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Soil Water Characteristic Curve for Unsaturated Soils from Sudan

E. O. Ahmed[1], A. M. Elsharief[2], and A. M. Zein[3]

[1]*PhD Canidate, Building and Road Research Institute, University of Khartoum.*

[2]*Professor, Building and Road Research Institute, University of Khartoum.*

[3]*Associate Professor, Building and Road Research Institute, University of Khartoum.*

**Corresponding author. eoahmed@yahoo.com*

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Abstract. This paper reviews current research being conducted by various researchers on suction moisture content relationships for unsaturated soils from Sudan, with special emphasis on the highly plastic swelling clays from central and eastern clay plains of Sudan. Data was collected for soil water characteristic Curve (SWCC) for clay (CH) samples from central, eastern, and southern clay plains of Sudan. Due to their inherent high suction, the filter paper method was used. Suction values higher than 10 MPa were measured for the highly plastic clays. A trend of linear relationship was obtained between air entry values (AEV) and plastic limit and AEV and liquid limit.

Keywords. Unsaturated soil, Suction, SWCC.

INTRODUCTION

Sudan lies in the tropical and semi-tropical climatic zone. Most of the soils are unsaturated due to the short rainy season, long summer, deep groundwater, and presence of clayey layers at the upper horizons.The unsaturated soil mechanics research in Sudan is dated back to the early 80th of the last century (Zein, 1985).

The clays from central Sudan exhibit higher suction values in order of 10 MPa (Elsharief, 1987).

The Soil water characteristic curve (SWCC) has been used extensively in agronomical and agricultural research as well as by geotechnical engineers, many International scholars had excreted well-recognized research efforts in characterization and modeling the SWCC in geotechnical research and applications (Brooks, 1965; Mualem, 1976).

The current paper reviews the available research efforts carried out by national scholars in the characterization of unsaturated soils via constructing SWCC for clayey soils collected from eastern, central, and southern parts of Sudan. Attempts are made to relate parameters derived from the SWCC with measured engineering soil properties.

LITERATURE REVIEW

Soil Suction Measurements

The behavior of unsaturated soil is highly dependent on the magnitude of soil suction, which in turn is influenced by soil water content for a given soil. Suction moisture content relationships for unsaturated soils require the measurement of soil suction and relating it to the degree of saturation, volumetric water content, and gravimetric water content. Measurement of soil suction (matric or total) could be carried out using direct or indirect methods.

The direct measurement techniques rely on the direct observation of the pore water pressure, whereas the indirect methods involve the measurement of soil properties that are directly related to suction through calibration with known values of suction i.e. relative humidity, resistivity, and water content.

Comprehensive descriptions of measurement methods are available in the literature) (Ridley and Wray, 1996). The indirect methods include filter paper, transistor and thermocouple psychrometers, thermal conductivity sensor, and electrical conductivity sensor whereas the direct methods include a pressure plate, pressure membrane, tensiometers, high suction probes, and null-type axis-translation (Ridley and Wray, 1995; Ridley and Burland, 1993). Among these methods, the conventional filter paper and pressure plate apparatus are the most commonly used methods.

The Filter Paper method

The filter paper (FP) method was developed by soil scientists and agronomists for measuring soil suction (Gardner, 1937).

The use of FP in geotechnical fields is well recognized (Leong and Rahardjo, 2002.). The filter paper method is an inexpensive and relatively simple laboratory test method, from which both total and matric suction measurements of soils are possible. It is highly dependent on the performance, speed of the operator, and calibration curves used. The calibration curve depends on the suction source, time to equilibrium, and hysteresis.

The working principle of FP is that if a soil specimen and filter paper are sealed in a closed container, moisture exchange will take place until equilibrium is reached. When the soil specimen and the filter paper are separated from each other, moisture transfer takes place via vapor transfer, and hence total suction can be measured.

Matric suction is measured if the soil specimen is in direct contact with the filter paper. In this case, the filter paper absorbs water through liquid flow. Schleicher and Schuell No. 589 and Whatman No. 42 are the most commonly used types of filter paper (ASTM, 2016) with detailed procedures for total suction (contact FP) and matric suction (non-contact FP) measurements.

