Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Effect of High Suction Measurement Technique on the SWCC of Expansive Soil

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Abstract. The determination of soil water characteristics curve (SWCC) for any particular soil is very essential to understand the suction variation or negative pore water changes with drying or wetting and to obtain the unsaturated soil property functions accurately. In this study, SWCC of three different types of expansive soil with liquid limit ranging from 300-500% were measured using two different techniques namely dew point potentiometer (WP4) and Relative humidity sensor (RHS). Based on the measured result, the influence of the two measuring device on SWCC was quantified for different qualities of expansive soils. It was observed that the suction measured using WP4 technique corresponds to only the desaturation portion of the WRCC. The near saturation portion and the residual portion were not clear from the measured plots. The result obtained from the RHS corresponds to very low water content as compared to WP4 technique and gives almost a straight line path while a non-linear trend was obtained for WP4 measurement. So, it is difficult to conclude which part of the WRCC corresponds to the RHS results. This aspect was studied by plotting the WP4 and RHS results together. It was found that the RHS results falls in the residual portion of the WRCC. Both the results merge exactly at higher suction above 10^4 kPa. So, it was seen that both WP4 and RHS results were essential to obtain the WRCC of expansive soil and the combination of these two results will help to obtain desaturation and residual part clearly. The SWCC Fitting parameters of Fredlund and Xing (1994) and Van-Genuchten (1980) models were obtained using the experimentally obtained data for both WP4, RHS and combined WP4+RHS and the possible variation was studied.

Keywords: WP4 dew point potentiometer, Relative humidity sensor; SWCC, Expansive soils

1 Introduction

The determination of soil water characteristics curve or SWCC for any particular soil is very essential to understand the suction variation or negative pore water changes with drying or wetting. It is very important to determine the SWCC so as to obtain the unsaturated soil property functions accurately [1, 2, 3]. However it has been found in the literature that different factors such as compaction state, water content, soil types, suction measuring technique etc. effects the SWCC behavior of a soil [4, 5]. These factors particularly the selection of appropriate suction measurement device suitable for the soil should be considered and taken in to consideration for obtaining its SWCC. For a sandy soil, a low range of suction measurement device is sufficient to measure the whole range of suction while for a clayey soil a high suction range measuring device is required to record the whole range of suction or sometimes more than one instrument need to be used [6, 7]. Another important factor which make the determination of SWCC for clayey soil is its volume change property. Clayey soil like bentonite which is very rich in montmorillonite mineral undergoes severe cracking when drying occurs. So, the use of direct suction measurement instrument in this soil is not suitable as the soil will loses its contact from the sensor [8, 9. So, for this type of soil indirect suction measurement technique is always preferred. There are few studies available in the literature which investigated the suitability of different indirect suction measurement technique for clayey soil having liquid limit of below 100% [10, 11, 12]. But there are little studies available on the comparison of indirect suction measurement technique for high clayey soil like bentonite with liquid limit range of more than 300%.

Thus the main objective of this study was to investigate two indirect suction measurement devices namely WP4 dew point potentiameter (WP4) and Relative humidity sensor (RH) for obtaining the SWCC of three different qualities of bentonite with liquid limit in the range of 300-500%. Based on the measured result, the influence of the two measuring device will be quantified for different ranges of bentonite. Also comparison of SWCC of the three bentonites will be carried out for each of the two devices.

2 Materials and Methods

The materials used in this study consist of three commercially purchased expansive soil having high liquid limit. These are designated as ES1, ES2 and ES3 in this study. All the soils have characterized for determining its physical and geotechnical properties as given in Table 1 below. These sample were used then used for the suction measurement using two high suction measuring devices WP4 dew point potentiameter and RH sensor.

