CHARACTERIZATION OF SOME UNSATURATED SWELLING SOILS FROM SUDAN

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Résumé

La vaste plaine argileuse du Soudan contient des argiles non saturées sévèrement déshydratées. Aux fins de la caractérisation de ces sols, les premières recherches ont combiné avec succès les propriétés intrinsèques du sol avec les critères de placement du sol. Récemment, la courbe caractéristique de l'eau du sol (SWCC) a été utilisée pour décrire ces sols. La méthode du papier filtre (FP) a été utilisée pour mesurer la succion matricielle en raison de la forte succion que les argiles hautement plastiques présentent par nature. Des valeurs de succion supérieures à 10 MPa ont été mesurées pour les argiles du centre du Soudan. Les paramètres de la courbe caractéristique de l'eau du sol (SWCC), y compris la succion d'entrée d'air et la succion, sont influencés par la plasticité, la concentration de particules et la minéralogie. Il a été constaté que la succion d'entrée d'air a une très bonne relation avec la valeur de succion à la limite plastique.

Mots - clés: sols non saturés, succion matricielle, courbe caractéristique de l'eau du sol, valeur d'entrée d'air

Abstract

The vast clay plains of Sudan are dominated by severely desiccated highly plastic unsaturated clays. For better understanding of the engineering behavior of these soils simple characterization techniques and methods are needed. This paper combines and reviews the methods used for characterization of the highly plastic soils of the clay plains of Sudan for better understanding of their volume change behavior and strength. Early research used combinations of intrinsic soil properties and soil placement factors to successfully characterize them. Recently Soil Water Characteristic Curve (SWCC) has been used for their characterization. The filter paper (FP) method was used to measure the matric suction because of the high suction values they exhibit by nature. Suction values greater than 10 MPa have been reported for clays from central Sudan. The soil-water characteristic curve (SWCC) parameters including air entry suction and residual suction were extracted from the data. It has been found that air entry suction has a very good relationship with the suction value at the plastic limit.

Keywords: Unsaturated Soils, Matric Suction, Soil Water Characteristic Curve, Air Entry suction

1-Introduction

Research efforts have been exerted in Sudan, since the seventies of the 20th century, to understand the behavior of the unsaturated highly plastic and highly desiccated clay soils which cover large plains in Central, Eastern and Southern Sudan. Efforts have been made to characterize these soils and determine simple parameters which could predict their swelling potential, compressibility and strength [1][2]. Current research has shown that soil water characteristic curves (SWCC) can be utilized to investigate the coupled hydro mechanical behavior of unsaturated soils. The importance of SWCC in understanding unsaturated soil behavior is highlighted [3][4]; SWCC is becoming increasingly common in engineering applications around the world. Many international scholars have generated well-known research efforts in the characterization and modeling of the SWCC in geotechnical research and applications [5][6].

This paper summarizes the out come of some research efforts carried out on unsaturated clay soils from Sudan. Early efforts combined soil intrisic and exrinsic parameters for characterization of the highly plastic soils. Special emphasis is given in this paper to the use of SWCC for characterizing these soils. SWCC data was collected for soils from different parts of the clay plains of Sudan. The data is analyzed and discussed**.**

2.0 Review of the Early Previous Research

2.1 Soil Intrinsic Properties and Placement Factors

The behavior of clayey soils in their unsaturated conditions is influenced by compositional 'intrinsic" factors such as mineralogy, clay content, gradation and pore water chemistry and environmental or placement factors such as water content (m.c), dry density (γd), soil structure, stress history and temperature [9]. Several soil parameters have been used to characterize unsaturated soils in order to predict their behavior in terms of swelling, compressibility and shear strength. Parameters combining intrinsic properties and placement factors such as liquidity index (L.I) and consistency index (C.I) were introduced long time ago [7].