Soil-Water Characteristic Curve (SWCC)

The soil-water characteristic curve (SWCC) can be defined as the relationship between suction and gravimetric water content, degree of saturation, or volumetric water content in unsaturated soils. It can be viewed as a continuous sigmoid function describing the water storage capacity of soil as it is subjected to various soil suctions (Ridley and Wray, 1995). For the highly plastic clays and clays with fine-grained materials, a much greater amount of pore water is required to satisfy the relatively large surface hydration energies associated with the high suction.

In the coarse-grained soils and soils will the little number of fines, very little water is absorbed under initial surface hydration mechanisms and capillary effects dominate over the majority of the unsaturated moisture content range.

Features of SWCC

Soil Water Characteristic curve is stress path-dependent, i.e. the curves established with drying differs greatly from those established with wetted samples. The difference between the drying curves and wetted ones is a result of soil hysteresis. Hysteresis is caused by several factors, such as non-uniformity of pores, changes in the contact angle during drying and wetting, entrapped air in the voids, and the development of air-water interface during the drying or wetting processes (Hillel, 1982).

The shape of the SWCC depends upon the pore size distribution and volume change of the soil. Both of these two characteristics are affected by the initial water content, soil structure, soil type, compaction effort, and stress history.

The key parameters used to define the SWCC are the air-entry suction value (AEV) and the residual water content. The AEV of the soil can be defined as the value of suction at which the air starts to enter the largest pores in the soil.

The residual water content can be defined as the water content where a large suction change is required to remove the additional water from the soil. A typical SWCC exhibits different zones along the drying curve.

Three zones of desaturation have been defined in figure 1 (Vanapalli et al., 1999; Likos and Lu, 2002.); namely, the saturation zone where almost all the soil pores are filled with water and the soil remains saturated, the desaturation zone (transition zone) where the soil starts to desaturate and the water content or degree of saturation reduces significantly with increase in suction and the residual zone where a large increase in suction lead to relatively small changes in soil water content or degree of saturation and characterized by a discontinuous water phase. The water content of soil at the residual zone is generally referred to as residual water content.

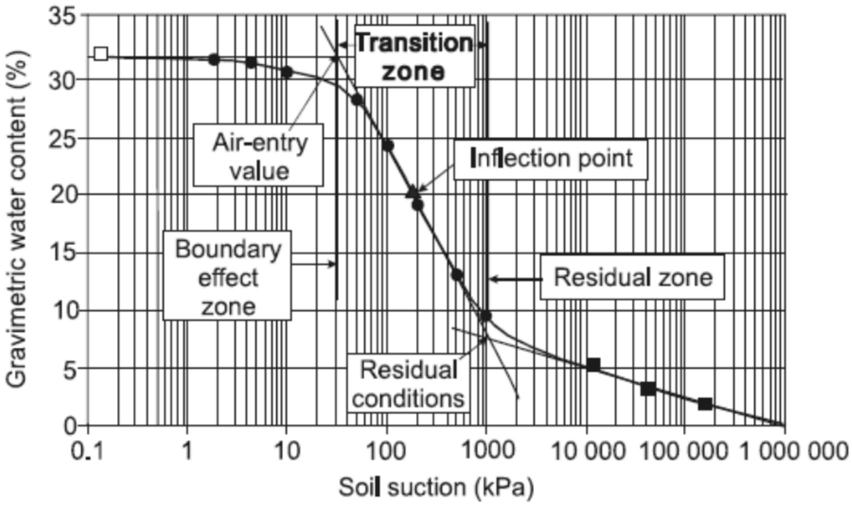

Fig.1. Typical SWCC and Identifiable zones (Vanapalli et al., 1999).

Factors influencing the SWCC

The shape of the SWCC is highly dependent on the pore size distribution and volume change of the soil (Ridley and Wray, 1995; Gens et al., 1995). The size of pores and their distribution is dependent on the soil particle orientation, which is governed by the initial moisture content. The particle orientation at dry of optimum leads to soil fabric that has more interconnected pores compared to wet of optimum (Mitchell et al., 1965; Yang et al., 2004).

