAPER CALIBRATION ON THE SOIL-WATER RETENTION CURVE OF AN UNSATURATED COMPACTED SILT SAND

EFEITO DA CALIBRAÇÃO DO PAPEL FILTRO NA CURVA DE RETENÇÃO DE UM SOLO ARENOSO SILTOSO COMPACTADO

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ABSTRACT

The soil suction is a key variable in the analysis of the hydro-mechanical behavior of unsaturated soils. The filter paper method (FPM) 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 matric suctions inferred from FPM depend on the calibration between the water content of the filter paper and suction. Therefore, some published calibration curves (Fawcett and Collis-George 1967; Hamblin 1981; Chandler and Gutierrez 1986; Chandler et al. 1992; ASTM D-5298 1992; and Oliveira and Marinho 2006) for the Whatman 42 filter paper are used to interpret the suction measurements of an unsaturated compacted silty sand. Experimental errors induced by using an inadequate calibration curve are discussed. The test results compared to other techniques used to measure or control suctions in the compacted soil specimens are reasonably accurate.

RESUMO

A sucção de um solo é uma variável essencial na análise do comportamento de solos não saturados, e é necessário e importante o desenvolvimento de técnicas, diretas e indiretas, de determinação da pressão capilar de solos, que tentam aliar à simplicidade de aplicação, o que se espera ser uma precisão aceitável para os problemas reais do dia a dia da engenharia de solos. O MPF determina a sucção de forma indireta e depende da precisão em que foi determinada a curva de calibração. Várias curvas de calibração para o papel filtro Whatman 42 têm sido propostas na literatura (Fawcett and Collis-George 1967; Hamblin 1981; Chandler and Gutierrez 1986; Chandler et al. 1992; ASTM D-5298 1992; e Oliveira and Marinho 2006). Este artigo discute o uso do MPF para determinar valores de sucção de um solo arenoso siltoso compactado não saturado. Comparam-se os resultados obtidos com outras técnicas utilizadas para medir ou controlar sucções de amostras compactadas do solo arenoso siltoso e conclui-se que o MPF com adequada curva de calibração pode apresentar resultados satisfatórios.

1. INTRODUCTION

The vast majority of civil infrastructure systems are founded on and in soils above the groundwater table, involving unsaturated soils. Examples of unsaturated state problems in engineering practice can be observed in many geo-environmental engineering problems, including the construction of embankments or earth dams, roads and railways, excavations around construction sites, slope stability, and clay liners in waste containment.

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. For this reason, the development of theoretical and experimental methods for defining soil suction has become one of the most important and active topics of research. For simplicity reasons, in this paper the word "suction" is used synonymously with soil matric suction and negative pore-water pressure unless stated otherwise.

A comprehensive description of the experimental techniques commonly used for measuring or controlling soil suctions can be found in many references (Fredlund and Rahardjo 1993; Lee and Wray 1995; Ridley and Wray 1996; Lu and Likos 2004). The techniques vary widely in terms of cost, complexity, and measurement range. The soil suctions can be determined from previous calibration or can be measured directly. Because of the various difficulties involved in the direct suction measurements, a simple and economical laboratory method for measuring suctions, 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 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 suction values inferred from filter paper measurements depend on a calibration between the water content of the filter paper and suction. Therefore, some calibration curves proposed at the literature (Fawcett and Collis-George 1967; Hamblin 1981; Chandler and Gutierrez 1986; Chandler et al. 1992; ASTM D-5298 1992; and Oliveira and 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 suctions in the compacted soil specimens.

2. CONTACT FILTER PAPER TECHNIQUE

Gardner (1937) was the first to introduce calibrated filter paper as an indirect mean of measuring the suction in soils. Since then, many researchers have been involved in the use of filter paper for soil suction measurement (Fawcett and Collis-George 1967; Al-Khafaf and Hanks 1974; Hamblin 1981; Chandler and Gutierez 1986; Greacen et al. 1989; Chandler et al. 1992; Ridley 1993; Marinho 1994; Houston et al. 1994; and Marinho and 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 (1992) 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 (1992) 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 and Gutierrez 1986; Chandler et al. 1992; Ridley 1993; and Marinho 1994). Marinho and 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. The calibration curve for the filter paper matric suction measurement is commonly established using a pressure plate apparatus (e.g., Al-Khafaf and 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 published calibration curves 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 % (corresponding 120 kPa > suction > 60 kPa). Figure 1 shows calibrations curves for Whatman 42 proposed by Fawcett and Collis-George (1967), Hamblin (1981), Chandler and Gutierez (1986), Chandler et al. (1992), ASTM D 5298 (1992), and Oliveira and Marinho (2006) for filter paper gravimetric water content (w) values ranging from 10 to 70 %. Chandler and Gutierrez (1986) presented a calibration curve for Whatman No. 42 filter paper that included their own results and also those from Fawcett and Collis-George (1967) and Hamblin (1981), therefore, the obtained calibration curves are similar. It should be noted the suction deviation between Chandler et al. (1992), ASTM D 5298 (1992) and Oliveira and Marinho (2006) increases for w < 47 % (corresponding suctions > 80 kPa). The use of Chandler et al. (1992)'s equation results in high suction values for these water content values while the one obtained by Oliveira and Marinho (2006) seems to underestimate the values of suction for suctions > 80 kPa.

