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Research Article

Determination of SWRC for Unsaturated Sands, Comparative Study – Filter Paper Method Versus Hanging Column Technique

Ayşe Pekrioğlu Balkıs[11], Bestun Shwan[2], Svala Surchi[3]

[1] Cyprus International University, Engineering Faculty, Civil Engineering Department, Nicosia, North Cyprus (ORCID: 0000-0001-7400-7211)
[2] Koya University, University Park, Danielle Mitterrand Boulevard, Koysinjaq KOY45, Koya, Iraq
[3]Cyprus International University, Civil Engineering Department (MSc), Nicosia, North Cyprus

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Abstract

Soil water retention characteristic is the key soil property used in many applications in the fields of irrigation, hydrology, geotechnical engineering and soil science in general and there are different methods used to obtain SWRC. Filter paper method and Hanging column test methods are two of them. The use of filter paper method for sands is quite limited in the literature in which only a number of studies have been conducted using this method. This study, therefore, aims to use the filter paper method for measuring matric suction for two different types of sands. Samples were prepared using the water pluviation technique. The samples were left to dry out and then monitored by weight to obtain different values of degree of saturation. This is to extend suction measurement beyond the residual suction and to fully define the shape of the soil water retention curve. The filter paper method then was validated with the hanging column technique, which is a method of controlling and applying suction. The obtained results are presented in order to highlight the differences / similarities between the methods and the advantages / disadvantages of each one. Suction values were derived using three different calibrations proposed by Chandler et al. (1992), ASTM D5298-03 (2007) and Marinho et al. (2006) for Whattman 42 filter paper. Matric suction obtained from equation recommended by (Chandler et. al) ranged from (3.523 to 45.233 kPa), 1.5 to 41.05 kPa by (ASTM) and 1.04 to 45.6 by (Oliveira & Marinho)'s recommendations for Soil-1. While for Soil-2 the highest suction value was 5.02 kPa (Chandler et al.) and 2.75 kPa, 2.29 kPa were observed by using (ASTM, Oliveira & Marinho, 2006) equations respectively. The lowest suction values were 2.96 kPa (Chandler et al.), 1.03 kPa ASTM D5298-03 (2007) and 0.68 kPa (Oliveira & Marinho, 2006). Although the FP is an indirect method of measuring suction in unsaturated soils, it has not been utilized broadly for fine-grained unsaturated sands. Results also showed that as degree of saturation increases suction values decreases. The use of the filter paper method for unsaturated fine sands is quite limited in the literature in which only a number of studies can be found using the filter paper method for unsaturated sands. Therefore, this paper provides an insight on the use of filter method for unsaturated fine sands. Testing two sand soil with different particle size distribution showed that Soil 1 is better than Soil 2 to be used for FP method. And this result is a good show for the range of utilization of FP method in fine sand soil.

Keywords: Filter paper; Hanging column technique; Matric suction; Soil water retention curve

Doymamış Kumlarda Toprağın Suyu Tutma Eğrisi Tayini, Karşılaştırmalı Çalışma - Asılı Kolon Tekniğine Karşı Filtre Yöntemi

Öz

Toprağın su tutma özelliği, genel olarak sulama, hidroloji, jeoteknik mühendisliği ve toprak bilimi alanlarında birçok uygulamada kullanılan temel toprak özelliğidir ve literatürde toprağın suyu tutma eğrisini elde etmek için kullanılan farklı yöntemler bulunmaktadır. Filtre kağıdı yöntemi ve Asılı sütun test yöntemleri bunlardan ikisidir. Filtre kağıdı yönteminin kum zeminler için kullanımı literatürde oldukça sınırlıdır. Her ne kadar filtre kağıdı yöntemi, doymamış topraklarda emme ölçmenin dolaylı bir yöntemi olsa da, ince daneli

[1] Corresponding Author: Uluslararası Kıbrıs Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Bölümü, Lefkoşa, KKTC, ORCID: 0000-0001-7400-7211, apekrioglu@ciu.edu.tr

