

# Factors Influences the Soil Water Characteristic Curve and its Parameters

Pa.Suriya, R.Jayalakshmi, EswarSudharsan.C

Aarupadai Veedu Institute of Technology, [pasurya1@gmail.com](mailto:pasurya1@gmail.com), +91-8056710954

**Abstract:** Soils are used as a construction material for different type of geotechnical engineering structures. The techniques of prediction of the behaviour of unsaturated soils are constantly under review. Fredlund (1979): Fredlund and Rahardjo (1993) and others have helped to establish a theoretical frame work for unsaturated soil. The soil water characteristic curve is constitutive relationship for interpreting the response of unsaturated soils. Pressure plate extractor is one of the devices used to determine the relationship between suction and water content. To understand the influence of type of soil, grain size distribution, consistency limits, initial water content and initial degree of saturation, the soil water characteristic curves of different soils are obtained using 15 bar soil pressure plate extractor by following standard test procedure. The soil water characteristic curve parameters such as air entry value, residual suction, residual water content and residual degree of saturation of the different soils were determined for the different type of soil and are compared. The compressions indices/volume change indices are also determined and compared.

**keywords:** soil suction, unsaturated soil, characteristic curve, degree of saturation, water content, plasticity index, soil density

## INTRODUCTION:

The use of compacted soil is inexorable in the geotechnical engineering. Soils of different types are being used for different types of earthen construction. Frequently, clays are used for containment facilities as barriers. Other type of soil is preferred for land reclamation, pavement, earthen embankment and earthen dam construction. Almost all these soils are placed at dry of optimum in the field, where the degree of saturation is always lesser than 100%. The engineering properties of these soils get altered due to wetting and drying process depending upon their environment condition. The determination of the soil water characteristics curve (SWCC) of these insitu placed soils are important, because this curve is the primary constitutive relationship for the prediction of the engineering behaviour of these unsaturated soil. Several methods are available to predict the SWCC for a given soil. They are broadly grouped into direct and indirect method. Direct method includes Pressure plate, Bunchner funnel, Tensiometer and Pressure membranes. These methods measure the pore water pressure in the soil or imposed air pressure into the soil. Among these methods conventional pressure plate extractor is widely used. Indirect methods use measurement or indicator of water content or a physical property that is sensitive to change in water content. Inadequacy in the requirement of laboratory facility made the researchers to develop empirical equation to predict SWCC. Most of these equations are derived predominantly from the grain size distribution curve and volumetric water content. It is understood that the general shape of soil water characteristics this curve (SWCC) is influenced by material properties such as the grain size distribution, clay content mineralogy and density of soil and the pore fluid characteristics. These papers discuss the influence of material properties of soil such as plasticity index, predominant minerals and density in the soil water characteristics curve parameters and its volume change indices.

## MATERIALS

Natural clay soils were collected from various parts of Chennai city, Tamilnadu, India. Commercially available bentonite and kaolinite soils were also collected. The index properties of these collected soils were determined in the laboratory as per relevant BIS. The predominant minerals present in these soils were also identified by X-ray diffraction analysis. The above determined properties are summarised in Table 1, Table 2 and Table 3.

Table 1 Grain Size Distribution Results

Location of Sample / Type of Soil	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
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Anna Nagar	-	4	42	56
K.K.Nagar	-	7	37	49
Thiruneermalai	-	4	25	71
Korattur	-	9	39	52
Thiruvanmiur	-	10	37	53
Taramani	-	10	32	58
Thirumullaivoyal	6	21	18	55
Marine Clay	1	40	35	24
Red Soil	-	21	61	18
Silty Soil	-	29	70	1
Bentonite	0	0	0	10

Table 2 Atterberg limits and classification

Location of Sample / Type of Soil	W <sub>L</sub> (%)	W <sub>P</sub> (%)	W <sub>S</sub> (%)	I.S. Classification
Anna Nagar	70	31	9	CH
K.K.Nagar	57	26	12	CH
Thiruneermalai	78.3	34.3	11.7	CH
Korattur	60	25	11	CH
Thiruvanmiur	64	27	10	CH
Taramani	61	22	10	CH
Thirumullaivoyal	60	25.3	10	CH
Marine Clay	52.5	15	11.5	CH
Red Soil	34	22	18	ML
Bentonite	325	90	-	-

Table 3 Minerals Present in the Soil

Location of Sample / Type of Soil	Minerals Present
Anna Nagar	Illite
K.K.Nagar	Montmorillinite
Thiruneermalai	Vermiculite
Korattur	Kaolinite
Thiruvanmiur	Quartz
Taramani	Mica
Thirumullaivoyal	Carbonate
Bentonite	Montmorillinite
Silty Soil	Feldspar

## DETERMINATION OF SOIL WATER CHARACTERISTIC CURVE

Using pressure plate extractor, the drying soil water characteristics curve was obtained in the laboratory for all the soil samples. This apparatus works in the principle of axis translation technique.