Likos and 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 and Lu (2002) for seven different batches of Whatman 42 and the calibration curves proposed by Chandler et al. (1992) and ASTM D 5298 (1992) 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 and 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 METHODS

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. 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- Calibration curves for Whatman 42 filter paper

Calibration curve	Suction	w (%) range	Reference	Log_{10} (suction) (kPa)
1a	Total and Matric	w <45.3	ASTM D5298	5.327 -0.0779 w
1b	Total and Matric	w >45.3	ASTM D5298	2.412 -0.0135 w
2	Matric		Hamblin (1981)	6.281-0.0822 w
3	Matric		Fawcett and Collis-George (1967)	5,777 – 0,060 w
4	Matric	(*)	Chandler and Gutierrez (1986)	5.85 -0.0622 w
5a	Matric	w < 47	Chandler et al. (1992)	4.842-0.0622 w
5b	Matric	w > 47	Chandler et al. (1992)	6.050-2.48 Log w
6a	Matric and Total	w < 33	Oliveira and Marinho (2006)	4.83 – 0.0839w
6b	Matric and Total	w > 33	Oliveira and Marinho (2006)	2.57 – 0.0154w

Note: w = Filter paper gravimetric water content
(*) suction range (80-6000 kPa)

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) following the drying path (degree of saturation < 85%). 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 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 suctions 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 degree of saturation in Figure 3. The term matric suction is used to indicate the negative pressure of water relative to atmospheric air pressure, i.e. - (u_w - u_{atm}). 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 six calibration curves proposed at the literature (Fawcett and Collis-George 1967; Hamblin 1981; Chandler and Gutierez 1986; Chandler et al. 1992; ASTM 1992; and Oliveira and Marinho 2006) to interpret the measured contact filter paper gravimetric water contents (w).

It can be seen from Figure 3 that the suction deviation among the calibration curves 1 (ASTM 1992), 5 (i.e., Chandler et al. 1992), and 6 (Oliveira and Marinho 2006) decreases at suctions less than about 80 kPa and corresponding degrees of saturation higher than 80%. Although it was observed a general agreement between the FPM test results using the calibration curves 1 (ASTM 1992) and 5 (Chandler et al. 1992) and other techniques used to measure or control suctions in the compacted soil specimens for 60% < degrees of saturation < 80 %, the calibration curves 1 and 5 overestimated the suctions for degree of saturation equal to 50%. Calibration curve 6 (Oliveira and Marinho 2006) seem to underestimate the values of suction. Calibration curves 2 (Hamblin 1981), 3 (Fawcett and Collis-George 1967), and 4 (Chandler and Gutierez 1986) overestimated the values of suction.

Therefore the proposed calibration relationships for the Whatman 42 filter paper determined by curve fitting to the experimental results of an unsaturated compacted silty sand are given by:

$\text{Log}_{10}(\text{suction})$ (kPa) = 5.00 -0.0735 w, for w< 45%
$\text{Log}_{10}(\text{suction})$ (kPa) = 2.40 -0.010 w, for w>45%

It should be noted the that the matric suctions inferred from filter paper measurements (FPM) depend on a calibration between the water content of the filter paper and suction. Therefore, the verification of the calibration curve should be always performed before applying the FPM. The FPM offers a promising simple technique for the determination of soil suction, provided that an adequate calibration curve is used for the investigated saturation range.