The WP4 dew point potentiometer (Decagon services, USA), as shown in Fig. 1 has been used to measure total soil suction, ψ. The instrument works on the principle of chilled-mirror dew point technique [12, 13]. It essentially consists of a sealed block chamber in which the soil sample can be placed in a 15 cc Polyurethane sampling cup. The relationship between the total suction, ψ, and the vapour pressure of air in the headspace of the block chamber can be expressed with the help of Kelvin's equation shown in Eq. 1[14:

$$\psi = \frac{R.T}{\chi} \ln\left(\frac{p}{p_o}\right) \qquad (1)$$

where, R is the universal gas constant (=8.31 J/mol.K), T is the temperature of the sample in K, χ is the molecular mass of water (=18), p is the vapour pressure of air and p_0 is the saturation vapour pressure. The block chamber (Fig. 1) consists of a mirror, dew point sensor, which is a photoelectric cell, a temperature sensor, which is a thermocouple, an infrared thermometer (optical sensor) and a fan. The dew point sensor detects the dew formation on the mirror, the temperature sensor measures the dew point temperature of the air and the infrared thermometer measures the temperature of the sample. The soil specimen placed in the PVC cup is equilibrated with the air in the headspace of the sealed block chamber for its relative humidity. At equilibrium, the water potential of air in the chamber is same as the water potential or suction of the sample, which occurs within 5 to 15 min. The fan enables to speed up the equilibration of the sample with the chamber environment. With the help of the built-in software, the suction of the soil sample, in MPa and pF, is displayed on the LCD panel along with the temperature of the sample.

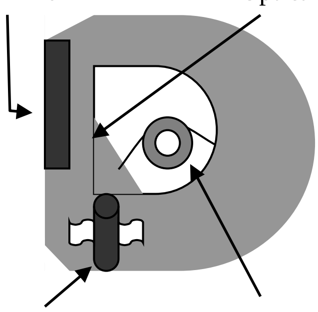

Fig. 1. WP4 dew point potentiameter device with the block chamber.

The RH sensor with the readout unit is shown in Fig. 2 below. In this method, required amount of oven dried soil sample was taken and was mixed properly with the required amount of distilled water before it was put in the desiccator for 24 hrs of maturation. A 38mm diameter and 75-80mm height compacted sample was prepared. The test setup consists of an air tight Teflon mould that houses the relative humidity sensor, a specimen holder and a readout unit. The relative humidity sensor measures the RH and temperature of the air surrounding it. The soil sample of about 10 mm thickness was placed in the specimen holder and the mould is sealed off. The relative humidity and temperature readings from the readout unit were noted at regular intervals of time for the next 3 days. It was known from the calibration process of the RH sensor that a minimum period of 3 days is required for the equilibration of air surrounding the RH sensor. The soil samples were removed from the mould after day 3 and oven dried for moisture content determination. Kelvin's equation was used for the determination of total suction values.

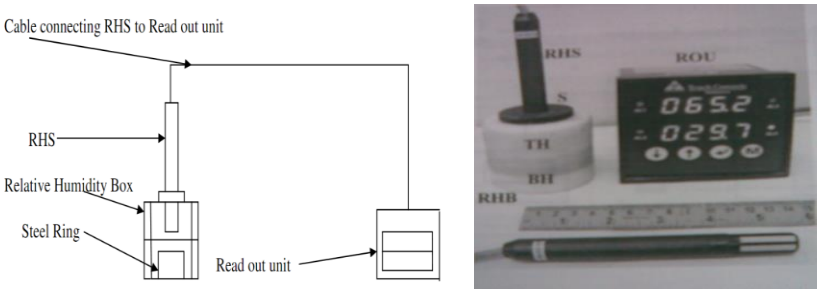

Fig. 2. Relative humidity sensor (a) Schematic diagram; (b) RH sensor with readout unit.

Table 1. Physical and Geotechnical properties of Expansive soils.