### Function of the Ceramic Pressure Plate Cell

Fig.1 illustrates a cross section view of a ceramic pressure plate cell mounted in a pressure vessel with outflow tube running through the vessel wall to the atmosphere and with a soil sample held in place on the porous ceramic surface of the cell. Each ceramic pressure plate cell consists of a porous ceramic plate, covered on one side by a thin neoprene diaphragm, sealed to the edges of the ceramic plate. An internal screen between the plate and diaphragm provides a passage for flow of water, an outlet stem running through the plate connects this passage to an outflow tube fitting.

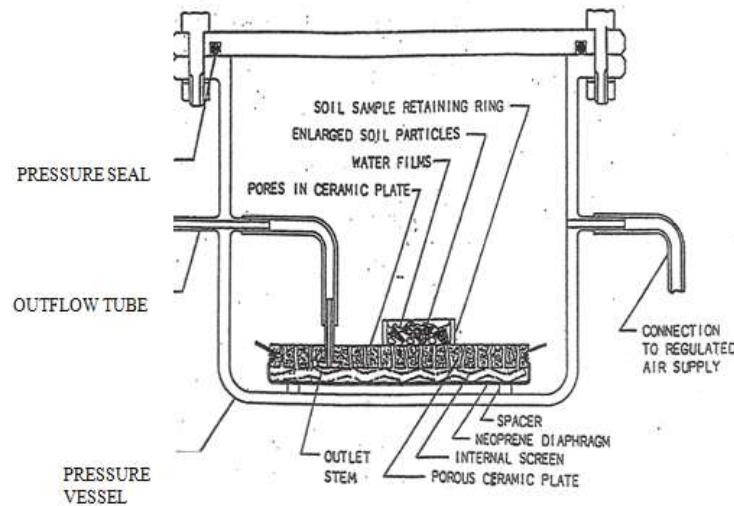


Fig.1 Cross Sectional View of Ceramic Pressure Plate Cell for Drying Curve

### Test Procedure

Soil samples were placed in the appropriate rings, levelled properly with care and covered with waxed papers. The soil samples were allowed to stand for saturation for at least 24 hours. They were removed after 24 hours, excess water from the ceramic plate was removed with pipette. The ceramic plate with the sample rings were mounted in the extractor and the outflow tube was connected with 'O' rings, the lid was mounted properly and the clamps were screwed down. The outflow tube was connected to the tip of the burette, fixed on a stand below the extractor cell.

The pressure in the extractor was turned on with a pressure unit and maintained at 1 bar. After one hour, water from the pressure plate cell started flowing into the burette. Once every hour, the water level in the burette or collector and the pressure cell were noted. The pressure is adjusted to maintain a constant value of 1 bar. After 24 hours the water level in the burette stops rising. The same pressure was then maintained for 6 more hours and it is ensured that there was no further rise of burette water level. This shows that equilibrium had been attained.

After covering the outflow tube with a tight polythene cover, the pressure in the pressure plate cell was released fully. The soil samples were taken out and weighed immediately. The soil samples were replaced again in the cell for continuation of the experiment at different suction values 3, 5, 8, 10, 12 and 14 bars. After the last run (14 bars) the samples were taken out for oven drying. The dry weight of the samples and moisture content and different pressure stages were computed. The levels of pressure maintained at equilibrium states were the suction values at the corresponding levels of water content.

For the purpose of comparison, suction tests were carried out in other natural soils such as red earth, marine soft clay and a slit, bentonite and kaolinite. Finally to find out the influence of density and the initial degree of saturation, the tests were also carried out at two different densities and on partially saturated conditions.

The relation between the suction and water content were obtained for all collected samples as listed in table 1. All these curves are shown in Figure 2 to 11. Some of the above curves are in semi logarithmic graph and others are in conventional graph. The degree of saturation and normalised water content and their respective relation with suction are shown in the Figures 12 to 17.