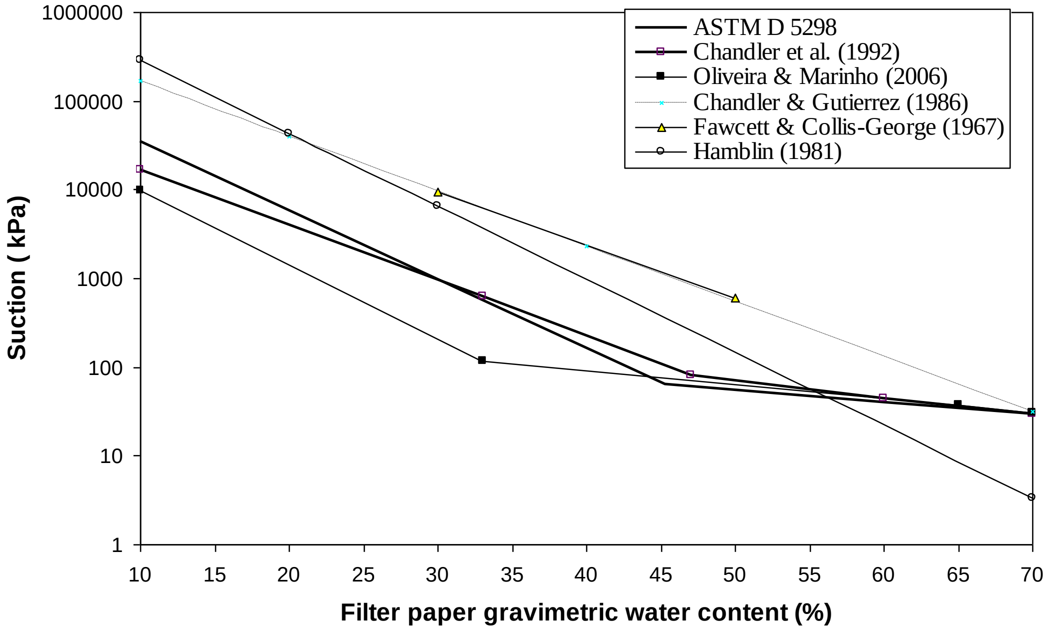

Figure 1 - Calibrations curves for Whatman 42 filter paper (10% < w < 70 %).

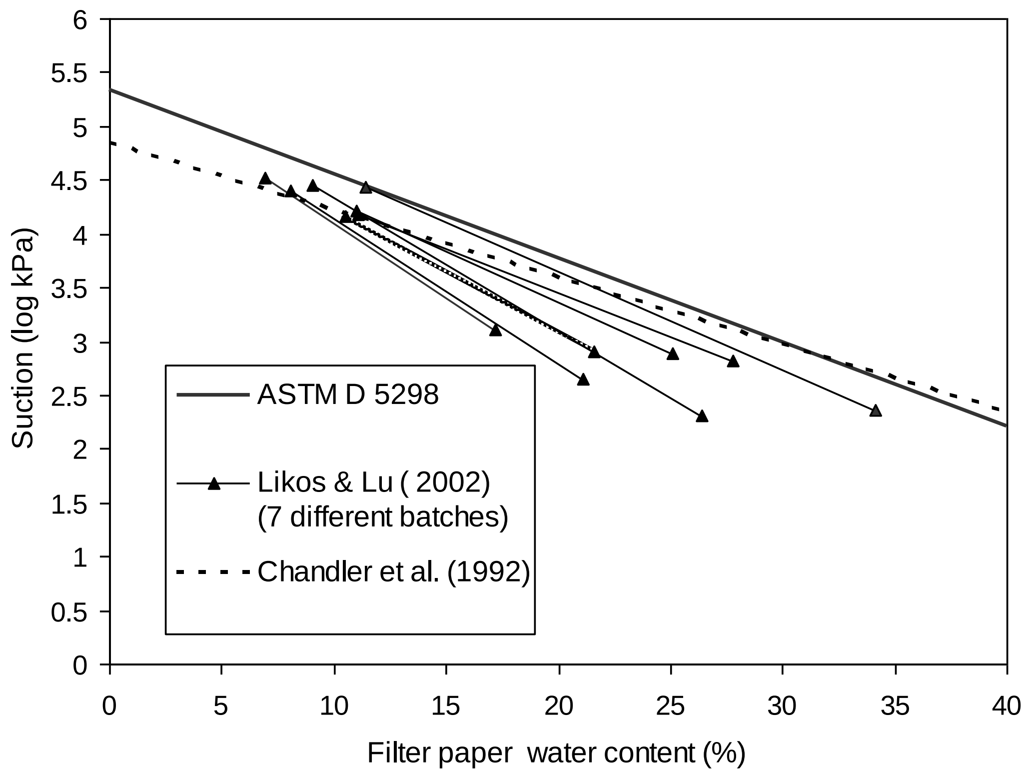

Figure 2 - Calibrations curves for Whatman 42 filter paper (0% < w < 40 %).

