Effect of soil plasticity and presence of fine particles on SWCC

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ABSTRACT: The soil water characteristics curve (SWCC) is a graphical representation of soil suction and the amount of water present (either in the form of gravimetric water content or volumetric water content or degree of saturation) in the soil sample, which is essential for modelling the unsaturated soil properties such as hydraulic conductivity, shear strength, compressibility and swelling potential of the soils. The shape and the model parameters of the SWCC is very much influenced by the presence of fine particles in the soil sample. So in this research, an attempt is made to observe change in the slope of SWCC curve and the model parameters with the increasing plasticity and percentage fine particles. Four soils ranging from low to high plasticity of IIT Guwahati campus were selected and the SWCC were measured using a dew point potentiameter (WP4-T). The experimental data were fitted with van Genuchten model and FX model to find the model parameter and the slope of the curve. A significant effect of plasticity and presence of fine particles is found on the model parameters as well as on the slope of the SWCC. Also the efficiency of the used fitting equations was checked with increasing plasticity.

KEYWORDS: Soil water characteristics curve (SWCC), soil suction, dew point potentiameter (WP4), gravimetric water content, unsaturated soils.

1. INTRODUCTION

Unsaturated soil mechanics has vast application in the field of geotechnical as well as geo-environmental engineering projects such as design of cover system of waste containment facilities, railway embankments, rainfall infiltration problem, unsaturated slope stability problems (Fredlund and Rahardjo 1993; Lu and Likos 2004). In all these applications the soils remain unsaturated and development of soil suction during drying plays an important role. Soil suction describes the thermodynamic potential of soil pore water relative to the free water. Free water in the sense that water with no dissolved solutes, having no interaction with any other phases and having no external forces other than gravity (Lu and Likos 2004). Therefore with the evaporation of water from the soil mass, the potential in the pore water decreases compared to the free water and the corresponding negative pressure i.e. soil suction increases. The variation of suction with the amount of water present in the sample is known as soil water characteristic curve and one of the most important parameter to understand the behavior of unsaturated soils. Unsaturated soil properties like hydraulic conductivity, shear strength, solute and thermal diffusivity, swelling potential can be obtained from the SWCC (Fredlund and Rahardjo 1993; Huang et al., 1995; Vanapalli et al., 1996; Delage et al., 1998) and the accuracy of those properties largely depends on the SWCC. So, proper understanding of SWCC and its parameter is very important. The shape of SWCC is very much influenced by the soil type, plasticity of the soil, percentage of fine particles present and many other factor. So, there is a need to understand the variation of slope of SWCC and other parameters with the plasticity and presence of fine particles. Keeping this in view, four soils from IIT Guwahati campus were collected with increasing plasticity.

A dew point potentiameter (model WP4-T) which works on the principle of chilled mirror hygrometer were used to experimentally measure the SWCC of the selected samples. The measured SWCC was fitted to two mathematical equation proposed by van Genuchten (1980) and Fredlund and Xing (1994) for obtaining the slope and other curve parameters to understand the influence of plasticity and presence of fine particles on SWCC. The efficiency of both the fitting equation was also verified as many of the unsaturated soil property are obtained from those fitting parameters.

2. BACKGROUND

SWCC can be represented in three forms i.e. gravimetric water content-suction variation, volumetric water content-suction variation and degree of saturation-suction variation. In this study, gravimetric water content-suction SWCC is used which does not require any volume measurement. The important parameter of a typical drying SWCC includes i) Saturated water content which is water content of a fully saturated soil, ii) air entry value which equal to suction value at which air first enters into the largest pores and iii) residual water content which is defined as the water content after which no considerable amount of water content changes.

Here, measured SWCC were represented by two mathematical equations i.e. van Genuchten equation (1980) and Fredlund and Xing equation (1994) presented by Eqn. 1 and 2 respectively.

$$w_{(\Psi)} = w_r + (w_s - w_r) \times \left[\left\{1 + \left(a_{vg}\Psi\right)^{n_{vg}}\right\}^{m_{vg}}\right]^{-1} \quad (1)$$

$$w_{(\Psi)} = w_s \left[1 - \frac{ln\left[1+\frac{\Psi}{h_r}\right]}{ln\left[1+\frac{10^6}{h_r}\right]}\right] \times \left[\left[ln\left[exp(1) + \left(\frac{\Psi}{a_f}\right)^{n_f}\right]\right]^{m_f}\right]^{-1} \quad (2)$$

Here, $w_{(\Psi)}$ represent gravimetric water content at any suction ψ, w_s and w_r are the saturated and residual water content respectively, h_r is the suction corresponding to residual water content and a, n and m are empirical fitting parameters.

