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SOIL WATER CHARACTERISTIC CURVES OF COMPACTED KAOLIN FOR VARIOUS INITIAL MOISTURE CONTENT

Muhammad Azril Hezmi*, Radzuan Saari, Mohd Zakri Zahari, Rini Asnida Abdullah, Nor Zurairahetty Mohd Yunus, Ahmad Safuan A Rashid

Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

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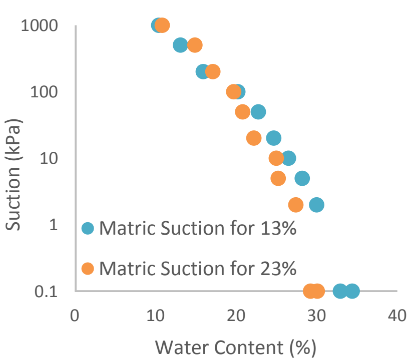
*Corresponding author
azril@utm.my

Graphical abstract



Abstract

The soil water characteristic curve (SWCC), also known as soil water retention curve (SWRC), describes the relationship between water content and soil suction in unsaturated soils. The importance of SWCC can be seen, as the relationship affects geotechnical properties such as shear strength, volume change, permeability and deformability of unsaturated soils. This paper presented a preliminary study on the effect of initial water content and the density on SWCC on unsaturated compacted kaolin. Filter paper technique was used for suction measurement on the unsaturated compacted kaolin soil. Filter paper was used to determine total suction and matric suction through contact and noncontact technique. The calibration curve was used to relate with the gravimetric water content obtained in filter paper with corresponding suction. A comparison on SWCC established through filter paper was also compared with that of the axis translation technique (pressure plate extractor). The study found that the initial water content and the density respectively, have great influence on the SWCC of compacted kaolin. However, the combined effect could be seen significantly at lower suction

Keywords: Soil water characteristics curve ; suction measurement; compacted kaolin

Abstrak

Lengkung ciri tanah-air (SWCC), juga dikenali sebagai lengkung tertahan air tanah(SWRC), menerangkan hubungan antara kandungan air dan sedutan di da;am tanah separa tepu. Kepentingan SWCC dapat dilihat, di dalam sifat-sifat geoteknikal seperti kekuatan ricih, perubahan isipadu, kadar resapan dan perubahan bentuk tanah separa tepu. Kertas ini membentangkan kajian pada kesan kandungan air awal dan ketumpatan kepada SWCC kaolin terpadat separa tepu. Teknik kertas turas telah digunakan sebagai pengukur sedutan tanah kaolin terpadat separa tepu. Kertas turas yang digunakan untuk menentukan jumlah sedutan dan sedutan matrik melalui teknik sentuhan dan tanpa sentuhan. Lengkung kalibrasi digunakan untuk mengaitkan dengan kandungan air gravimetrik yang diperolehi dalam kertas turas sepadan dengan sedutan. Perbandingan SWCC yang diperoleh dari kertas turas dengan SWCC teknik perubahan paksi (Ekstrator plat tekanan). Kajian mendapati bahawa kandungan air awal dan ketumpatan mempengaruhi SWCC bagi kaolin yang padat. Walau bagaimanpun, kesan kedua kedua faktor ini lebih jelas pada sedutan yang rendah.

Kata kunci :Lengkung ciri tanah-air; pengukuran sedutan; kaolin terpadat

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1.0 INTRODUCTION

Soil mechanics cover a vast range of soil types either be saturated with water or have other fluids in the voids example air. The development of classical soil mechanics focuses on particular type of soils. Saturated sands, silts and clays, and dry sands are materials have been the emphasis in soil mechanics. However, soils consist of numerous materials whose behavior is not consistent with the principles and concepts of classical, saturated soil mechanics [1]. Commonly, soils those are unsaturated is difficult to deal with engineering practice as it is not adhere in behavior to classical, saturated soil mechanics. It is therefore, the differentiation between saturated and unsaturated soils becomes necessary.

The pore-water pressure of unsaturated soil is negative relative to the pore-air pressure and possible de-saturation. It is associated with any soil near the ground surface, present relatively arid environment. Arid and semi-arid regions are the area where the unsaturated soils occur naturally. The rate of precipitation of this area is lower than evaporation and evapotranspiration. Generally in these natural conditions, the soils in an unsaturated state are located above the ground water level. The soil immediately above the water table is called the capillary fringe. It wills remains saturated even through the pore-water pressure are negative. Usually, the soils above the capillary fringe are unsaturated condition.