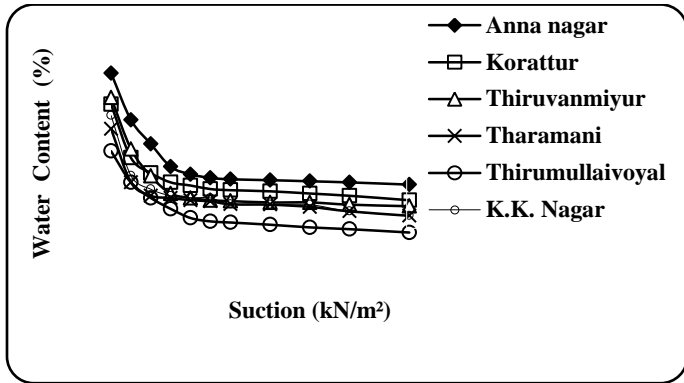


Fig 2. Suction Versus Water Content Relationship of Natural Soils

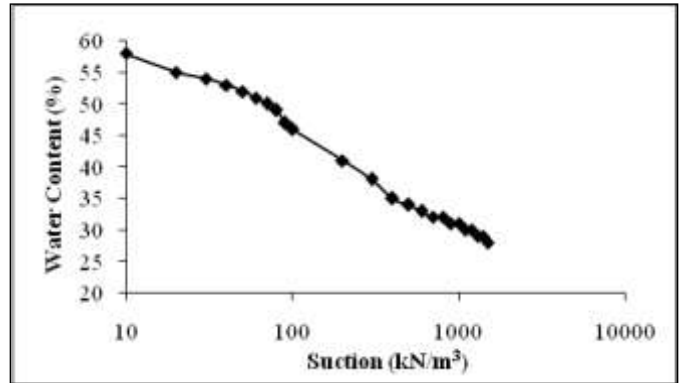


Fig 5. Suction Versus Water Content (Korattur Clay)

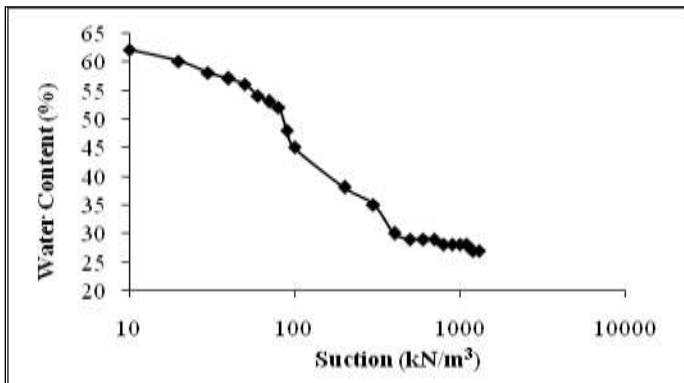


Fig 3. Suction Versus Water Content (Anna Nagar Clay)

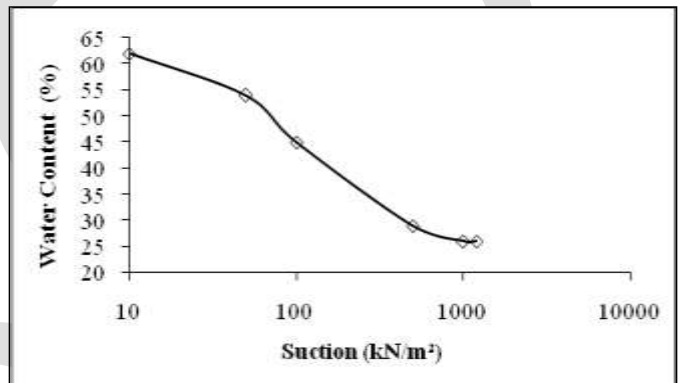


Fig 6. Suction Versus Water Content (Thiruvanmiyur Clay)