doymamış kumlar için geniş çapta kullanılmamıştır. Bu nedenle, bu çalışma doymamış ince kumlar için filtre yönteminin kullanımı hakkında bilgi edinilmesi amacıyla gerçekleştirilmiştir. Bu nedenle, bu çalışmada, iki farklı granülometriye sahip kum tipi zeminde matris emişini ölçmek için filtre kağıdı yöntemi kullanılarak bu yöntemin etkinliğinin belirlenmesi amaçlamaktadır. Numuneler su pluviasyonu tekniği kullanılarak hazırlanmıştır ve farklı doyma derecesi değerleri elde edilmiştir. Bu, emme ölçümünü ve toprak su tutma eğrisinin şeklini tam olarak tanımlamak için yapılmıştır.
Emme değerleri, üç farklı kalibrasyon kullanılarak elde edildi, bunlar Chandler ve arkadaşları (1992), ASTM D5298-03 (2007) ve Marinho ve diğ. (2006)'dır. Zemin-1 için (Chandler ve diğerleri) tarafından önerilen eşitlikten elde edilen matris emme değerleri (3.523 ila 45.233 kPa), 1.5 ila 41.05 kPa (ASTM) ve 1.04 ila 45.6 (Oliveira & Marinho)'dur. Zemin-2 için en yüksek emme değeri 5.02 kPa (Chandler ve diğerleri) ve 2.75 kPa iken, sırasıyla (ASTM, Oliveira ve Marinho, 2006) denklemleri kullanılarak 2.29 kPa emme değeri gözlenmiştir. En düşük emme değerleri 2.96 kPa (Chandler ve diğerleri), 1.03 kPa ASTM D5298-03 (2007) ve 0.68 kPa'dır (Oliveira ve Marinho, 2006). Filtre kağıdı yönteminden elde edilen sonuçlar daha sonra asılı kolon tekniği sonuçları ile karşılaştırılmış ve doğrulanmıştır. Elde edilen sonuçlar, iki yöntem arasındaki benzerlikleri/farklılıkları belirlemek ve avantajlı/dezavantajlı durumları değerlendirmek amacıyla karşılaştırılmıştır. Sonuçlar, Zemin-1'in Zemin 2'ye göre filtre kağıdı yöntemi için daha uygun bir zemin olduğunu göstermiştir. Ve bu sonuç, ince kum zeminde filtre kağıdı yönteminin kullanılabileceğinin bir göstergesidir.

Anahtar Kelimeler: Filtre kağıdı; Asılı kolon tekniği; Matris emme; Toprağın suyu tutma eğrisi

1. Introduction

Several disciplines such as agricultural, soil science, hydrogeology, ceramics, petroleum especially geo-environmental and geotechnical engineering, have contributed towards current understanding of unsaturated soil mechanics. The performance of an unsaturated soil in engineering is significantly affected by the suction in the soil. Theoretical concepts related to soil suction were initially introduced by soil scientists with the aim of describing the forces of migration and equilibrium of soil water for agricultural purposes. The theoretical concepts were later adopted in the field of geotechnical engineering due to the need for the establishment of unsaturated soil mechanics. Accordingly, a theoretical framework for unsaturated soil mechanics has been well developed and its behavior is identified to be governed in terms of two independent stress state variables – matric suction (u_a-u_w) (where u_a is pore air pressure; u_w is pore water pressure) and net normal stress ($\sigma - u_a$), [1].

Knowledge of soil suction in unsaturated soils is highly required for solutions in various geotechnical problems in the soil type. Typical of such engineering problems are related with swelling and shrinkage, slope stability, compaction and lateral pressures. Appropriate assessment of soil suction is required for the analysis of the problematic soils – residual soils, collapsing soils, swelling soils and soft clays. One of the key features of the unsaturated soils is the soil water retention curve (SWRC) which represents the fundamental relationship between matric suction and soil water. SWRC generally reflects soil behaviour for adsorption and desorption processes. It is usually presented as a relationship between water content (gravimetric or volumetric), or degree of saturation against soil suction which can be expressed in kPa.

The relationship between the capillary pressure (or matric suction), and water content has been traditionally represented using soil water retention curves (SWRC). Methods available to obtain this relationship include the Hanging Column Test, Pressure Extractor, Chilled Mirror Hygrometer, and Centrifuge Test (ASTM 2008). SWRC's have often been assumed to be independent of the soil void ratio, as a state parameter. Even the most commonly used SWCC mathematical models such as Van Genuchten (1980) and Brooks and Corey (1964) do not account for changes on it [2].

The van Genuchten equation is expressed as:

$$\theta (h)=\theta_r+(\theta_s-\theta_r)[1+(\alpha h)^n]^{-m} \qquad (1)$$

where, θ is the volumetric water content; h is the pressure head; θs and θr represent the saturated and residual water contents, respectively; α, n and m are empirical shape parameters. The residual water content is one of the most important parameters to express the soil water characteristics and hydraulic conductivity in unsaturated soils. . Residual water content is the water content for which the gradient becomes zero.