Besides occurrence of unsaturated in natural soil condition, compacted soil is commonly faced unsaturated condition. Deformation, bearing capacity, slope stability and soil heaving are common problems encountered in unsaturated compacted soils. Most of these problems involves with mechanical behaviour and water retention behaviour (hydraulic behaviour). Water retention is capability of water retained (water content) in soil which may be link to soil suction. Soil suction and water content are among controlling parameters in geotechnical properties such as soil shear strength, permeability and deformability.

The relationship between water content and soil suction a known as soil water characteristic curve (SWCC). Therefore, in this study an investigation on SWCC of unsaturated compacted kaolin was conducted.

Generally, an unsaturated soil is a three-phase system containing solid, water and air phase. However, Fredlund [1] have proved that the unsaturated soil is a four phase system. The phase is included the three (soil grained, water and air) and the other phase is the interfacial surface between water and air known as a contractile skin. Basically, there are three reasons for the soil to become unsaturated such as nature process, generation of gas due to biological activities and compaction process.

The soil water characteristic curve for a soil is defined as the relationship between water content and suction of soil [2]. In soil science, volumetric water content is commonly used, in which it defined as the amount of water content within the pore of the soil. In geotechnical engineering practice, gravimetric water content, *w*, which is the ratio of the mass of water to the mass of solids, is commonly used. In addition degree of saturation, *Sr* is another term commonly used to indicate the percentage of the void that is filling with water. The above mentioned variables have also been used in normalized form where the water content are referenced to be residual water content or to become zero water content [3].

Axis translation technique via pressure plate extractor is commonly used to measure the soil water retention curve. This technique is directly controls matric suction by the increasing air pressure while maintaining pore water pressure equal to atmospheric pressure. The advantages of axis translation technique (pressure plate) such as can use more samples for the one unit of pressure plate and not sensitive for the measurement of suction.

Soil suctions also can be measured by using filter paper technique as an indirect manner. This method has many advantages such as its simplicity and low cost. Other than that, it also able to measure suctions in a wide range. The filter paper technique is reliable if the basic concepts are perfectly understood and a strictly practiced laboratory protocol is carefully followed since it is a simple and economical technique [4]. Because this method is simple and convenient it can lead to a lack of understanding of the method and thus cause improper usage.

Recent findings have emphasized that the used of filter paper in suction measurement required lot of precautions. The filter paper technique uses either non-contact or contact or both procedures. The non-contact filter paper will produce the total suction while the contact filter paper will produce the matric suction.

The influence of different compaction conditions on the SWCC with regards to the hydraulic and mechanical behaviour was investigated by previous researchers [5], [6], [7], [8], [9] and [10]. In particular, Romero *et al*. [6] and Romero and Vaunat [7] showed that the pore and the aggregate structure on the SWCC affected the compaction conditions. Furthermore, the influence of several compaction conditions (compaction water contents and dry densities) on the SWCC under various vertical stresses has been investigated on volcanic soils. The results show that the SWCC of compacted grained soil is strongly influenced by the initial water content. It is also depends on the history of drying and wetting conditions.

This study is beneficial to the researchers as a reference study in the future, towards exploring the unsaturated behaviour of Malaysian soils. The study focused on to establish the SWCC of unsaturated compacted kaolin, to compare the effect of water content during the specimen compaction on SWCC of compacted kaolin and to compare the effect of compaction energy on SWCC of unsaturated compacted kaolin.

2.0 METHODOLOGY

There are three major preliminary studies of basic soil properties tests conducted, which are particle size distribution, Atterberg limit test and compaction test. The particle size distribution conducted through dry sieving and hydrometer tests. Particle size distribution analysis and the Atterberg limit test (liquid limit and plastic limit tests) were conducted to verify the soil properties as fine grained and the degree of plasticity that can be used to interpret the SWCC of compacted kaolin. The results of the Atterberg limit test of the kaolin were liquid limit of 54%, plastic limit of 32% and the plasticity index of 23%. For particle size distribution, it was found that the kaolin had high content of silt rather than sand and clay.