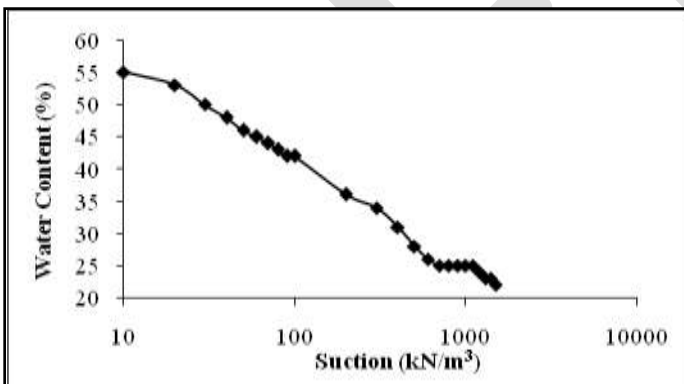


Fig 4. Suction Versus Water Content (K.K Nagar Clay)

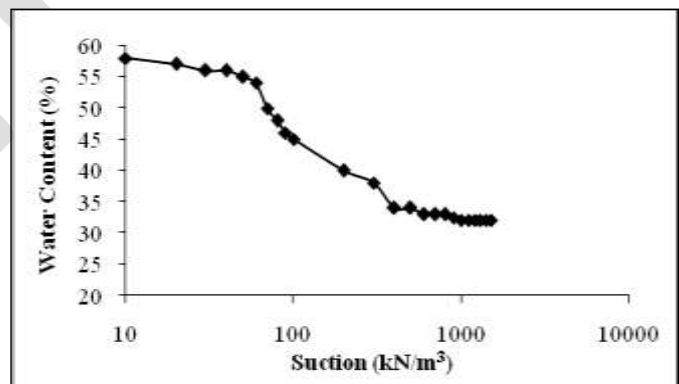


Fig 7. Suction Versus Water Content (Thiruvanmiyur Clay)

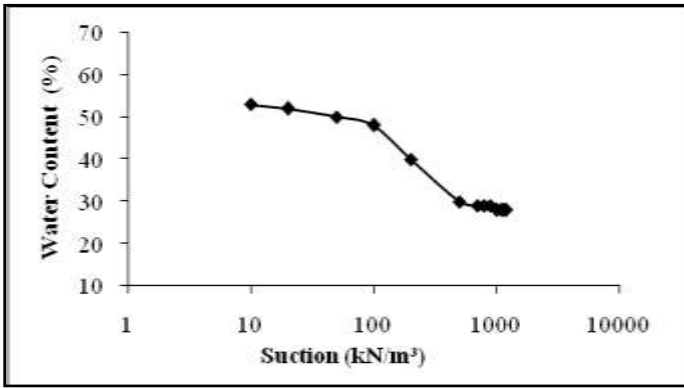


Fig 8. Suction Versus Water Content (Thirumullaivoil Clay)

