EXPERIMENTAL INVESTIGATIONS FOR STUDYING INFLUENCE OF VARIOUS PARAMETERS ON SOIL WATER CHARACTERISTIC CURVE

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ABSTRACT
The paper emphasises on experimental investigation to measure suction of silty soil using a dew point potentiameter, WP4. Soil Vision 3.04, knowledge-based database, has been used to develop soil-water characteristic curve, SWCC, utilizing laboratory results. Efforts have been made to demonstrate the usefulness of WP4 in measurement of high suction ranges . The study reveals that the dry unit weight of the soil, practically, does not influence its suction parameters such as the air entry value and the residual water content. The study also brings out an important observation that Fredlund et al. PTF (Pedo-transfer function) is the most generalized PTF which can be utilize to generate SWCC for fine grained material.

RÉSUMÉ
Ce mémoire repose sur une recherche expérimentale dont l'objectif est de mesurer la succion de sols vaseux en employant le potentiomètre à point de saturation de type WP4. La base de données cognitives Soil Vision 3.04 a servi pour mettre au point une courbe caractéristique sol-eau (SWCC) à l'appui des résultats obtenus en laboratoire. Des efforts ont particulièrement été fournis pour démontrer l'utilité de WP4 dans les plages de mesure à haute succion. L'étude démontre que le poids de l'unité à sec du sol n'influence pratiquement pas ses paramètres de succion comme la valeur de pénétration de l'eau ou bien la teneur en eau résiduelle. L'étude met également à jour une observation importante, soit que Fredlund et al. PTF (fonction de pédo-transfert) est le la règle de pédo-transfert la plus généralement utilisée pour générer une courbe de type SWCC sur matières à grains fins.

1. INTRODUCTION

The role played by suction on properties of partially saturated soils is becoming an important issue. Some of the situations where measurement of soil suction becomes very important are; construction and design of earthen embankments for roadways and railways, environmentally sensitive projects, such as waste containment in the landfill sites and nuclear storage installations etc. It is mainly due to the fact that many of the process of concern to the environment and the water resources, occur in the upper portion of the sub surface soil that lies above the water table and can be termed as the vadose-zone (the zone in which the pore water pressure is negative). It has been demonstrated by researchers that in this zone, the soil hydraulic conductivity is a function of soil suction (Fredlund, 1995). Realizing the influence of soil suction on the properties of the soil mass, several models have been developed to co-relate soil water content with the suction in it (Fredlund et al.1997, 1998; Fredlund and Xing, 1994) and it has been demonstrated recently that it is mainly suction rather than water content which determines the stress state in the soil (Brady, 1988; Ridley, 1995).

Utility of soil-water characteristic curve, SWCC, which is a relationship between soil suction (ψ) and its gravimetric water content (w) has been demonstrated very well by the several researchers (Stannard 1992; Lee and Wray 1995; Woodburn and Lucas 1995; Fredlund et al. 1996,Sneha 2001). It has been noticed that to establish the SWCC, several soil suction measurement devices have been used (and based on the results obtained, different fitting functions have been proposed (Burdine 1953; Gardner 1956; Brooks and Corey 1964; Mualem 1976; Van Genuchten 1980; Fredlund and Xing 1994). Also, several Pedo-transfer functions (PTFs) are available in the literature, which can be used for estimating the SWCC even if the laboratory (suction) data is not available. Experimental investigations were conducted to measure soil suction of silty soil or locally called Powai silt. The results have been used to develop SWCC for Powai silt using knowledge-based database SoilVision 3.04 (SoilVision 2001) which is reported to be quite useful by various researchers for estimating saturated and unsaturated soil properties, based on the volume-mass properties and grain-size distribution (Fredlund et al. 1996; SoilVision 2001; Singh et al. 2001; Singh and Sneha 2002). Based on the study, efforts have also been made to demonstrate the influence of the soil type, its compaction state i.e. dry unit weight and gravimetric water content, on the SWCC and various suction parameters used in the fitting functions.

2. Details of the Dew Point Potentiameter (WP4)

Present study is enrich with the usefulness of WP4 as depicted in Fig. 1, employs the chilled-mirror technique to measure suction of the soil sample. A block chamber, in which the soil can be placed, is consists of a mirror, a fan, a dew point sensor depicted as optical sensor, and a temperature sensor. The dew point sensor measures the dew point temperature of the air and the infrared thermometer measures the temperature of the sample. The fan speeds up the equilibration of the sample with the chamber environment. WP4 yields results in term of MPa and pF with corresponding soil ambient temperature. To insure proper functioning of the instrument, its calibration was done using KCl solution of different molarities (M) and the results are presented in Fig. 2.