3. MATERIALS AND METHODOLOGY

3.1 Materials

Four locally available soils from IIT Guwahati campus were selected for this study. The basic geotechnical properties namely specific gravity, consistency limits and particle size distribution were evaluated as per the guidelines provided by the IS standards (IS 2720: Part II; IS 2720: Part III; IS 2720: Part IV; IS 2720: Part V). The Particle size distribution curves are presented in Figure 1 while all the basic properties of the used samples are listed in Table 1. The sample plasticity varies from non-plastic to high plastic and also the percentage of fine particles increases with sample no.

Table 1. Basic Properties of the used soils

Properties	S1	S2	S3	S4
Specific Gravity	2.61	2.66	2.66	2.69
Particle Size Characteristics				
Coarse sand (4.75-2 mm)	5.4	2.9	1.1	0.5
Medium Sand (2-0.425 mm)	37.5	26.5	26.3	5.7
Fine Sand (0.425-0.075 mm)	18.5	22.6	22.6	7
Silt (0.075-0.002 mm)	29.8	39.8	34.6	35.3
Clay (<0.002 mm)	2.2	6.0	14.7	50.4
Consistency Limits				
Liquid limit (LL)	NP	36.5	41.4	52.6
Plastic limit (PL)	NP	22.4	17.6	19.2
Plasticity Index (PI)	NP	14.1	23.8	33.4

3.2 Experimental methodology

A dew point potentiameter (model WP4-T, Decagon, USA) shown in the Figure 2 has been used to measure total suction of the samples. This instrument works on the principle of chilled mirror hygrometer technique and estimate the relative humidity of the sample. Total suction is computed from the measured relative humidity by the Kelvin equation. This instrument can measure total suction up to 300 MPa (WP4 user manual, Decagon devices 2003).

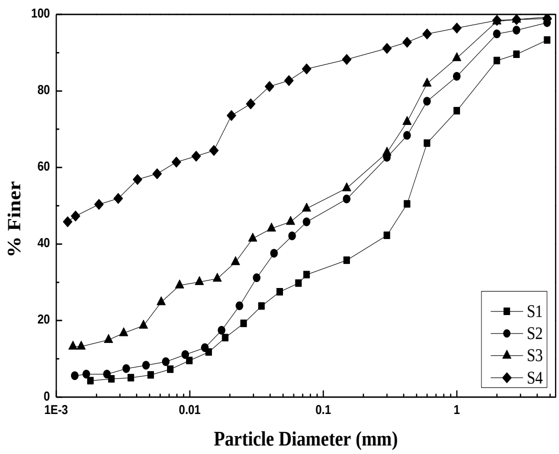

Fig. 1 Particle size distribution of the used soils

For measurement of suction the air dried soil samples passing through 425μ passing sieve was mixed with deionized water to obtain water content slightly above the liquid limit. The sample was then kept in humidity chamber for three days for proper maturation. After completion of maturation the sample was poured in the PVC cup as per the guideline provided by the manufacturer. The cup should be half filled with soil sample and the remaining half should be empty. At the time of suction measurement the weight of the sample was also taken to calculate the water content. This process was repeated several times until it reaches its residual condition. At the end of the test dry weight of the sample was taken and gravimetric water content corresponding to each suction was computed.

Fig. 2 Dew point potentiameter (WP4-T)

4. RESULT AND DISCUSSION

The total suction (ψ) corresponding to different gravimetric water content (w) was obtained with WP4 instrument starting from the fully saturated state to a low degree of saturation close to oven dried state. The measured SWCCs for the four samples were plotted in Figure 3. The graph shows that as the soil plasticity increases from non-plastic to high plastic the water retention behaviour changes. The rate of water loss is very high in case of non-plastic soil and also it reaches to its residual water content at lower suction compared to plastic soil. It can be seen that all the data points are greater than suction value 300 kPa due to the fact that relative humidity concept in the low suction range is not reliable (Fredlund and Rahardjo 1993). Small fluctuation in the temperature can cause variation in total suction value.