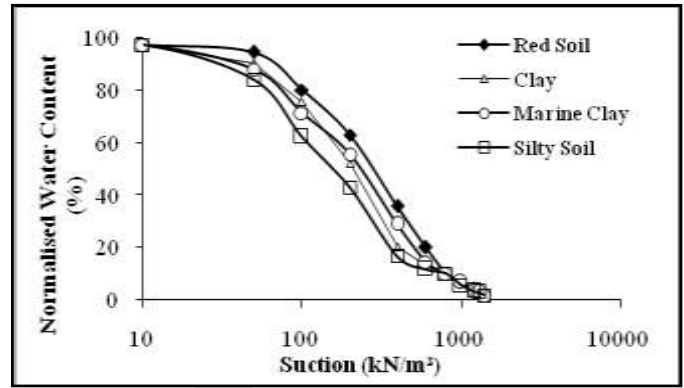


Fig 12. Suction Versus Normalised Water Content of Natural Soil

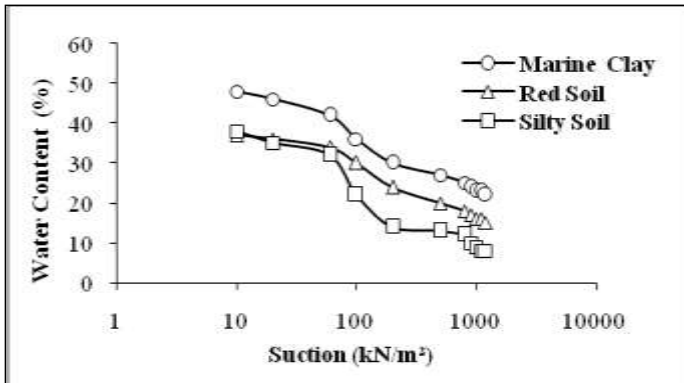


Fig 9. Suction Versus Water Content of Natural Soils

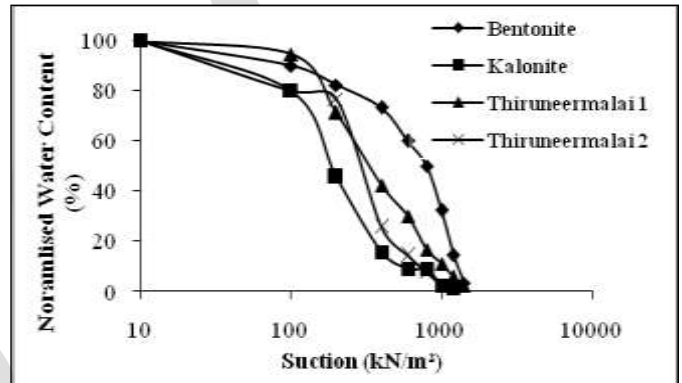


Fig 13. Suction Versus Normalised Water Content of Bentonite, Kaolinite and Thirneermalai Clay

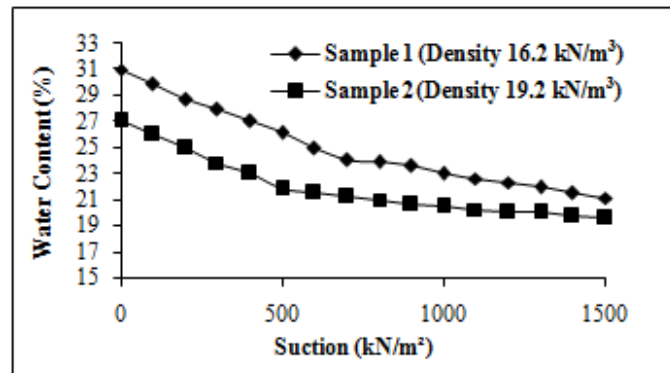


Fig 10. Suction Versus Water Content of Partially Saturated Clay (Thiruneermalai Clay)

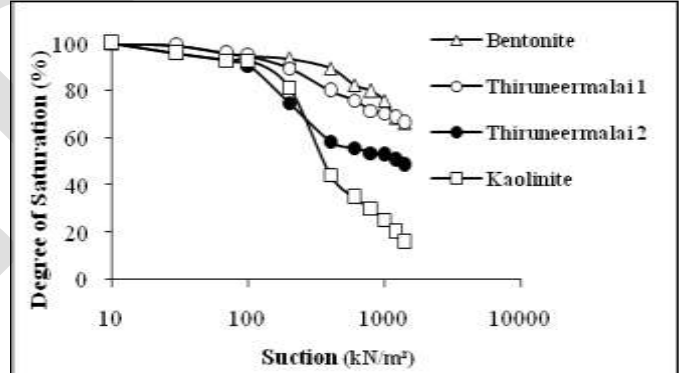


Fig 14. Suction Versus Degree of Saturation of Bentonite, Kaolinite and Thirneermalai Clay

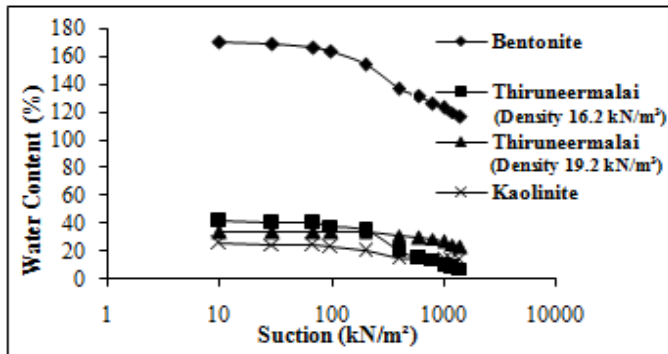


Fig 11. Suction Versus Water Content of Bentonite, Kaolinite and Thirneermalai Clay