Prpoerty	ES1	ES2	ES3
Specific gravity(G)	2.71	2.73	2.74
Particle size characteristics in %			
Coarse sand (4.75-2mm)	0	0	0
Medium sand (2-0.425mm)	0	0	0
Fine sand (0.425-0.075mm)	2	4	1
Silt size (0.075-0.002mm)	32	38	40
Clay size (<0.002mm)	66	58	59
Atterbergs' limit (%):			
Liquid limit	300	433	244
Plastic limit	51	54	60
Plasticity index	249	379	184
Classification	CH	CH	CH

3 Results and Discussion

3.1 SWCC of expansive soil obtained using WP4

In Fig. 3, the SWCC obtained using the WP4 device for the three expansive soils ES1, ES2, ES3 and ES3 are shown. The samples were prepared at higher water content close to its liquid limit (LL) for getting a low suction value during the initial stages of measurement. This will help in getting the slope of desaturation portion more precisely. As seen in Fig. 3, the WRCC of ES1 consists of the desaturation portion and residual portion only. For ES1, the desaturation portion starts from 300 kPa to 10^4 kPa of suction corresponding to a water content of W= 300% to 25 % respectively. Above 10^4 kPa, there is no further change in water content and the sample attains its residual state completely. This is because at the initial stage of measurement due to very high water content present in the sample, the force of attraction between the solid soil particle and water is less [15], so water is removed easily, which results in decreasing the water content within a low suction range. After this water has been removed, the water particle present will be tightly bonded with the solid soil particle, and hence more energy is required to remove this amount of water. This increase in energy results in increasing the suction which is also defined as the amount of energy required to remove unit volume of water from an unsaturated soil [15]. For ES2 and ES3 the measured results gave only the desaturation portion of the WRCC. The WRCC for these samples starts from almost the same suction (i.e. 1000 kPa) for different initial water content of the samples. At the initial desaturaion stage there is a drastic decrease in the water content of the sample at suction close to 1000 kPa. Above 1000 kPa the suction gradually increases with further decrease in water content. The maximum suction measured are i) for ES2, around 17000 kPa at w= 40% and ii) for ES3, around 16000 kPa at w= 30%. On the other hand, crack had been developed in the sample due to shrinkage of the expansive soil which exposed the bottom of the WP4 sample cup. As the bottom of the WP4 sample cup should be filled completely with soil sample during measurement [13], so the experiment was stopped when maximum part of the cup get exposed to the atmosphere. So, due care should be given while measuring the suction property of high swelling expansive soil like bentonite.

3.2 SWCC of expansive soil obtained using RH sensor

Figure 4 gives the SWCC obtained using the Relative humidity (RH) sensor for the same expansive soils ES1, ES2 and ES3. For a particular expansive soil, different samples were prepared at different water content and the RH and temperature (^{0}C) were noted for each sample. The suction was then calculated using these RH and temperature (^{0}C) reading by using Kelvin's equation (Eq. 1). In this way, SWCC of expansive soils were obtained from a high water content to a very low water content. It was observed that the SWCC obtained using the RHS technique gives only a part of the total WRCC and hence was difficult to tell which part of the WRCC corresponds too. The maximum suction obtained by the RH sensor method falls in between 10^5 to 10^6 kPa at an air dry state. The FX and vG fitting parameters were also obtained similar to WP4 results to see the variation for the different expansive soils as given in Table 2.

3.3 Comparison of WP4 and RH sensor method

Fig. 5 depicts the comparison of suction obtained by using RH and WP4 for all the expansive soil used in this study. It was observed that the suction measured using WP4 technique corresponds to only the desaturation portion of the SWCC. The near saturation portion and the residual portion were not clear from the measured plots. However, for ES1, the WP4 measurement yields the desaturation portion clearly. The result obtained from the RHS corresponds to very low water content as compared to WP4 due to the reason stated above. The result of RH shows almost a straight line path while a non linear trend was obtained for WP4 measurement. So, it is difficult to conclude which part of the WRCC corresponds to the RH results. This aspect was studied by plotting the WP4 and RHS results together. It was found that the RHS results falls in the residual portion of the WRCC. Both the results merge exactly at higher suction above 10^4 kPa. So, it was seen that both WP4 and RH results were essential to obtain the WRCC of expansive soil and the combination of these two results will help to obtain desaturation and residual part clearly.