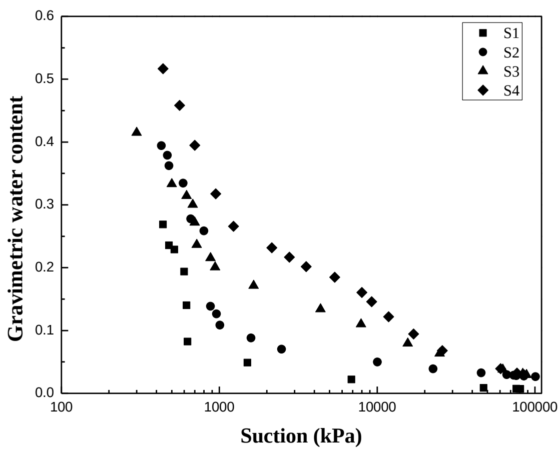

Fig. 3 Measured SWCC of the used soils

The measured data were fitted to van Genuchten (vG) equation (1980) and Fredlund and Xing (FX) equation (1994) to verify the efficiency of these two equations for the complete drying curve. Here, in this study vG equation was fitted by taking $m_{vg}=1-1/n_{vg}$ (i.e. with applying constraints) in one case while in other case all the parameters obtained independently. With the applied constraint, number of unknown reduced for parameter optimization and it also facilitate closed form analytical solution (Kousugi et al. 2002; Likos and Yao 2014). The measured SWCC and fitted curve for the four soil samples were presented in Figure 4-7. It can be seen from the figure that the vG fit is not accurate in high suction range for low plastic soils. Similar observation was made by Thakur et al. (2006).