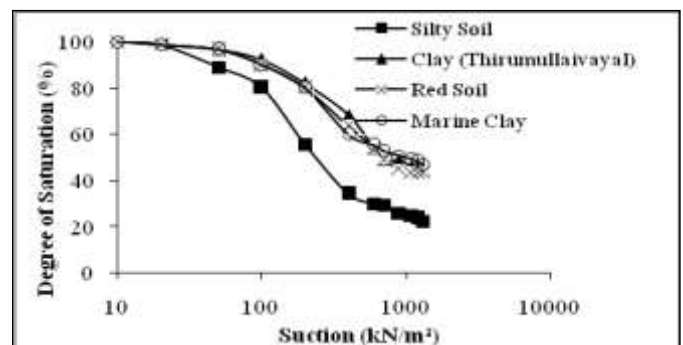


Fig 15. Suction Versus Degree of Saturation of Natural Soil

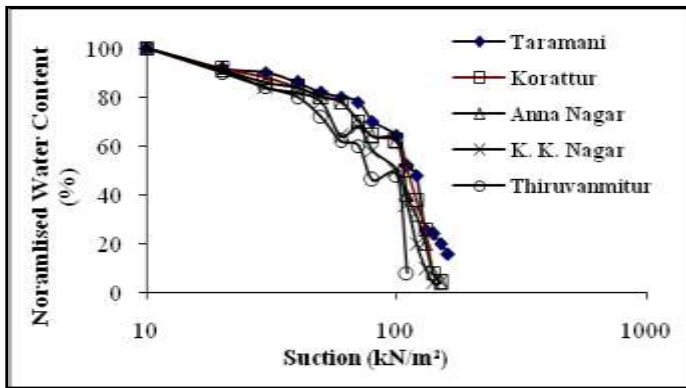


Fig 16. Suction Versus Normalised Water Content of Natural Expansive Clay

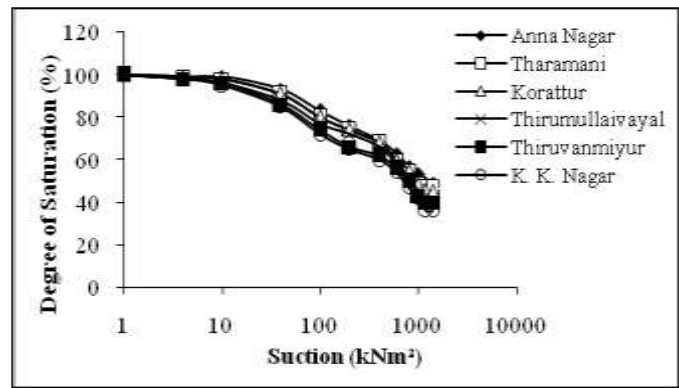


Fig 17. Suction Versus Degree of Saturation of Natural Expansive Clay

## DISCUSSION

### Soil Water Characteristics Curve Parameters

The SWCC parameters such as initial water content ( $w_i$ ), residual water content ( $w_r$ ), air entry value ( $\Psi_i$ ) and residual suction ( $\Psi_r$ ) values for different soils are read from the above graphs and are listed in Table 4.

Table 4 SWCC parameters

Location	$\Psi_r$ kN/m <sup>2</sup>	$\Psi_i$ kN/m <sup>2</sup>	$W_i$ (%)	$W_r$ (%)
Anna Nagar	950	106	68	35
K.K.Nagar	690	100	56	27
Korattur	560	76	58	32
Thirumullaivoyal	540	80	54.8	24
Thiruvanniyur	800	116	61	28
Taramani	763	70	58.5	29
Red Soil	220	75	38.8	16.3
Marine Clay	390	82	49.5	23.5
Silt	200	68	39	9
Kaolinite	585	70	25.3	16.7
Bentonite	1400	110	168.3	115

The saturated (initial) water content obtained for each sample is found to be lower than the liquid limit value which indicates that the soil is in the solid state but in a swollen condition. The residual water content is around the plastic limit value. This indicates that the prominence of swelling and shrinkage phenomena of the soil is between the plastic limit and the liquid limit. Also it is observed that as plasticity decreases, the residual water content is also reduced.

The air entry value ( $\Psi_i$ ) of all the natural soils tested (Chennai clays) is within a range of 68 – 116 kN/m<sup>2</sup>. For the Chennai clays the  $\Psi_i$  (air entry value) is found to be in the range of 70 kN/m<sup>2</sup> – 116 kN/m<sup>2</sup> and the residual suction values are in the range of 540 kN/m<sup>2</sup> - 950 kN/m<sup>2</sup>. For relatively coarse grained soil i.e. for silt these values are 68 kN/m<sup>2</sup> and 200 kN/m<sup>2</sup> respectively. For silty soil the residual water content is 9%, very low, for clayey soil it is comparatively high and is 39%. The residual suction of silty soil is 200 kN/m<sup>2</sup>. The air entry value is less for coarse grained and low plastic clay, where as it increases as a plasticity and percent fines increases. The gradation also plays a role in deciding the air entry value. From figure 9 it may be noted that the density of the soil sample and the initial degree of saturation of the soil sample also influence the shape of the soil water characteristics curve. The saturated water content and residual water content is less for higher density samples.