3.4 SWCC parameterization

Fitting parameters of Fredlund and Xing(FX) 1994 and van Genuchten (vG) 1980 (Eq. 2 & Eq. 3) [16, 17] models were obtained using the experimentally obtained data for both WP4, RHS and combined WP4+RHS results as given in the Table 2. The regression coefficient (R2) is close to unity which indicates a good fit to the measured data. The air entry value (AEV) obtained from FX and vG fitting function is very high which can be attribute due to the inability of WP4 to measure the lower suction range and also the absence of transition portion between the saturated and desaturated portion of the WRCC. However, it is clear from this observation that WP4 gives good results for expansive soil above 1000 kPa suction.

$$\theta(\psi) = \theta_s \left[1 - \frac{\ln\left[1 + \frac{\psi}{h_r}\right]}{\ln\left[1 + \frac{10^6}{h_r}\right]} \right] \mathrm{X} \left[\left[\ln\left[\exp(1) + \left(\frac{\psi}{a_f}\right)^{n_f} \right] \right]^{m_f} \right]^{-1} \tag{2}$$

$$\theta(\psi) = \theta_r + (\theta_s - \theta_r) \mathrm{X} \left[\left[1 + (a_{vg}\psi)^{n_{vg}} \right]^{m_{vg}} \right]^{-1} \tag{3}$$

Where, $\theta(\psi)$ is the volumetric water content at any suction, ψ; θ_r is the residual volumetric water content; θ_s is the volumetric water content at saturation; a_{vg} and a_f are fitting parameters primarily dependent on the air entry value (AEV); n_{vg} and n_f are fitting parameters that are dependent on the rate of extraction of water from the soil; m_{vg} and m_f are fitting parameters which depend on θ_r; h_r is the suction (in kPa) corresponding to residual state.

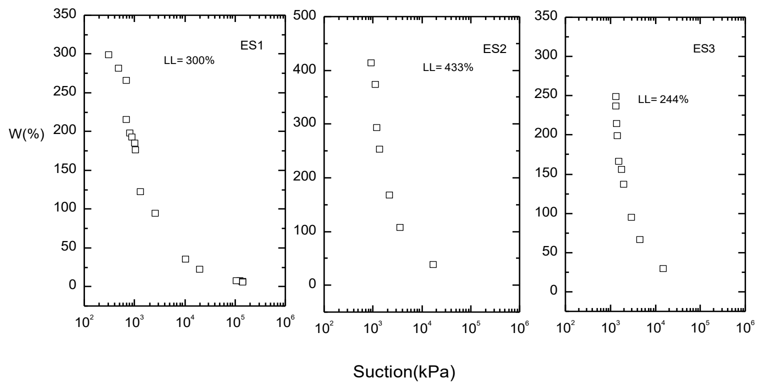

Fig. 3. SWCC obtained using WP4 dew point potentiameter device.

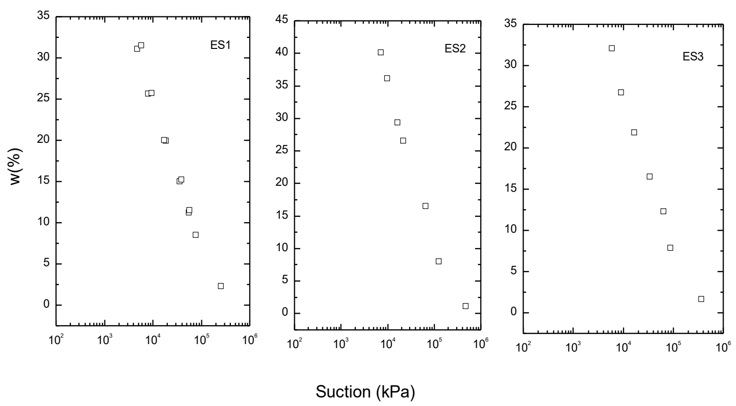

Fig. 4. SWCC obtained using WP4 dew point potentiameter device.