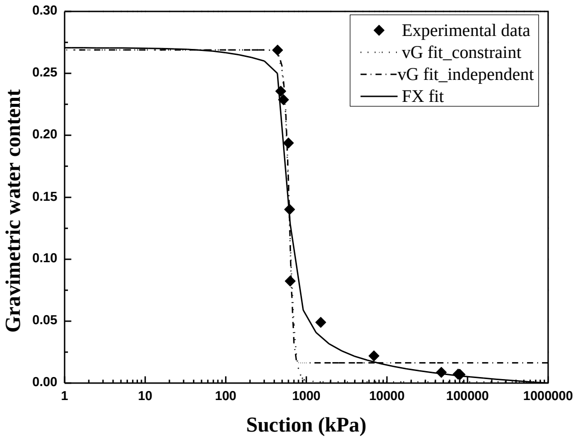

Fig. 4 Comparison of FX and vG fit for S1

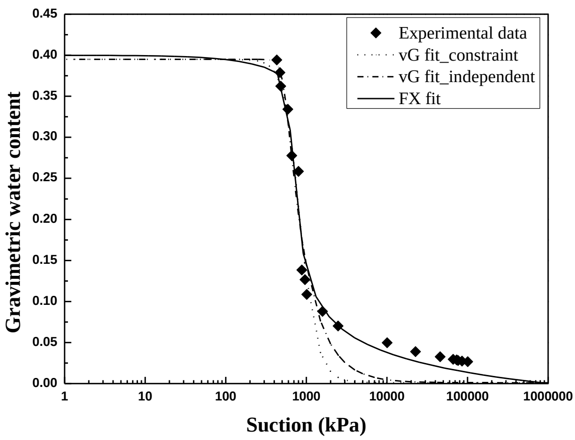

Fig. 5 Comparison of FX and vG fit for S2

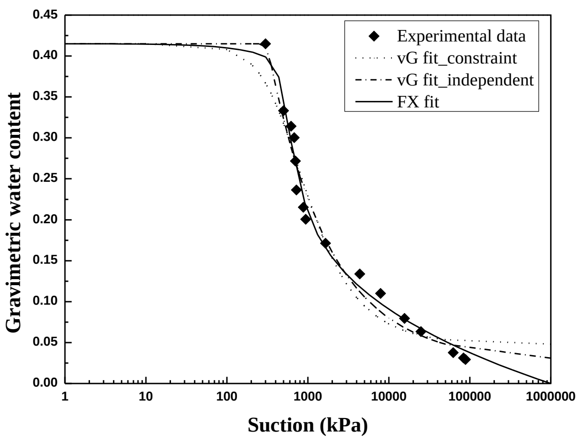

Fig. 6 Comparison of FX and vG fit for S3

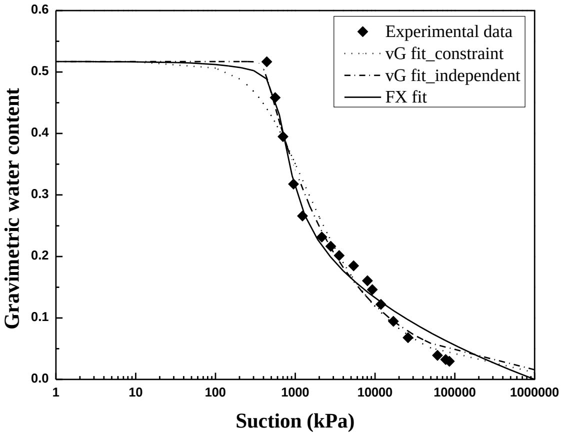

Fig. 7 Comparison of FX and vG fit for S4

From these comparisons it is clear that for the whole drying curve the Fredlund and Xing (1994) fitting equation is the most accurate. Therefore the use of FX model is recommended specially for the non-plastic to low plastic soil where the accuracy of vG model is not good. The FX equation fitted curve for the four samples were presented in Figure 8. It can be seen that the water retention capacity is greatly affected by the soil plasticity and the presence of fine particles. As the soil plasticity and the presence of fine particle increases the capacity to hold the water also increases and the slope of the desaturation portion decreases. The plasticity of soil also affects the saturated water content which can be observed form the figure. The saturated water content of high plastic sample S4 is significantly higher compared to non-plastic sample S1.

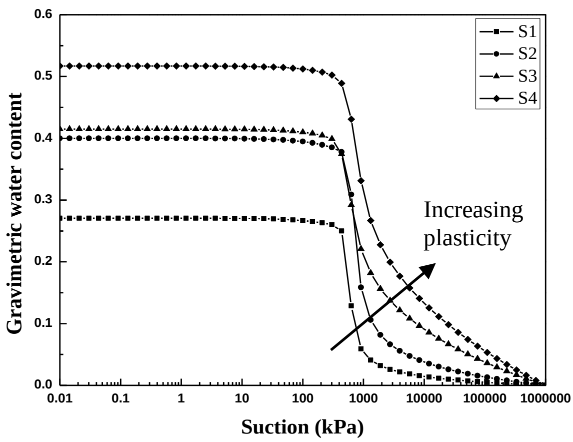

Fig. 8 Comparison of FX model fit for the four soils

The fitting parameters of these FX equation were tabulated in Table 2. Here a_f parameter is a function of air entry value of soil; n_f is the function of rate of extraction of water from the soil sample which also represent the slope of SWCC of the desaturation portion; m_f is the function of residual water content (Fredlund and Rahardjo 1993). The FX model parameters are compared for the used soil and presented in Figure 9. The value of n_f reduces as the soil plasticity increases which also implies that the rate of extraction of water is more in S1 compared to others and subsequently the slope of the desaturation portion is steeper. The parameter h_r which represents the suction value at residual condition also increases as plasticity as well as percentage of fines increases. In this study, it can be seen that S1 reaches to its residual condition at lower suction value compared to other samples.

Table 2. Details of the FX model parameters

Properties	**S1**	**S2**	**S3**	**S4**
w_s	0.269	0.395	0.415	0.517
a_f (kPa)	547.71	615.69	485.38	586.39
n_f	20	10.87	6.9	6.4
m_f	0.612	0.569	0.366	0.342
h_r (kPa)	936.6	1064.4	1165.7	1626.7
R^2	0.95	0.97	0.98	0.98

5. CONCLUSION

SWCCs of four different soil having plasticity starting from non-plastic to high plastic were experimentally measured in this study. A comparison was made using different fitting equation including vG equation (considering all the parameter independently and with applying constraint) and Fredlund and Xing equation (1994) to check the efficacy of theses equation over the wide range of suction. Later, the FX model parameters were compared for different soil sample with increasing plasticity and presence of fine particles. The following are some important observations made from this study:

i) The accuracy of the Fredlund and Xing equation (1994) to fit the measured SWCC is reasonably good even in high suction zone.

ii) vG equation using both the approaches unable to fit the measured data specially in the high suction range for low plastic soil. However, as the plasticity increases this error reduces to large extent and both the equation gives almost satisfactory results.

iii) Therefore, use of FX model is recommended to fit the measured data up to high suction value of 10^6 kPa especially for low plastic soil.

iv) Slope of the SWCC and other parameter is influenced by soil type, plasticity and presence of fine particles. As the plasticity increases the slope of SWCC becomes less steep and the water retention capacity increases.

v) The ineffectiveness of relative humidity concept in lower suction zone may influence the fitting parameters. Further investigation is required to measure the SWCC starting from low suction up to very high suction by some other methods.