2.1 Sample Preparation

The kaolin was compacted initially by using the Standard Proctor and Modified Proctor hammers. The initial water content for both samples (standard proctor and modified proctor) used was 10%, 15%, 20%, 25% and 30%. Figure 1 shows the compaction curves for both Standard and Modified Proctor test results.

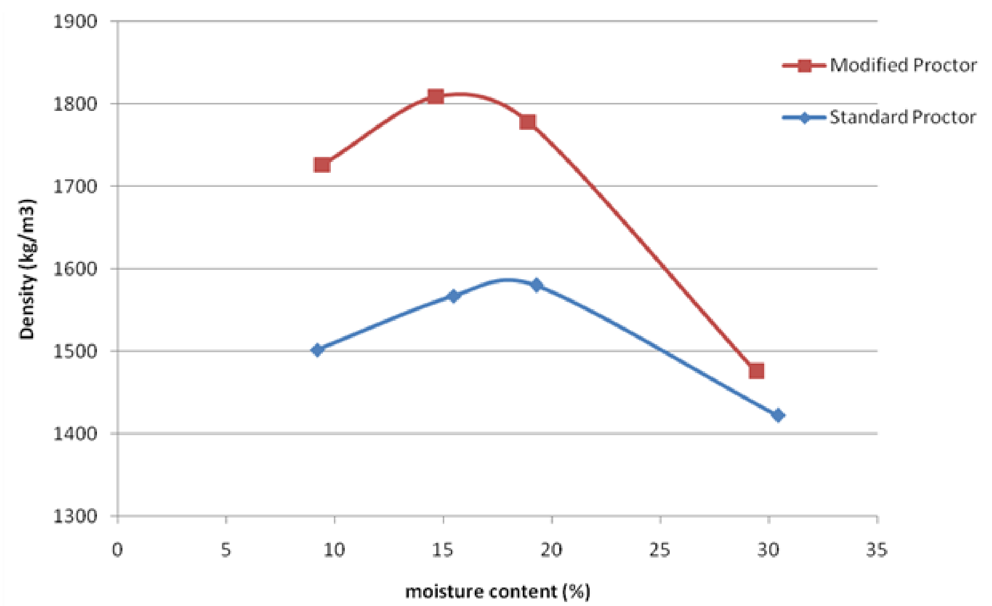

Figure 1 Compaction curve of compacted using Standard and Modified Proctor

For suction measurement through axis translation technique (pressure plate extractor), specimens used were obtained through samples cored through sample compacted in Standard Proctor. Two different sets of soil specimens with different initial water content (13% and 23%). Both set of soil specimens were compacted with the density of 1540 kg/m³. The density was selected based on 97% of maximum dry density (MDD). If possible, the specimens should be prepared at 95% to simulate the field compaction requirement but some limitations were discovered for samples at 95% of MDD. The effect of initial of water content of unsaturated compacted kaolin could be investigated through sample preparation described. After the compaction completed, samples were extruded and cored from the middle section of standard or modified proctor compacted soil cylinder. Later samples were trimmed to 50 mm diameter and 20 mm thickness. A total of 24 specimens were prepared and divide equally between both initial water content. In filter paper technique, the specimens used were obtained through samples cored through sample compacted in Standard and Modified Proctor.

Different initial water content varies from 10% to 30% were used, the sample prepared in order to investigate the effect of density or compaction energy on SWCC of compacted kaolin. Samples were cored from the middle section of standard or modified proctor compacted soil cylinder and then trimmed to 50 mm diameter and 20 mm thickness. A total of 10 specimens were prepared and divided equally between both compaction methods (Standard and Modified Proctor).

2.2 Method to Determine SWCC of Compacted Kaolin

Axis translation technique (pressure plate extractor) and filter paper technique were used to measure the suction and to establish the SWCC of compacted kaolin. Followings are further details on the method used:-

i) Axis translation technique via pressure plate extractor

The sample preparation for pressure plate test as explained in Section 3.2. The test procedure is as described in ASTM D 5298. Both set of samples with different initial water content (13% and 23%) were tested in the pressure plate apparatus in Universiti Putra Malaysia (UPM). Initially, after sample preparation the specimens were saturated for 24 hours before the specimens undergo drying path started with 2 kPa ended with 1000 kPa in pressure plate. Using the axis translation technique through pressure plate, suction was applied by increasing air pressure in the pressure plate chamber and setting up the pore water at zero (via the water outlet expose to atmosphere, water outlet must be level at the middle height of sample).