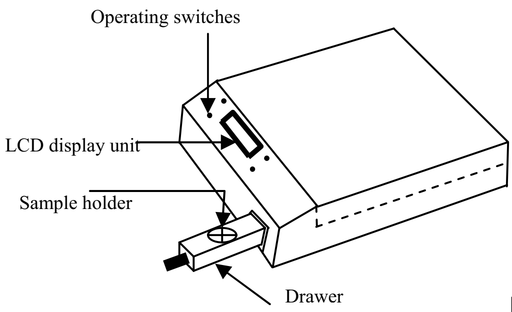

Fig. 1
Schematic diagram of the WP4

It can be noted that the slope of the experimental results (=4.79) is 1.10 time higher than the slope of the standard results (=4.37) which is possibly due to laboratory working conditions. Hence, the obtained suction values have been reduced by a factor 1.1.

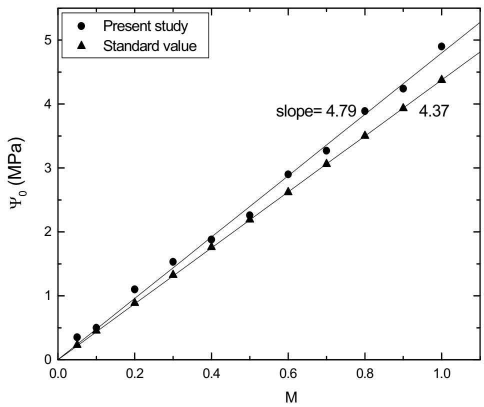

Fig. 2. Calibration of the WP4 using KCl solutions of different molarity

3. EXPERIMENTAL INVESTIGATIONS

3.1 Soil properties

Powai silt sample was characterized and its properties are listed in Table 1. The Proctor compaction characteristics of this soil attains maximum dry density, γ_{dmax} of 17 kN/m^3 corresponds to 20.8% water content and 91.2% saturation.

3.2 Sample preparation and WP4 tests

Preparations of sample have been done in two phases. First phase associated with the maturing the oven-dried sample thoroughly mixed with demineralised water in desiccators for 24 hours. Preparation of sample at different density and different moisture content is the second phase of the work.

Table 1. Properties of Powai silt

Soil Property	**Powai Silt**
Specific gravity	2.79
Particle size characteristics:	
Sand (%):	
Coarse (4.75-2.0 mm)	4
Medium (2.0-0.425 mm)	17
Fine (0.425-0.075 mm)	28
Fines (%):	
Silt size (0.075-0.002 mm	36
Clay size (<0.002 mm)	15
Consistency limits (%):	
Liquid limit	41
Plastic limit	28
Plasticity index	13
USCS Classification	ML

Due to the restrictions associated with the size of the test sample and to ensure complete covering of the bottom of the sample cups properly, 1.5 mm thick stainless steel rings were fabricated and used for preparing the soil sample. These rings are 35 mm in internal diameter and are 5 mm long. These rings were used to slice out the sample from the mould. The biggest advantage of this procedure is that it insures preparation of identical soil sample for tests. These ring samples have been used number of times to measure different suction value in WP4 at different moisture content.
To vary the moisture presented in sample, drier was used and every time their moisture content readings have been taken. Table2. presents the details of sample at the prior stage of experiemnt.

Table 2. Details of the soil samples used for suction measurement

Sample	γ_d **(kN/m^3)**	**w (%)**	S_r **(%)**
A	12.1	46.6	98.1
B	14.2	46.0	96.9
C	15.3	29.5	95.6
D	16.2	25.6	96.2
E	17.1	22.5	97.9

The most important feature of this SoilVison 3.04 database is that it can be used for development and estimation of the SWCC of a soil. Equations 1, 2 and 3 are most commonly used fitting equations suggested by Fredlund and Xing (1994), van Genuchten (1980) and Brooks and Corey (1964), respectively, has been used in the present study.