A Brooks-Corey model is a type of nonlinear curve fitting model for fitting water retention characteristics using experimental data. The Brooks-Corey functions can be defined as:

$$\theta (h)=\theta_r+(\theta_s-\theta_r)(\alpha h)^{-\lambda} \qquad (2)$$

Where, θr is the residual water content (cm^3/cm^3), θs is the saturated water content (cm^3/cm^3), h is the matric potential (cm), λ and α are empirical shape parameters.

Generally, porous materials have a fundamental capability to attract and retain water. In engineering terms, the presence of this fundamental feature in soils is termed as suction or negative pore water pressure. According to [3], soil suction and positive pore water pressure are two very important parameters with regards to the description of the behaviour of unsaturated and saturated soils, respectively. For several engineering applications, the distinction in suction based on the seasonal moisture movement is very vital information.

According to [1], the measurement techniques for soil suction can be divided into two categories: direct or indirect. For engineering practices, the direct measurement of matric suction would be most desirable. However, this has been limited to less than 100 kPa because of cavitation problem in the measuring system. As a result of the limitations of the direct measurement of matric suction, any development in the indirect measurement could feature difficulty in verification and interpretation. Most of the instruments are found to have technical limitations with regards to their range of measurements, the equilibration times, equipment deterioration and cost.

Consequently, there is a need for a suction measurement approach which is capable of covering the full range of measurement and can be adopted for a routine basis while at the same time it is economical or inexpensive. The filter paper is an indirect method of measuring suction in unsaturated soils; it has not been utilized broadly for fine sands. The aim of this paper is to use the filter paper method for measuring matric suction for different types of sands and compare results with respect to values obtained by hanging column technique. The objective is to investigate the filter paper method as an alternative approach for measuring soil suction for sandy soil. In addition, the available calibration techniques for filter paper drying curve are investigated. Soil suction measurement for unsaturated soils would also be investigated by conducting laboratory work with reference to literature.

2. Methodology

2.1. Material Selection

In this study, two types of sand soils were collected locally in Koy Sanjaq town located in Erbil. Sieve analysis was performed on soil samples to see their particle size distribution. Soil samples were given in Figure 1a and 1b.

a) b)

Figure 1. a)Soil 1 b)Soil 2

After pouring the dry soil sample onto the sieve, the sieve set was subjected to a shaker for about 10 minutes. After sieving, when clusters and aggregated particles were observed, wet sieving was done. Aggregated samples were washed till to have clear water passing through the bottom sieve. Samples retained on each sieve corresponding to a specific diameter were placed in containers and left overnight in an oven for drying. Then, samples were classified according to their particle diameters and placed in plastic bags together with the sample obtained from the mechanical sieving (samples with no cluster). Unified Soil Classification System was used to classify the soil (ASTM D2487-11) and ASTM D7263 - 09(2018)e2 was used for dry density determination.

Soil samples were obtained by mixing different percentages and sizes, and the values are given in Table 1. Two sand soil (SP) having different particle size distribution which are suction compatible for both the filter paper (FP) and the hanging column technique (HCT) were used to analyze the use of FP method effectiveness of suction measurement on unsaturated fine sands.

Table 1. The suggested percentage of samples which were mixed together

Samples	**Sieve size (mm)**	**Suggested percentage %**

Soil-1	0.300-0.425	40
	0.150-0.212	40
	0.090 -0.106	20
Soil-2	0.425-0.500	40
	0.300-0.425	40
	0.150-0.212	20

After mixing defined percentages of sands, sieve analysis were conducted for Soil-1 and Soil-2 that their particle size distributions are given in Figure 2. Soil-2 has finer particle size distribution. Soils are classified as poorly graded sand according to USCS (Unified Soil Classification System). Soil-2 contains 40% medium sand however Soil-1 is purely fine sand which is shown also in Figure 2. Table 1 gives different amount of sand soil passing through different sizes of sieves.