To find the influence of clay mineral, the SWCC of kaolinite and bentonite are also obtained. For a bentonite sample, the residual suction value is beyond the capacity of the testing apparatus and for kaolinite it was 585 kN/m<sup>2</sup>. From this it is understood that the presence of mineral also decides the characteristics of SWCC.

The residual degree of saturation is also found to be the function of plasticity and gradation and density. Almost all the natural samples reached the residual state within 1500 kN/m<sup>2</sup> as mentioned by Fredlund and Rahardjo (1999).



## Volume Change Indices

Volume change indices such as  $D_m(\Delta w / \log(\Psi_r/\Psi_i))$ ,  $b_m(\Delta w / \Delta \Psi)$  and  $C_r$ (Johnson,1977) are calculated from SWCC and are listed in the Table 5. The  $D_m$  values are in the range of 0.3 to 0.4 for the expansive clays. For red soil and bentonite it is 0.48. but for kaolinite it is 0.093 only and is very minimal. For non plasticsilty soil 0.64. For all clay it is in the narrow range of 0.3 to 0.4. The  $b_m$  values are in the range of  $3 \times 10^{-4}$  to  $7 \times 10^{-4}$  for expansive clays. For red and silty soil it is comparatively higher than other soils ( $15.5 \times 10^{-4} \text{ m}^2/\text{kN}$  and  $22.7 \times 10^{-4} \text{ m}^2/\text{kN}$ ). For kaolinite it is as low as  $1.7 \times 10^{-4} \text{ m}^2/\text{kN}$  and for bentonite it is  $4.132 \times 10^{-4} \text{ m}^2/\text{kN}$ .

Table 5 Volume Change Indices

Location	( $D_m$ )	( $b_m$ ) $10^{-4}$	$C_r$
Anna Nagar	0.346	3.909	0.078
K.K.Nagar	0.340	4.915	0.073
Korattur	0.300	5.372	0.076
Thirumullaivoyal	0.371	6.695	0.079
Thiruvanmiur	0.393	4.824	0.061
Taramani	0.384	4.230	0.095
Red Soil <sup>+</sup>	0.481	15.517	0.011
Marine Clay <sup>+</sup>	0.384	8.441	0.065
Silt <sup>+</sup>	0.640	22.747	-
Kaolinite <sup>+</sup>	0.093	1.669	-
Bentonite <sup>+</sup>	0.482	4.132	0.077

+ on remoulded soil

The values of volume change indices also indicate their dependency on gradation, its distribution, plasticity index, density and mineralogy of the given soil. Hence the use of the volume change indices in the prediction of heave shrinkage settlement in expansive clay and settlement due to ground water lowering in silty soil are valid.

## CONCLUSIONS

The SWCC of expansive clay and other soils such as red soil, marine clay, silt, kaolinite and montmorillonite has obtained. The air entry values of all the soils are found to be in the range of 70 to 116 kN/m<sup>2</sup>. The residual suction values are less than 1400 kN/m<sup>2</sup>. For bentonite the residual suction value is greater than 1400 kN/m<sup>2</sup>. For fine grained plastic soil the residual water content is around the plastic limit. It is also observed that for a silty soil, the soil SWCC parameters are less than those for all the other soils studied. From these data it is inferred that the SWCC is defined by grain size, its distribution, plasticity index, density, mineralogy and degree of saturation.

The various volume change indices such as  $D_m$ ,  $b_m$  and  $C_r$  are evaluated. Values of  $D_m$  are confined to a fairly close range of 0.3 to 0.4 except bentonite for which it is around 0.48. The values of  $C_r$  are seen to vary over a wide range, 0.07 to 2.08 for all clays and 0.011 for silt. The  $b_m$  value is in a smaller range for all fine grained soils studied. For coarse grained soils the values are comparatively high.

Hence from this study it is concluded that SWCC is a function of grain size, its distribution, density, plasticity index and mineralogy of the given soil and the use of SWCC in the determination of volume change characteristics of fine grained soil is very much valid.

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