ii) Filter paper

The sample prepared for the filter paper technique was described in Section 3.1. The trimmed compacted kaolin samples were placed in air tight container with pre-caution. One should avoid specimens to be exposed samples too long to atmosphere because there is possibility the water content after compaction change rapidly. Prior to the placement of the filter papers in the container, the dry mass of filter papers should be measured. Contact and non-contact technique were used to determine the matric suction and total suction, respectively. For contact technique (matric suction) three filter paper was placed on the bottom of sample in container. However, only the middle filter paper should be measured as matric suction. While non-contact (total suction), two filter papers were required to place on top of the samples without any contact with samples. Once the specimens and the filter paper in place, the container was closed and sealed with duct tape on the lid. After 7 days, the sample may reach equilibrium state, later the mass of wet filter paper were measured. Once the water content of filter paper calculated, calibration curve was used to correlate with suction measurement.

3.0 RESULTS AND DISCUSSION

Figure 2 shows SWCC of unsaturated compacted kaolin with different initial water content during compaction. After the specimens preparation, initial saturation was conducted, then both specimens undergo drying path, samples were applied with suction of 2, 5, 10, 20, 50, 100, 500 and 1000 kPa. The result shows the specimens with higher initial water content has steeper curve compared with the specimens of lower initial water content. At lower suction, a gap can be seen between both SWCC, however as the suction reaching higher suction zone (i.e 100 kPa and above) both curves seen to converge. The occurrence corresponds with the findings by Vanapalli *et al*. [6], where the occurrence was due to the inner forces between soil aggregates that are very strong in resisting de-saturation behavior at high suction values. Apparently, water films at these suctions are so thin that all the water is within the range of influence of osmotic and adsorptive fields. Therefore, soil structure and aggregate seems to have negligible influence on the soil-water characteristic behavior in this high suction range. Therefore, it can be concluded that when suction is very high, the effect of initial water content can be ignored.

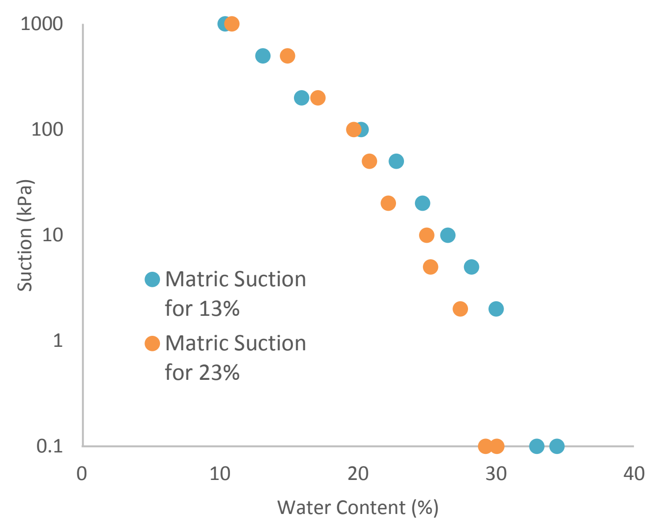

Figure 2 Water retention curves against matric suction using axis translation technique

Figure 3 shows the results of SWCC for soil specimens compacted through Standard and Modified Proctor. All the compacted samples were compacted at similar initial water content (10%, 15%, 20%, 25% and 30%) and initial water content has been labeled as Figure 3. Since, the compaction energy generated in Standard Proctor and Modified Proctor were different, this indirectly produce samples compacted at different densities. The matric suction measurement was conducted by contact filter paper technique. Figure 3 shows the effect of compaction or density on SWCC was significant at all zone of suction. However, as the suction goes higher up 5000 kPa suction, both for SWCC seems to converge.

Based on the result, the point of graph for higher suction is near or about the same but for the lower suction the point of graph is very far. In agreement to Vanapalli *et al*. [6] it is assumed that for the Lias-clay tested at water content lower than the described threshold boundary. It is due to the water films that are so thin, the absorptive and osmotic force, in comparison to the capillary forces, which are decisive for the soil suction. It can be concluded that the micro-pores structure is affected by the compaction water content. In addition, the initial conditions have no significant influence on the identified soil suction in the high suction range.