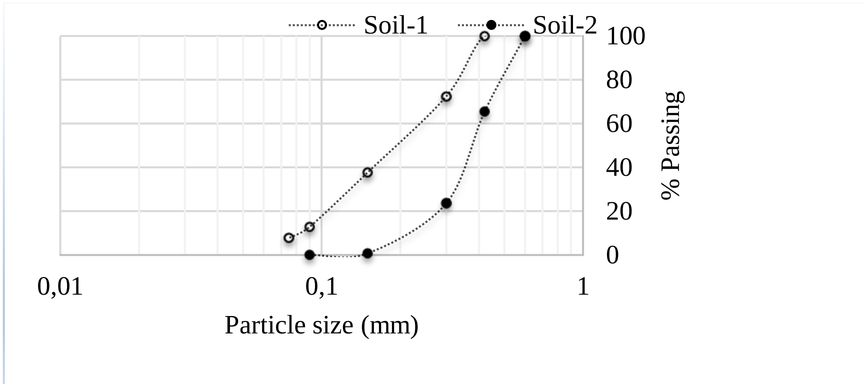


Figure 2. Particle size distributions of Soil-1 and Soil-2

2.2. Sample Preparation for FP Method and Suction Measurement

In this study, Whattman No. 42/ Ashless (diameter 55 mm) of filter paper was used for matric suction measurement [4]. Samples were prepared using the water pluviation technique and containers of known sizes (diameter, height & volume) were used. The water pluviation method resembles the air pluviation, except that the medium in which the sand is pluviated is de-aired water instead of air. For the water plwiation method, a sampie is boiled, an de-aired, in a pycnometer. This pycnometer is Nled to the brim with water and ovemirned into the ring shear cell which was itself filled with distilled water. The pycnometer must be moved smoothly dong the ring shear ceil's channel to permit the formation of a uniform sample. Soil samples were poured into containers using hanging funnel and a pipette at zero distance to evenly distribute soil particles and ensure smooth surface to give close contact between samples and the filter paper that will be placed on it. Also samples were left for drying and then monitored by weight to obtain different values of degree of saturation. Two samples were placed on each other by placing filter paper between them. By using tweezers, three filter papers were placed on top of each of the soil sample, where top and bottom filter papers were for protection against flow out of particles and the one in the middle was used to get suction data. The two glass containers were sandwiched and sealed using electrical tape to ensure they were held together properly and are airtight. Also melted candles wax was used for waxing the sample to protect it from any vapor transfer and ensure minimal effect of surrounding temperature.

Containers were weighed and recorded as empty cold tare mass (Tc) by using balance with 0.0001 gr. accuracy. After an equilibrium time of seven days, the containers were opened and the middle filter paper was taken out carefully by using tweezers in few seconds (Figure 2a) and placed into previously weighted empty container. Mass of wet filter paper and cold tare was recorded as M_1.

Figure 2. Sampling: a) Removing middle filter paper by using tweezers b) Samples left inside oven overnight

After the overnight period of the samples in the oven (Figure 2b), before taking them out, the lids were covered back and left in the oven for a further five minutes for equilibrium, afterwards the containers were weighed again and recorded as M_2 (mass of dry filter paper + hot tare). Then emptied containers weighed and recorded as hot tare mass (Th). The water content value of filter paper was determined by using following formula [6]. Table 2 shows calibration curves for Whatman 42 filter paper.

$$M_w = M_1 - M_2 - Tc + Th \quad (3)$$

$$M_f = M_2 - Th \quad (4)$$

$$W\% = \frac{Mw}{Mf} x100 \quad (5)$$

Table 2. Calibration curves for Whattman 42 filter paper

References	**w%**	**Log_{10} (kPa)**
ASTMD5298-03 (2007) [6]	w>45.3	2.412-0.0135w
Chandler et al. (1996) [5]	w>47	6.050-2.48 Log w
Oliveira & Marinho (2006) [7]	w>33	2.57-0.0154w

* where w is filter paper water content.

2.3. Hanging Column Technique

Hanging column apparatus was used in the experiment, which consists of three separate parts that include a suction supply part, a specimen chamber, and an outflow measurement tube. There is specimen chamber, which comprises a porous plate that holds the soil specimen to be tested. The porous plate or ceramic disk placed to diminish air bubble formations, and in order to remove the air bubbles that diffused through the ceramic disk the flushing system were incorporated, circular grooves below the disk used to remove the air from the ceramic plate. Figure 3 shows Hanging funnel and a pipette and Figure 4 shows the apparatus. The water coming out during experiment was measured and water height was checked to obtain matric suction values [8-9]. A transparent flexible plastic tube connected to the saturated sample chamber was used to connect the next end of the capillary tube (Burette) to the chamber of the suction apparatus using the same type of transparent tubes, de-aired water was used to fill the sample chamber. Samples were prepared using water pluviation technique. Size and mass of containers were obtained at the beginning and then soil samples were distributed evenly and placed into containers by using a pipette at zero distance using a hanging funnel. To ensure a smooth and flat surface, close contact between the particles and the samples with filter paper to be placed on it has been achieved. Samples were also left to dry and then monitored for weight to obtain different values of saturation degree. When the level of tension applied to the sample is very small and close to saturation (close to zero), using a Hanging Column is recommended. A hanging water column is a simple and very accurate method for applying small levels of tension to soil. 5 samples were prepared for both soil types.