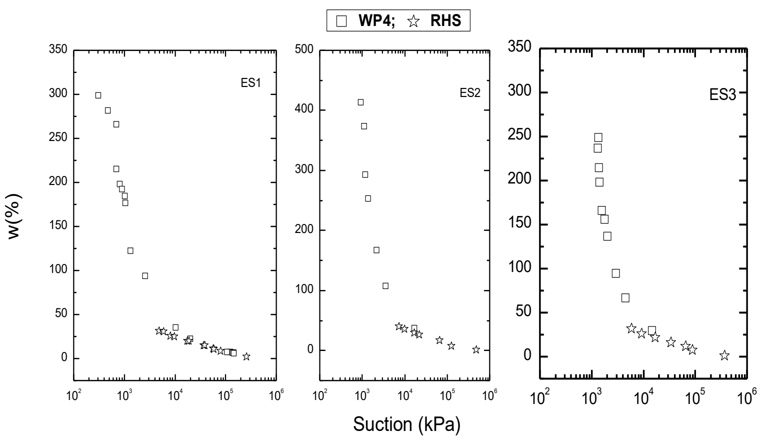

Fig. 5. SWCC obtained using WP4+RH sensor measurement.

Table 2. Comparison of FX fitting paramneters for WP4, RH and WP4+RH measurements.

Material	Fredlund and Xing (1994) Parameter	Measurement method		
		WP4	RHS	WP4+ RHS
	a_f kPa)	822.6906	2499.999	884.31
ES1	n_f	3.06	1.274	2.86
	m_f	1.05	0.494	1.23
	h_r(kPa)	934170.6	943559.2	888610.6
	w_r(%)	27.8	27.5	27.9
	AEV(kPa)	520.46	9709.71	526.62
	R^2	0.9824	0.7563	0.9862
	a_f kPa)	1116.939	2.47×10^{-10}	1218.18
ES2	n_f	10.543	0.000349	5.18
	m_f	0.537	1.387	0.916
	h_r(kPa)	972294.9	999998.9	953042.1
	w_r(%)	22.6	0.0	28.1
	AEV(kPa)	887.19	163672	919.62
	R^2	0.9737	0.4783	0.9795
	a_f kPa)	1421.215	2499.999	1523.609
ES3	n_f	10.069	1.150	6.41
	m_f	0.530	0.526	0.809
	h_r(kPa)	953042.1	943559.2	934170.6
	w_r(%)	27.8	29.3	26.1
	AEV(kPa)	1221.9	9424.50	1173.64
	R^2	0.9661	0.7793	0.9791

Table 3. Comaprison of vG fitting paramneters for WP4, RH and WP4+RH measurements.

Material	van Genuchten (1980) Parameter	Measurement method		
		WP4	RHS	WP4+ RHS
	$a_{vg}(x10^{-5})kPa^{-1}$	123.62	4.254	109.05
ES1	n_{vg}	3	1.475	3
	m_{vg}	0.467	0.846	0.599
	w_r(%)	10.0	10.0	10.0
	AEV(kPa)	491.22	6475.79	526.45
	R^2	0.9678	0.9727	0.9648
	$a_{vg}(x10^{-5})kPa^{-1}$	63.51	2.712	60.78
ES2	n_{vg}	3	1.476	3
	m_{vg}	0.7737	1.059	0.854
	w_r(%)	10.0	10.0	10.0
	AEV(kPa)	839.41	8972.64	852.85
	R^2	0.9407	0.9716	0.9595
	$a_{vg}(x10^{-5})kPa^{-1}$	47.71	2.061	45.66
ES3	n_{vg}	3	1.265	3
	m_{vg}	0.8535	1.527	0.948
	w_r(%)	10.0	10.0	10.0

AEV(kPa)	1102.31	7468.84	1121.14
R^2	0.9187	0.9730	0.9602

4 Conclusions

The present study was carried out to investigate the unsaturated behavior of three different qualities of expansive soil using two different technique having different range of suction measurement capacities. The first device used was WP4 dew point potentiometer and the other device is a relative humidity (RH) sensor. From the results, it was clear that both the methods can be used to measure high soil suction in expansive soil. WP4 method was found to be more reliable than the RH sensor, but at very high suction range RH sensor also gave better result. The combination of the result yield a very good SWCC for all the three soils used in this study. The measured SWCC were also used to determine fitting parameters of FX and vG SWCC models for only WP4, RH and combining WP4+RH results. The parameters from the combined WP4+RH SWCC could be used further for any unsaturated modeling study for similar types of expansive soil.

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