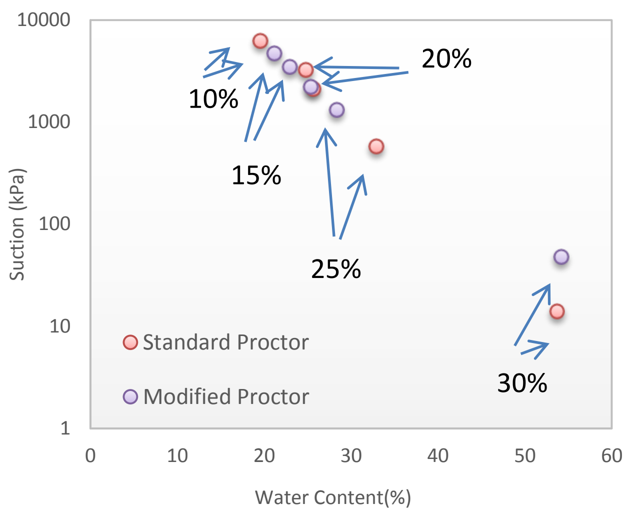

Figure 3 Water retention curves against matric suction using filter paper technique for specimens prepared using Standard and Modified Proctor method

Figure 4 shows comparison of SWCC between filter paper using different calibration curves and also SWCC establish by pressure plate. Overall the shape of SWCC with different calibration curve of filter paper used mostly similar but on lower suction zone significant difference was identified. The comparison between all SWCC of filter paper curve with different calibration curves shown SWCC established from axis translation technique did not superimpose with others.

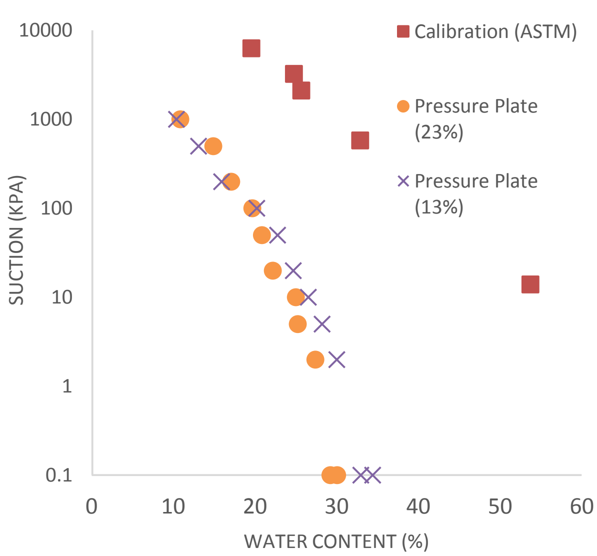

Figure 4 Matric suction curve for Standard Proctor specimen of filter paper technique and Standard Proctor specimen of axis translation technique for two different initial water contents compared to ASTM calibration curve

There are possibility that the results obtained from filter paper technique were not done in a correct manner which resulted a big gap difference between SWCC obtained from the pressure plate and that of the filter paper technique. However, without sufficient data at the zone where water content between 35% to 50%, it is difficult to conclude the possibilities of errors in filter paper technique. Besides that the initial condition between both samples used in filter paper and pressure plate were different.

To ensure the possibility of errors come from the filter paper, it would be good if the research could be expanded by full investigation of effect of initial water content using filter paper. Besides that, adding modified proctor samples to investigate the effect of density using pressure plate on unsaturated compacted kaolin will strengthen the research findings.

4.0 CONCLUSION

In this paper, the measurements of suction for unsaturated compacted kaolin using axis translation technique (pressure plate extractor) and the filter paper technique and SWCC of unsaturated compacted kaolin have been presented. The conclusions were as follows:

1. It was found that the samples with higher initial water content has steeper curve compared with lower initial water content.
2. At lower suction, a gap can be seen between both SWCC, however as the suction reaching higher suction, both curves seen to converge.
3. The initial water content had higher effect on SWCC at lower suction. The effect of compaction energy or density on SWCC on unsaturated compacted kaolin could clear be found at lower suction zone, the curves for standard and modified proctor samples were big at lower suction but converge as the suction increase. A significant combined effect of initial water content and density can clearly been seen at lower suction

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