Figure 3. Hanging funnel and a pipette

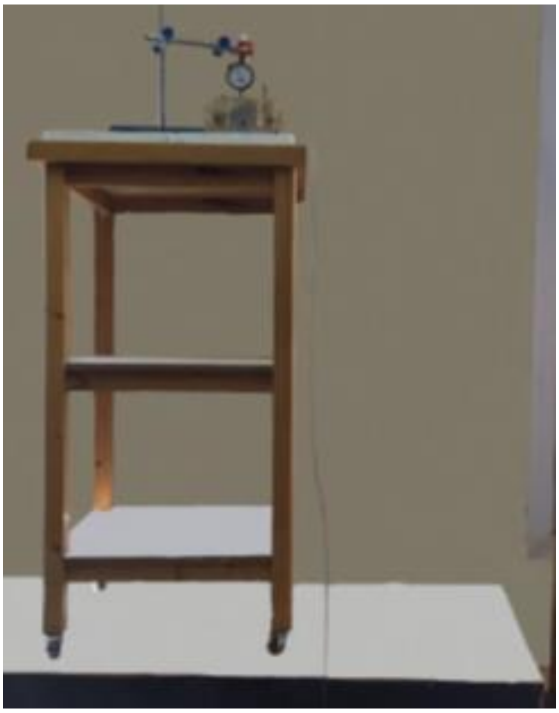


Figure 4.Hanging column test apparatus

3. Results and Discussion

3.1. Suction Measurement Results with FP Method

There were total of 15 soil samples for Soil-1 and 17 samples for Soil-2 used at different degree of saturation to define the shape of the soil water retention curve (SWRC). After obtaining water content and matric suction values by using three different equations, Figure 5 and Figure 6 were drawn to show relation between water content and matric suction for Soil-1 and Soil-2, respectively. The points on the graph correspond to the measurement of suction values in different degrees of saturation where suction increases with the decrease of water content (degree of saturation). Suction values calculated with three different method give similar behavior for Soil-1 which is finer than Soil-2. As degree of saturation increases suction values decreases.

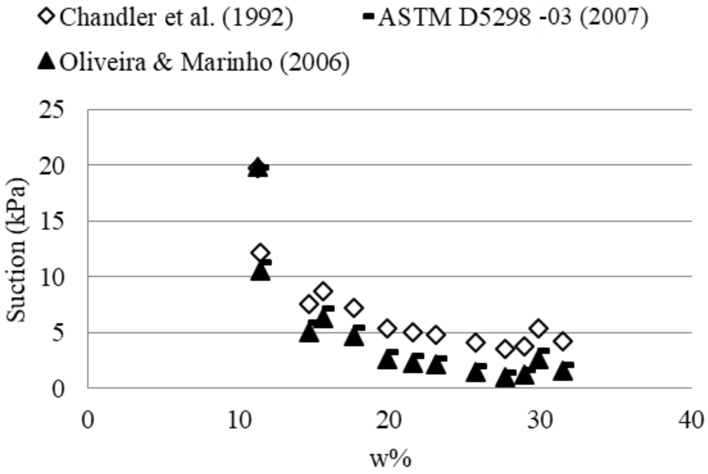


Figure 5. SWRC obtained for Soil-1

For Soil-1, all equations give similar behavior and values.

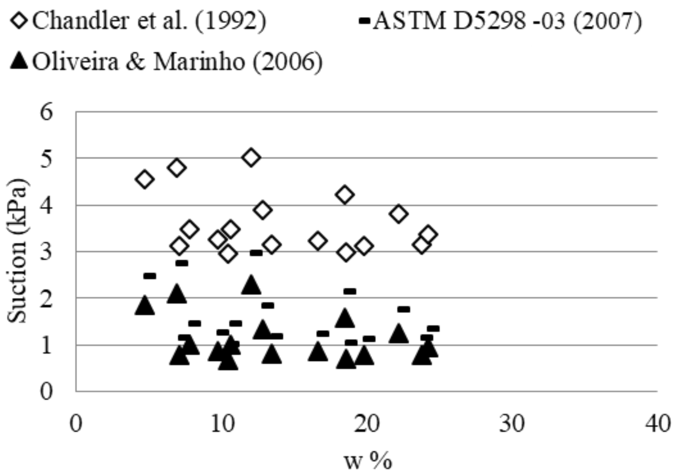


Figure 6. SWRC obtained for Soil-2

Suction values calculated by using ASTM D5298-03 (2007) and Marinho et al. (2006) give similar results for Soil-2, meanwhile suction values obtained from Chandler et al. (1992) equation gave higher suction values for the same water content values. Suction values does not show direct decrease for Soil-2 as in Soil-1.