$$L.I = \frac{(M.C-P.L)}{P.I} \qquad (1)$$

$$C.I = \frac{(L.L-M.C)}{P.I} \qquad (2)$$

Where m.c is moisture content and PI is plasticity index and L.L is liquid limit P.L is plastic limit. Liquidity index is an indirect indicator of desiccation. Negative L.I values are indicator of m.c< PL and consequently higher desiccation. A new factor, termed H facor was established by Elsharief et al [7] It is given by the following relationship**:**

$$H = \frac{(C.I * \gamma d)}{P.I} \qquad (3)$$

When m.c equals PL, H equals γd and when M.C equals L.L, H goes to zero. H is plotted against L.I for data of undisturbed natural upper crest clayey soils from Khartoum and good relationship was established; the dry density of the natural desiccated clays could be estimated when the Atterberg limits and natural moisture content are known. This deduction implies that the densification of the investigated upper clay crust in its depositional environment could be attributed to desiccation rather than the action of overburden [7].

A study on the factors influencing the strength of compacted unsaturated clay soils used for construction of the embankments of Roseires dam in Sudan [8]; has shown that the unconfind strength of the compacted soils is well related to m.c/PI as presented in Figure 1 below.

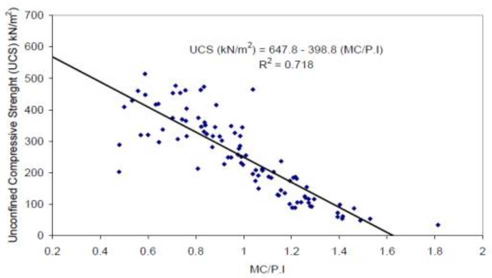

Fig. 1: Unconfind strength versus m.c/PI for compacted highly plastic soils of Damazin [9]

An other factor combining the intrinsic properties and placement factors was introduced for prediction of swelling pressure of two soils from Central Sudan [9]. The factor termed Fc is given by

$$FC = C.I * \left(\frac{\gamma d}{\gamma w}\right) * e \qquad (4)$$

Where γw is the density of water and e is void ratio of the soil. Very good relationship was found between swelling pressure and Fc as shown in Figure 2.

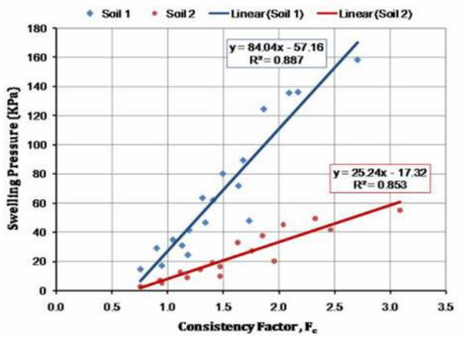

Fig. 2: Swelling Pressure versus consistency factor Fc for two clay soils from Sudan [12]

2.2 Soil-Water Characteristic Curve (SWCC)

The soil-water characteristic curve is the connection between suction and gravimetric water content, degree of saturation, or volumetric water content in unsaturated soils (SWCC). It is a continuous sigmoid function that describes a soil's water storageability as a function of soil suction [10]. Soil Water Characteristic curve is stress path dependent, i.e. the curves established with drying path is differ from that of wetting path. The shape of the SWCC is influenced by the soil's pore size distribution, volume change, the initial water content, soil structure, soil condition, compaction effort, and stress history. The air-entry suction value (AEV) and residual water content are the two main parameters used to describe the SWCC. The AEV of the soil is known as the suction value at which air begins to reach the soil's largest pores. The residual water content is the water content at which significant suction change is needed to remove the excess water from the soil. Along the drying curve of a standard SWCC, various zones can be seen. Figure 3 illustrates three areas of desaturation [10]&[11]; specifically, the saturation region, where nearly all of the soil pores are filled with water and the soil remains saturated; the desaturation zone (transition zone), in which the soil begins to desaturation and the water content or degree of saturation decreases dramatically as suction increases , and the residual region, which is characterized by a discontinuous water period and is characterized by a significant increase in suction resulting in relatively minor changes in soil water content or degree of saturation. Residual water content refers to the amount of water in the soil at the residual region.