The effect of initial compaction water content is clearer for the near saturation portion in the SWCC in which capillary forces are present. At high suction, SWCCs with different initial water contents tend to converge (Vanapalli et al., 1999).
Researchers have different assessments on the effect of density on SWCC. Some of them tend to assume the minimum effect of density variation on SWCC, whereas others advocate that soil dry density has a remarkable effect on SWCC because density is a function of the pore sizes and soil structure (Yang et al., 2004).

Determination of air-entry value (AEV) and residual suction

Atypical SWCC of unsaturated soil is given in figure 1. The procedure for the determination of AEV and residual suction involves first drawing a line tangent to the curve through the inflection point on the straight-line portion of the SWCC. The air entry value of the soil is obtained by extending the constant slope portion of the SWCC to intersect to the line representing the SWCC in the low suction range (Vanapalli et al., 1999).
In case of desaturation, the point remains close to the plastic limit, the suction corresponding to the plastic limit may be considered as the AEV (Fredlund et al., 2011).
The residual degree of saturation can be defined at the intersection of the tangent line and the extended line representing the SWCC in the high suction range. The suction corresponding to the shrinkage limit of clay could be the residual suction (Fleureau et al., 1993). However, the soil may de-saturate prior to the shrinkage limit, hence the shrinkage limit may well differ from the air entry water content.

SWCC from previous works

The current paper summarized and combines the work of several national authors, who attempted to measure or determine SWCC of swelling unsaturated soils of Sudan. The suction measurements (mainly matric) were carried out for samples from different parts of Sudan using the filter paper method.

Physical Properties of tested clayey soils

Data was collected for ten high plastic potentially expansive soil samples. The physical index properties for the tested clay soils are summarized in table 1with their corresponding references and the sample locations.

The Soil water characteristic curves for the tested soils are presented in figure 2

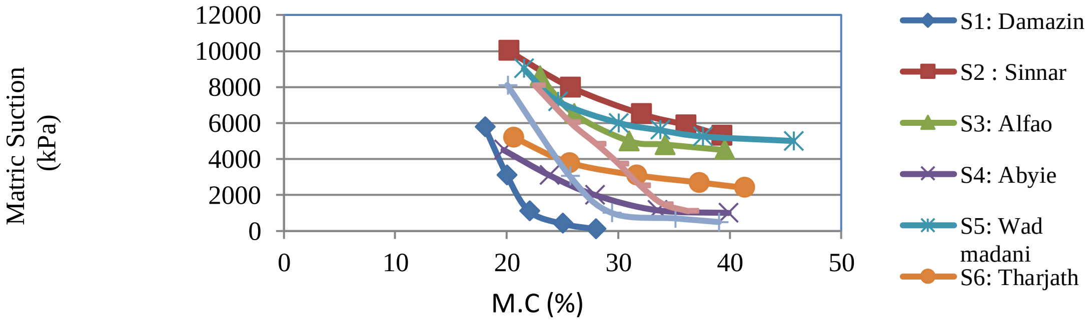

Fig. 2. SWCC for tested soils from different parts of Sudan.

Table1. Summary of physical properties of swelling Soils characterized by national researchers.

Soil No	Reference	Location	Soil Properties					Activity	OMC %	MDD gm/cm^3
			L.L %	P.L %	P.I %	Fine Content %	Clay Content %			
S1	[20]	Aldamazien	55	26	29	73	48	0.604	22	1.48
S2	[21]	White Nile	62	28	34	77	42	0.809	23	1.46
S3	[21]	Alfao	70	30	40	81	58	0.69	25	1.44
S4	[21]	Tharjath	50	19	31	74	40	0.775	23	1.46
S5	[21]	Wad madani	64	31	33	76	65	0.508	23	1.46
S6	[21]	Sinnar	76	30	46	86	38	0.83	26	1.42
S7	[21]	Abyie	49	23	26	71	15	1.73	21	1.48
S8	[22]	Alfao	66	29	37	79	24	1.542	24.3	1.43

The air entry suction and residual suction values were obtained following the graphical procedures recommended by Vanapalli et al. (1999).