3.2. Hanging Column Test Results

The suction measurement was carried out by hanging column test to obtain soil water retention curve. The equilibration time for Soil-1 and Soil-2 was 3 hr and 4 hr, respectively. From the observed soil water retention curve, two points along the curve were determined, namely; air entry value represented as the pressure at which the air entered to the pores of soil sample and residual condition where desaturation starts at transition stage.

Figure 7 shows the SWRC for Soil-1 where (291.55 gr.) of soil and (100 gr.) of water were used to saturate the sample. The drying path starts at water content of 34.3% that corresponds to degree of saturation 92%, where the second reading were water extracted at water content of 33.29% corresponds to degree of saturation 89% and 0.22 kPa suction measurement. The air entry value corresponds to the water content of 26.45% and 3.83 kPa suction measurement where the residual condition occurs at 8.86% of water content, which corresponds, to 6.01 kPa suction values. The highest suction value is 13.18 kPa at water content of 0.82 kPa as shown in Figure 7. The SWRC for Soil-2 is shown in Figure 7, where (338.5 gr. of soil with (91 gr.) of water were used to saturate the sample in which the soil suction has an air entry value of 1.41 kPa with the water content of 21.65% at 81% of degree of saturation and residual suction is 3.33 kPa with 3.45% of water content. The highest suction value recorded was 4.58 kPa at water content of 2.14%.

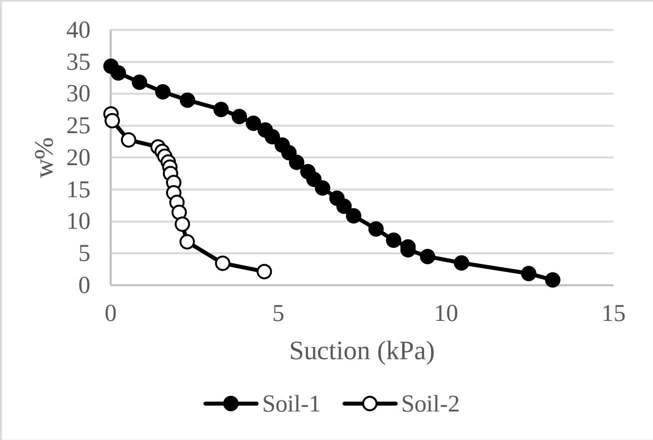
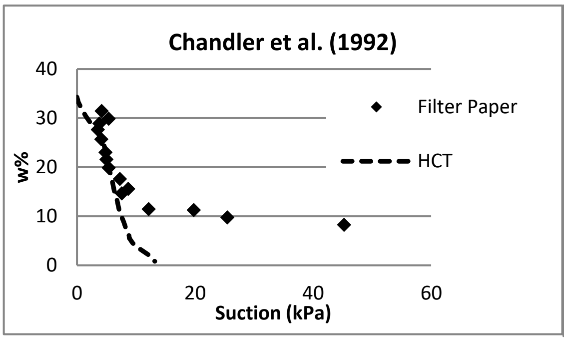
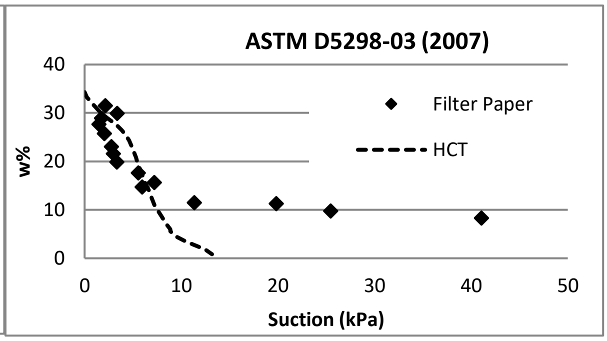


Figure 7. SWRC by HCT method

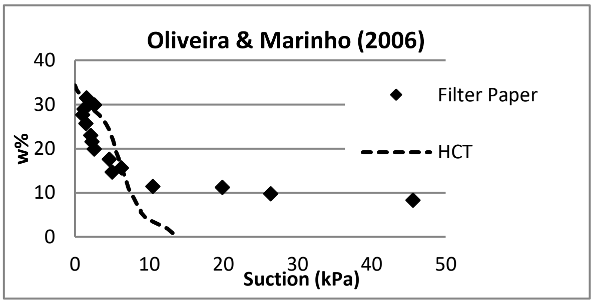
4. Comparison of SWRC Curves Obtained by FP Method and Hanging Column Test