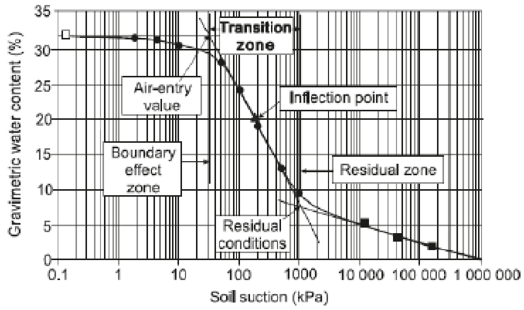

Fig.3 : Typical SWCC and Identifiable zones [11]

2.3 Factors influencing the SWCC

The pore size distribution and volume change of the soil have a major impact on the form of the SWCC [10], and [14]. The size and distribution of pores are determined by the orientation of soil particles, which is determined by the initial moisture content. In comparison to the wet of optimum, particle orientation at dry of optimum results in a soil fabric with more interconnected pores [11],[15], and [16]. For the near saturation portion of the SWCC where capillary forces are present, the impact of initial compaction water content is more obvious. SWCCs with different initial water contents appear to converge at high suction [11]. The impact of density on SWCC is reviewed differently by researchers. Since density is a function of pore sizes and soil structure, some of them believe that density variation has little effect on SWCC, while others argue that soil dry density has a significant impact on SWCC [11].

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

Figure 3 shows an example of a typical SWCC of unsaturated soil. Drawing a line tangent to the curve through the inflection point on the straight line portion of the SWCC to determine AEV and residual suction is the first step. Extending the constant slope section of the SWCC to intersect with the line reflecting the SWCC in the low suction zone yields the soil's air entry suction[11]. The suction corresponding to the plastic limit can be called the AEV if the desaturation point remains close to it [11]. The tangent line and the extended line reflecting the SWCC in the high suction range converge to determine the residual degree of saturation. The residual suction may be the suction corresponding to the clay shrinkage limit [6]. However since soil may dehydrate before reaching the shrinkage limit, the shrinkage limit can vary significantly from the water content of the air entry suction.

3. Materials Used and Methods of Testing

The current paper summarized the work done by several national scholars [17, 18, 19, and 20] on swelling clayey soils of Sudan, the filter paper method was used for matric suction measurements since it is the available one; although it is time consuming and costly. Samples from different part of Sudan were collected and SWCC were presented in Fig 4. The physical and placement parameters were determined for the selected samples, Table 1 summarized some of the test results for the collected samples.

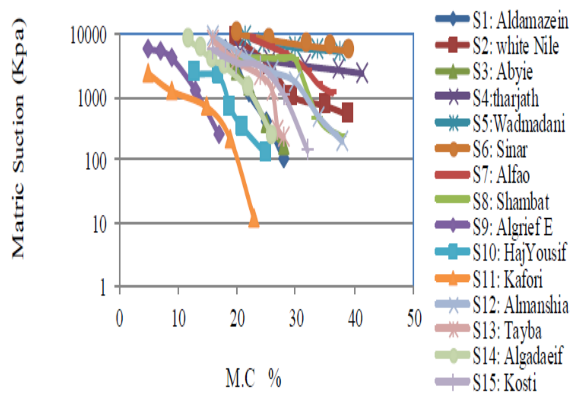

Fig. 4 : SWCC for the Clayey Soils [17, 18, 19, and 20]

Table.1 : Basic Physical Properties of Characterized Clayey Soils

Soil No	Source	Location	Soil Properties				
			L.L (%)	P.L (%)	P.I (%)	OMC (%)	MDD (g/cm^3)
S1	[17]	Aldamazeein	55	26	29	22	1.48
S2	[18]	white Nile	62	28	34	23	1.46
S3	[18]	Tharjath	50	19	31	23	1.46
S4	[18]	Wad madani	64	31	33	23	1.46
S5	[18]	Sinar	76	30	46	26	1.42
S6	[18]	Abyie	49	23	26	21	1.48
S7	[19]	Alfao	66	29	37	24.3	1.43
S8	[20]	Shambat	58	38	20	--	---
S9	[20]	Algraif East	33	17	16	--	---
S10	[20]	HajYousif	41	21	20	16.28	1.72
S11	[20]	Kafori	29	19	10	16.91	1.75
S12	[20]	Almanshia	72	30	42	25.96	1.42
S13	[20]	Tayba y	38	22	16	16	1.66
S14	[20]	Algarief	42	26	16	---	--
S15	[20]	Kosti	55	28	27	28.27	1.45

4. Discussion of the Results

The relationship between plasticity index (PI) and air entry suction is plotted in Fig. 5 The plotted data showed trend of increase of AEV with increase in PI. An exponential relationship between AEV and Plasticity index (P.I) could be observed. Air entry suction tends to increase with plasticity index for PI values greater than 25.