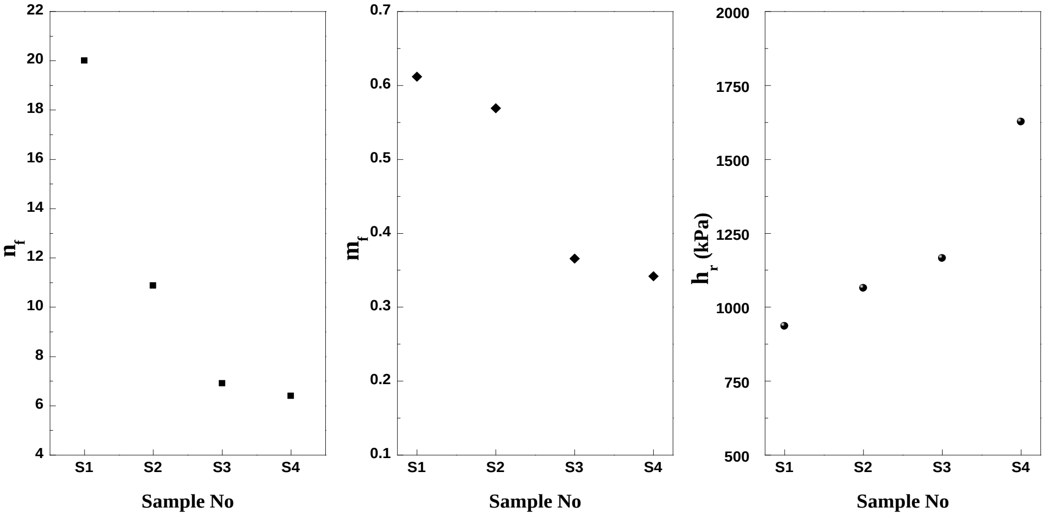

Fig. 9 Comparison of different FX model parameters of the used sample

References

ASTM. (2006a) *Standard practice for classification of soils for engineering purposes (unified soil classification system)*, D2487-06, West Conshohocken, PA.

Delage, P., Howat, M. and Cui, Y.J. (1998) 'The relationship between suction and swelling properties in a heavily compacted unsaturated clay', *Engineering Geology*, 50(1–2), pp31–48.

Fredlund, D.G. and Rahardjo, H. (1993) *Soil mechanics for unsaturated soils*, Wiley, New York.

Fredlund, D.G., Xing, A. and Huang, S. (1994) 'Predicting the permeability function for unsaturated soils using the soil-water characteristic curve', *Canadian Geotechnical Journal*, 31(4), pp533-546.

Huang, S.Y., Fredlund, D.G. and Barbour, S.L. (1995) 'Measurement of coefficient of permeability of unsaturated soil', *Proceedings of the First International Conference on Unsaturated Soils (edited by E.E. Alonso and P. Delage)*, Paris, 2, pp505–512

IS 2720, Part II, (1973) *Methods of Test for Soils: Determination of water content*, Indian Standards Institute, New Delhi, India.

IS 2720, Part III, (1973) *Methods of Test for Soils: Determination of specific gravity*, Indian Standards Institute, New Delhi, India.

IS 2720, Part IV, (1985) *Methods of Test for Soils: Grain size analysis*, Indian Standards Institute, New Delhi, India.

IS 2720, Part V, (1985) *Methods of Test for Soils: Determination of liquid limit and plastic limit*, Indian Standards Institute, New Delhi, India.

Kosugi, K., Hopmans, J. W., and Dane, J. H. (2002). *'Parametric models', Methods of soil analysis: Part 4—Physical methods*, Soil Science Society of America, Madison, WI.

Likos, William J., and Jun Yao. (2014) 'Effects of Constraints on van Genuchten Parameters for Modeling Soil-Water Characteristic Curves', *Journal of Geotechnical and Geoenvironmental Engineering*, 140(12), p06014013.

Lu, N., and Likos, W. J. (2004) *Unsaturated soil mechanics*, Wiley, New York

Thakur, V. K. S., Sreedeep, S. and Singh, D. N. (2006) 'Laboratory investigations on extremely high suction measurements for fine-grained soil', *Geotechnical and Geological Engineering*, *Springer*, 24, pp565-578.

van Genuchten, M. T. (1980) 'A closed form equation for predicting the hydraulic conductivity of unsaturated soils', *Soil Science Society of America Journal*, 44, pp892-898.

Vanapalli, S.K., Fredlund, D.G., Pufahl, D.E. and Clifton, A.W. (1996) 'Model for the prediction of shear strength with respect to soil suction', *Canadian Geotechnical Journal*, 33(3), pp379-392.

WP4 operator's manual (2003). Decagon Devices, Inc., USA.