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

$$w(\psi) = w_r + (w_s - w_r) \times \left[\left[1 + (a_{vg}\psi)^{n_{vg}} \right]^{m_{vg}} \right]^{-1} \quad [2]$$

$$w(\psi) = w_r + (w_s - w_r) \times \left[\frac{a_c}{\psi} \right]^{n_c} \quad [3]$$

where, $w(\psi)$ is the gravimetric water content at any suction, ψ, w_r, is the residual water content, RWC, w_s is the gravimetric water content at saturation, a_f, and a_{vg} are soil parameters primarily dependent on the air entry value, AEV, n_f and n_{vg} are soil parameters and are dependent on the rate of extraction of water from the soil beyond the AEV, m_f is the soil parameter which is a function of the RWC, h_r is the suction (in kPa) corresponding to the RWC, m_{vg} a fitting parameter, a_c is the bubbling pressure (in kPa) and n_c is the pore size index.

4. RESULTS AND DISCUSSION

Results obtained from the WP4 test for Powai silt at different density are used to plot the SWCC i.e. variation of suction with respect to water content. Fig 3 depicts the SWCC for the sample B and similarly other densities result can be plot separately.

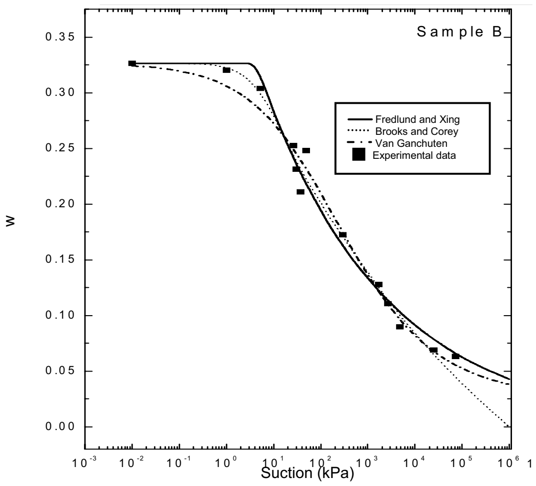

Fig. 3. SWCCs for samples B developed with the help of various fits

Variations of suction with respect to moisture content at different densities presented in same plot (Fig. 4.). It can be noticed that all experimental results at different densities are falling on coinciding and slight scatter is may be due to the experimental error. This study indicates that there is as such no influence of density on suction. The same plot have been taken for predicting the SWCC and computing its parameter for best fits as shown in table 3 using Soil Vision 3.04 data base at different density.

Fredlund and Xing (1994), van Gunechuten (1980) and Brooks and Corey (1964), which are very common in practice and it is found that Fredlund and Xing is a very good fit. Soil Vision 3.04 can also be used for predicting the SWCC in the absence of experimental data using various PTFs provided in Soil Vision 3.04. Further experimental data were put on the same plot to check the suitability of PTFs. It has been found that Fredlund et al. PTF (1997) is matching quiet well with the experimental results (Fig.5).