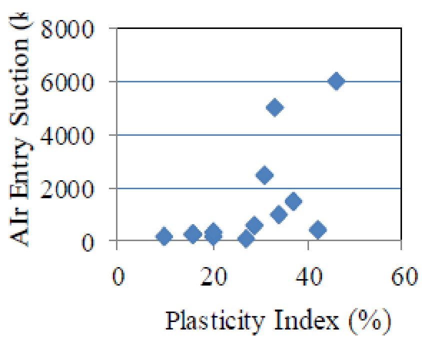

Fig. 5 : The plasticity Index (P. I %) versus Air Entry suction (AEV)

The relationship between liquid limit and the air entry suction is plotted in Fig. 6. The plotted data has shown nearly a trend similar to the relationship of AEV with plasticity index; as the liquid limit increases the air entry suction increases too. The increase is pronounced for LL >50. Figure 5 and Figure 6 shows very low AEV for low plastic clays (LL<50 and PI <25). Air entry values increase almost exponetially with increase in PI and LL for highly plastic clays.

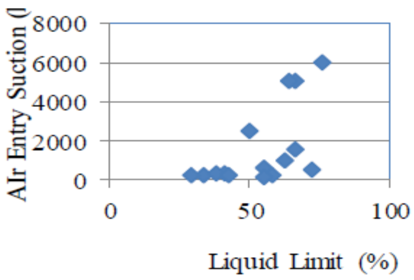

Fig. 6 : The liquid limit (L.L %) versus Air Entry suction

The relationship between the air entry suction value and the suction values at plastic limit for the tested soils is plotted in Fig. 7. The plotted data has shown exponential trend with very good relationship (R^2=0.827); so as the air entry suction increases the suction at plastic limit increases, and vice versa.

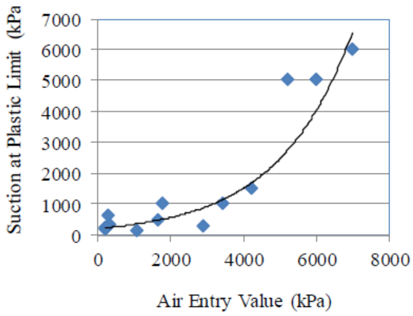

Fig. 7 : Air Entry suction versus suction at plastic limit

The relationship between suction at plastic limit ΨLP (kPa) and Air Entry suction ΨAE (kPa)

$$\Psi(LP) = 213.5\, e^{0.0005\,(\Psi(AE))} \quad : R2{=}0.827$$

5. Conclusion

- This paper summarizes the early research carried out for characterization of unsaturated clay soils from Sudan carried out by national scholars using intrinsic soil properties, placement factors and combination of them. It also summarizes the recent work of characterizing plastic soils using soil suction.

- Combinations of intrrisic soil properties (LL, PI) and soil placement factors (m.c., void ratio and dry density) were successfully used to predict the strength and swelling characteristics of natural and compacted soils.

- Using the developed combined parameters, the dry density of natural desiccated clays could be estimated when the Atterberg limits and natural moisture content are known. This implies that the densification of the upper clay crust in its depositional environment could be attributed to desiccation rather than the action of overburden.

- The data collected were used to re-construct soil water characteristic curve (SWCC) in order to obtain parameters such as air entry suction values (AEV).

- Trends of exponential relationship was found between the air entry suction and plasticity index, and AEV and Liquid Limit for highly plastic soils.

- Very good relationship was found between air entry suction and suction at plastic limit.

- for a better understanding and characterizing the Sudanese soils, the measurement tools and method of soil suction testing needed to be improved;

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