Suction measurements, which were obtained by the HCT and FP methods, were compared. A comparison between the results of suction measurements using FP method and HCT for Soil-1 was shown in the Figure 8.





a) b)

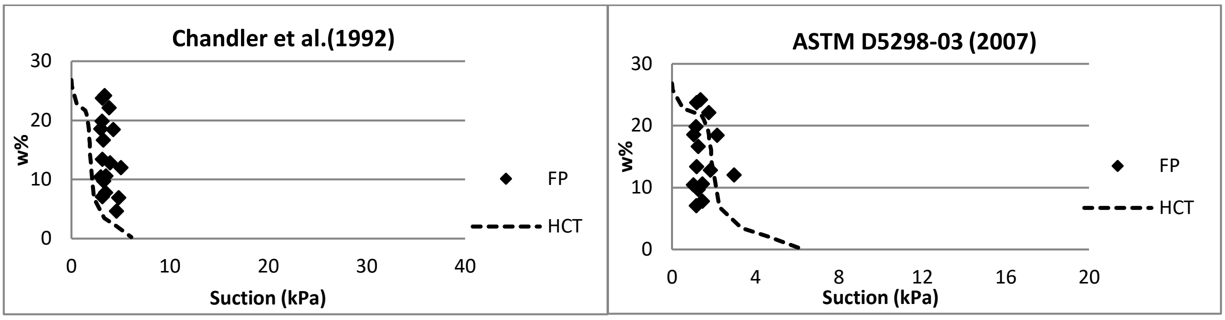


c)

Figure 8. Suction measurement versus water content obtained using FP method and HCT for Soil-1

Points determined by FP method had higher values than the results of HCT however, in some points which corresponds to higher water content (higher degree of saturation) it shows a good agreement, possibly due to having enough water amount to flow from the defined height. The results of the FP reasonably matched well with the HCT, despite some discrepancy at higher suctions. The difference appears to be smaller than 0.5 for suction values, where in HCT the suction values of 5.87 kPa (w = 17.79%) and 1.54 kPa (w = 30.31%) fits well within the filter paper suction values (kPa) of 5.54 (w = 17.61%) and 1.73 (w = 28.92%).

For Soil-2 the HCT compared to all the three recommendations in order to observe the best-fitted results between the two techniques.



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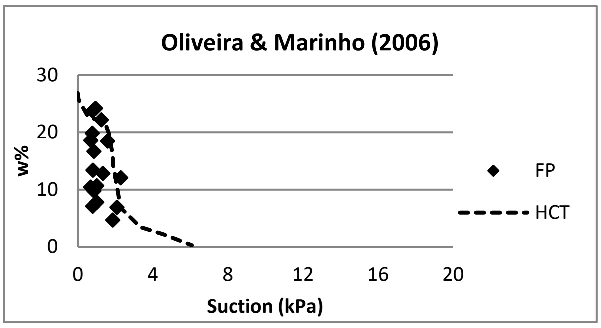

c)

Figure 9. Suction measurement versus water content obtained using FP method and HCT for Soil-2

Figure 9a shows the comparison of suction values that estimated from filter paper method by using the equation suggested by ASTM with hanging column test. The results were close, into which the best fitted point was observed at water content of 12% where the suction value of FP measurement was 1.85 kPa and 1.97 kPa for HCT.

Figure 9b shows a good agreement between the estimated suction values from FP method that obtained by the equation which suggested by Marinho et al. (2006) and the suction values observed from HCT. From which more than two points lie on each other that shows relatively similar measurements of suction between the two methods, in which at 6.8% water content suction values for FP and HCT were (2.1 - 2.27 kPa) respectively and for 21.8% the suction values measured were (1.26 kPa for FP, 1.41 kPa) for HCT.

As shown in (Figure 9c) the results from both techniques were obtained to be similar considering Chandler's calibration. The closest point appeared at water content of 11.44% where the suction was 2.04 kPa in HCT while for 10.44% the value of suction was 2.96 kPa in filter paper method.

Hanging column method measures a higher volumetric moisture content for each suction head except the zone in residual moisture for beach sand with respect to large soil column test [10-11]. The portion of the SWCC measured with the hanging column is comparable to that measured with the LFPPE (leak-free pressure plate extractor), indicating that the same water retention characteristics were measured using the two independent measurement techniques [12]. Brooks and Corey (1964) and van Genuchten (1980) fits have been obtained for data obtained for Soil 1 and Soil 2. Parameters calculated are given in Table 3.