RESULTS AND DISCUSSION

Suction values reported by Sofyan (2013) and Elsharief et al. (2013), for Alfao soil were consistent with values reported by Elsharief (1987).

The suction values corresponding to the optimum moisture content and plastic limit are generally higher than the air entry value for soils under consideration, which reflects that soils at optimum moisture are too far from saturation.

The relationship between the plasticity index and the air entry suction is plotted in figure 3. The plotted data showed a trend of linear direct relationship between AEV and Plasticity index (P.I). Air entry value tends to increase linearly with the plasticity index.

The relationship between the liquid limit and the air entry suction is plotted in figure 4. The plotted data has shown a linear trend, as the liquid limit increases the air entry value increases.

The relationship between Activity and the air entry suction is plotted in figure 5. Plotted data shows a scattered pattern.

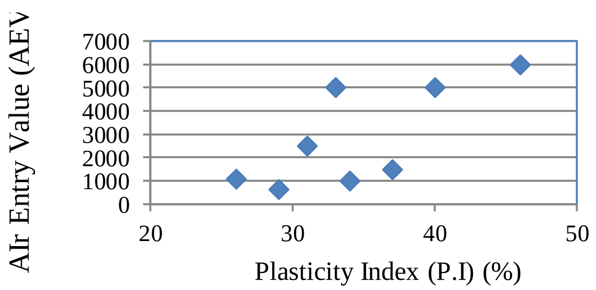

Fig.3. The plasticity Index versus Air Entry Value.

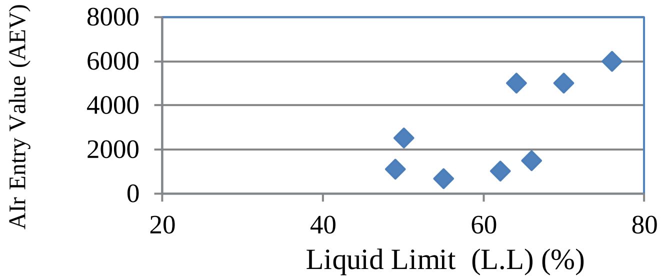

Fig.4. The liquid limit (L.L %) versus Air Entry Value (AEV).

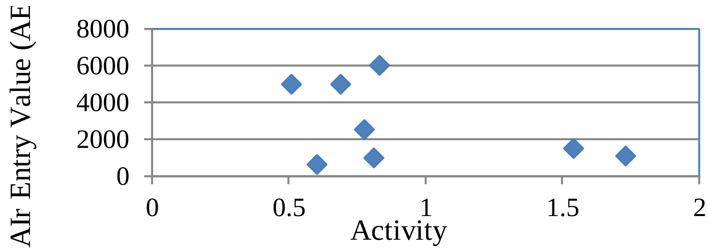

Fig.5. Activity versus air entry value (AEV).

CONCLUSION

This paper summarizes the available SWCC data for highly plastic swelling clay Soils from Sudan. Due to limited suction measurement capabilities in Sudan and the inherent high suction of the tested specimens, the Filter Paper method (FP) is the most widely used method for measurement of soil suction. The data showed high suction values of tested soil (S2,S3, S5, S6, and S8) in their dry conditions. The trend of linear relationship was found between the air entry value and plasticity index, and Air Entry Value and Liquid Limit; the poor relationship was found between air entry and activity. The suction values corresponding to the optimum moisture content and plastic are generally higher than the air entry value for soils under consideration, which reflects that soils at optimum moisture and plastic limit are still too far from saturation. The measurement tools and methods of testing need to be improved. More efforts are needed to characterize the unsaturated highly plastic clay soils of Sudan with a special focus on their mineralogical properties, swelling, shear strength, and compressibility behavior in unsaturated conditions.

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