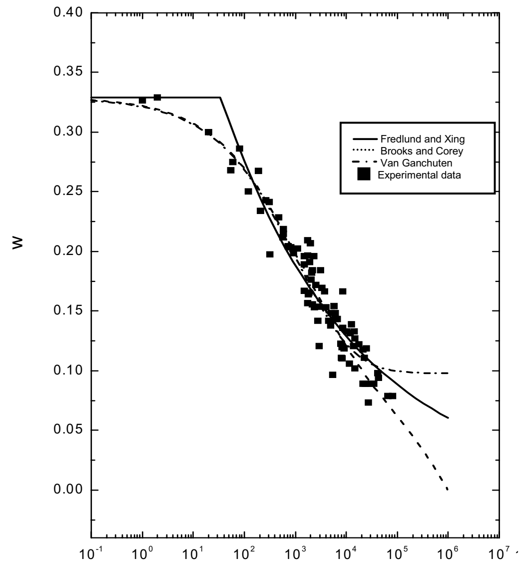

Fig. 4 SWCCs with the help of various fits using all experimental data

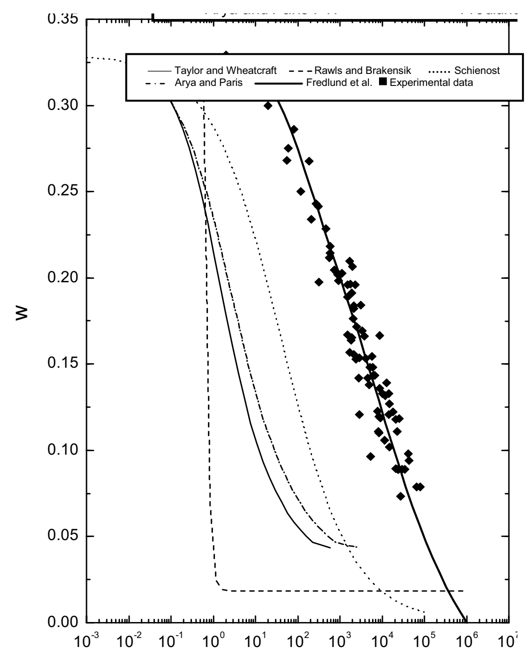

Fig. 5. Estimated SWCCs for the Powai silt using various PTFs

Table3. summery of various SWCC paprameters obtained from Soil Vison 3.04

Fits	Parameter	Sample					All Samples
		A	B	C	D	E	
Fredlund & Xing	a_f (kPa)	402.53	785.82	296.43	456.56	587.10	528.05
	n_f	0.53	0.52	0.62	0.55	0.47	0.5069
	m_f	1.47	1.56	1.35	1.22	1.52	1.46
	h_r ($\times 10^5$) (kPa)$^{-1}$	8.62	8.79	8.36	8.97	8.88	8.80
	Error	0.9988	0.9991	0.9989	0.9972	0.9982	0.9985
	w_r (%)	0.28	0.28	0.29	0.29	0.29	0.29
	AEV (kPa)	23.20	39.46	26.88	35.24	22.37	26.47
Van Genuchten	a_{vg} ($\times 10^{-5}$) (kPa)$^{-1}$	16.0	6.0	18.9	3.6	5.1	2.85
	n_{vg}	0.57	0.54	0.59	0.45	0.47	0.48
	m_{vg}	3.37	3.93	3.60	3.82	3.85	5.12
	Error	0.9754	0.9799	0.9667	0.9972	0.9839	0.9793
	w_r (%)	0.29	0.29	0.29	0.29	0.30	0.29
	AEV (kPa)	29.75	47.76	30.22	26.04	24.22	27.41
Brooks & Corey	a_c (kPa)	41.53	41.66	26.83	34.83	40.23	34.20
	n_c	0.19	0.17	0.18	0.14	0.16	0.17
	Error	0.9797	0.9501	0.9537	0.9745	0.9642	0.9067
	w_r (%)	0.18	1.12	0.01	0.15	0.11	0.15
	AEV (kPa)	41.22	41.40	26.52	34.26	39.92	33.51

It can be noticed that SWCC parameter is not changing with respect to change in soil density. It is clear from the table 3 that especially AEV and W_r for different densities are fairly similar, which controls the shape of SWCC. Furthermore it can be consider that the SWCC for individual densities will be similar irrespective of any influence of compaction state.

5. CONCLUDING REMARKS

This study have been attempted to demonstrate the utility of dew point potentiameter (WP4) and Soil Vision3.04 in the field of unsaturated soil mechanics. This study also emphasized on experimental investigation of SWCC parameters and its influence on dry density. It is found that there is no change in SWCC parameter with respect to density and this cause a unique SWCC for any soil. It is also found that Fredlund and Xing (1994) for estimating the SWCC and Fredlund et al. PTF (1997) are very well matching with the experimental results. This also proves the efficiency of Soil Vision 3.04 data base. In short we can say that density is not influencing the soil suction.

List of Symbols

γ_{dmax} : maximum dry unit weight;
γ_d : dry unit weight;
a_c : bubbling pressure in kPa;
AEV : air entry value;
a_f, a_{vg} : soil parameters which are dependent on the AEV;
h_r : suction corresponding to RWC;
M : molarity of the KCl solution;
w : gravimetric water content;
m_f : soil parameter which is a function of RWC;
m_{vg} : fitting parameter;
n_c : pore size index;
n_f, n_{vg}, : parameters which depend on the rate of extraction of water from the soil beyond AEV;
PTF : pedo-transfer function;
RWC : residual water content;
S_r : degree of saturation;
w(ψ) : gravimetric water content at any suction,
w_r, : residual water content;
w_s : gravimetric water content at saturation;
Ψ : total suction;
Ψm : matric suction;
Ψo : osmotic suction;

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