Table 3. Brooks and Corey and van Genuchten model parameters

Model	**Soil Type**	**Equation**	**Parameters**	**R^2**	**AIC**
Brooks and Corey	Soil-1	$S_e = (h/h_b)^{-\lambda}$ $(h>h_b)$ $S_e=1$ $(h\leq h_b)$	$\theta_s = 88.021$ $\theta_r = 0.006374$ $h_b = 19.449$ $\lambda = 0.54944$	0.69356	147.01
van Genuchten		$S_e = (1/(1+(\alpha h)^n)^m$	$\theta_s = 81.814$ $\theta_r = 2.0213e^{-04}$	0.99367	46.127

		(m=1-(1/n))	α = 0.016991 n = 4.3853		
Brooks and Corey	Soil-2	$S_e = (h/h_b)^{-\lambda}$ ($h>h_b$) $S_e=1$ ($h \le h_b$)	θ_s = 592.11 θ_r = 0.0046846 h_b = 3.4971 λ = 0.50578	0.91285	134.37
van Genuchten		$S_e = (1/(1+(\alpha h)^n)^m$ (m=1-(1/n))	θ_s = 603.05 θ_r = 3.5485 α = 0.50369 n = 1.3470	0.79877	148.60

- AIC (Akaike Information Criterion) = n ln(RSS/n)+2k, where n is sample size, RSS is residual sum of squares and k is the number of estimated parameters.
- Effective saturation, $S_e = (\theta-\theta_r)/(\theta_s-\theta_r)$. Therefore $\theta = \theta_r + (\theta_s-\theta_r)S_e$. [13]

For Soil-1, van Genuchten model predicts soil water characteristic more accurately with five parameters model and Brooks and Corey model having four parameters model gives best fit for Soil-2.

4. Conclusions and Recommendations

Filter paper method is an indirect method for measuring matric suction, which allows a large range of suctions to be measured. The use of the filter method for unsaturated fine sands is quite limited in the literature therefore in this study two types of soil were investigated which were classified as poorly graded sand to obtain the matric suction (using the contacted method). There were a total of 15 soil samples for Soil-1 and 17 samples for Soil-2, which were prepared at different degree of saturation. Suction values were derived using three different calibrations proposed by Chandler et al. (1992), ASTM D5298-03 (2007) and Marinho et al. (2006) for Whattman 42 filter paper. Matric suction obtained from equation recommended by (Chandler et. al) ranged from (3.523 to 45.233 kPa), 1.5 to 41.05 kPa by (ASTM) and 1.04 to 45.6 by (Oliveira & Marinho)'s recommendations for Soil-1.

While for Soil-2 the highest suction value was 5.02 kPa (Chandler et al.) and 2.75 kPa, 2.29 kPa were observed by using (ASTM, Oliveira & Marinho, 2006) equations respectively. The lowest suction values were 2.96 kPa (Chandler et al.), 1.03 kPa ASTM D5298-03 (2007) and 0.68 kPa (Oliveira & Marinho, 2006). Soil water retention curves were also illustrated from the soil moisture content of the samples versus the suctions that were obtained from both types of soils using all the three recommendations. Suction measurement was carried out by hanging column technique, which is a method of controlling suction used broadly for coarse-grained soils. In order to compare it with the results from suction values that was obtained from filter paper method.

To validate the FP results, the HCT method was utilised and results for both soil types were compared. In general, there was a good agreement between the matric suction values that were obtained by FP and HCT methods. However, it showed good agreement between all the proposed equations but the better agreement for Soil-1 was suction values that obtained from the equation proposed by Chandler et al. (1992) and for Soil-2 the equation that was proposed by Oliveira and Marinho (2006). Due to the reason of applying different heads and water suctions in both methods, there are some discripancies in the obtained results.

Although the FP is an indirect method of measuring suction in unsaturated soils, it has not been utilized broadly for fine-grained unsaturated sands. The use of the filter paper method for unsaturated fine sands is quite limited in the literature in which only a number of studies can be found using the filter paper method for unsaturated sands. Therefore, this paper provides an insight on the use of filter method for unsaturated fine sands. Testing two sand soil with different particle size distribution showed that Soil 1 is better than Soil 2 to be used for FP method. And this result is a good show for the range of utilization of FP method in fine sand soil. Huriye et. al. [14] agrees with the similar behavior. It is recommended to study filter paper and hanging column test on larger range sand soil to see the repeatability of the test and differences and similarities in the results.

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