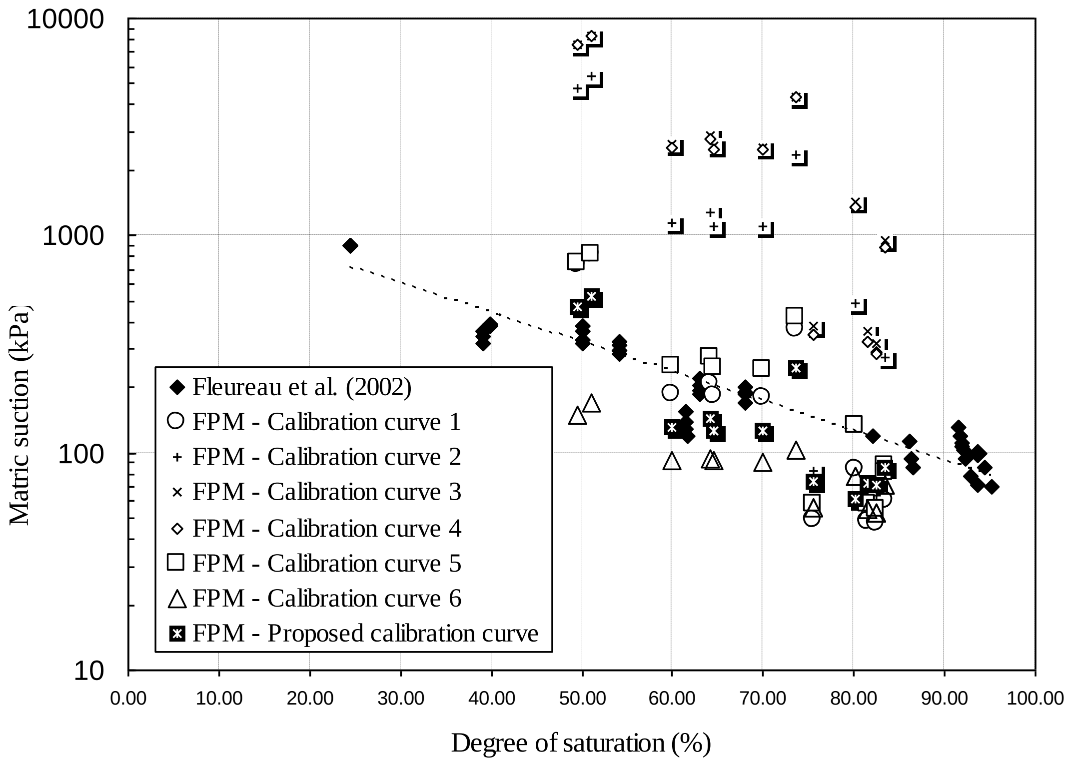

Figure 3 – Effect of the filter paper (FPM) calibrations on the measured soil suctions versus degrees of saturation for compacted Perafita sand specimens.

5. CONCLUSIONS

We conclude from our results that, for the range of water content investigated, the matric suctions inferred from filter paper measurements depend on the used calibration curve between the water content of the filter paper and suction and the deviation among the calibration curves proposed by Chandler et al. (1992), ASTM D 5298 (1992), and Oliveira and Marinho (2006) decreased at suctions less than about 80 kPa and corresponding degrees of saturation higher than 80%. Although it was observed a general agreement between the FPM test results using the calibration curves ASTM D 5298 (1992) and Chandler et al. (1992) and other techniques used to measure or control suctions in the compacted soil specimens for 60% < degree of saturation < 80 %, the calibration curves overestimated the suctions for degree of saturation equal to 50%. Oliveira and Marinho (2006) seems to underestimate the values of suction. Calibration curves proposed by Fawcett and Collis-George (1967), Hamblin (1981) and Chandler and Gutierez (1986) overestimated the values of suction. Therefore, the FPM offers a promising simple technique for the determination of soil suction, provided that an adequate calibration curve is used. It is always recommended to verify if the calibration can be used without causing significant errors in the suction values to be determined.

ACKNOWLEDGMENTS

The first author is grateful for sponsorship by the Brazilian government agency CAPES.

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