EXPERIMENTAL STUDY ON WETTING SOIL WATER CHARACTERISTIC CURVE OF SAND WITH MIXTURE OF BENTONITE CLAY

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OF

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IN
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CANDIDATE'S DECLARATION

I, AATIF AHMED, 2K19/GTE/04, student of M.Tech (Geotechnical Engineering), hereby declare that the project Dissertation titled "EXPERIMENTAL STUDY ON WETTING SOIL WATER CHARACTERISTIC CURVE OF SAND WITH MIXTURE OF BENTONITE CLAY" which is submitted by me to the department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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Date: 31st July, 2021

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CERTIFICATE

I hereby certify that the Project Dissertation titled "EXPERIMENTAL STUDY ON WETTING SOIL WATER CHARACTERISTIC CURVE OF SAND WITH MIXTURE OF BENTONITE CLAY" which is submitted by me **AATIF AHMED** (2K19/GTE/04) belonging to Master of Technology, Geotechnical engineering, Civil engineering department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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Date: 31st July, 2021

Prof. Raju Sarkar
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ABSTRACT

Soil-water characteristic curve (SWCC) also known as water retention curve is an integral part of unsaturated soil mechanics. SWCC is a constitutive relation in unsaturated soil mechanics where soil suction is related to water content. Wetting SWCCs were determined for different sand-bentonite clay mixtures. With the help of the Van-Genuchten equation, acquired test data were fitted. Wetting SWCC can be related to flow of water through unsaturated zones of soil from the groundwater table to the ground surface. Negative column test was employed to determine SWCC since it is fairly simple and simulates the actual field conditions. In the present paper, different soil samples, where sand is mixed with varying proportions of bentonite clay are considered, for determining wetting SWCC. Finer the soil particle, higher will be the soil suction for a given water content. Hence, as the content of clay increases, SWCC slightly shifts towards the right, indicating the increment in soil suction. In turn, water entry value(WEV) also shoots up.

Keywords: Soil-water characteristic curve, drying SWCC, wetting SWCC, column test, soil suction.

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LIST OF ABBREVIATIONS AND SYMBOLS

1. SWCC : Soil Water Characteristic Curve
2. WEV : Water Entry Value
3. AEV : Air Entry Value
4. ψ_a : Air entry value
5. ψ_w : Water entry value
6. ψ_r : Suction corresponding to residual water content
7. θ_s : Saturated volumetric water content
8. θ_r : Residual volumetric water content
9. θ_w : Volumetric water content
10. h : Pressure head
11. $a,\ n,\ m$: Soil parameters in Van Genuchten equation
12. V_w : Volume of water in soil
13. V : Volume of total soil
14. RETC : Retention Curve
15. VPPE : Volumetric Pressure Plate Extractor
16. ρ_d : Dry density of soil
17. ρ_w : Density of water
18. w : Gravimetric water content

CHAPTER 1

INTRODUCTION

The role of soil water characteristic curve in unsaturated soil mechanics has been demonstrated in numerous studies. The unsaturated coefficient of permeability (Fredlund et al., 1994) and the shear strength of soil can be compared to the soil water characteristic curve (Vanapalli et al., 1996).

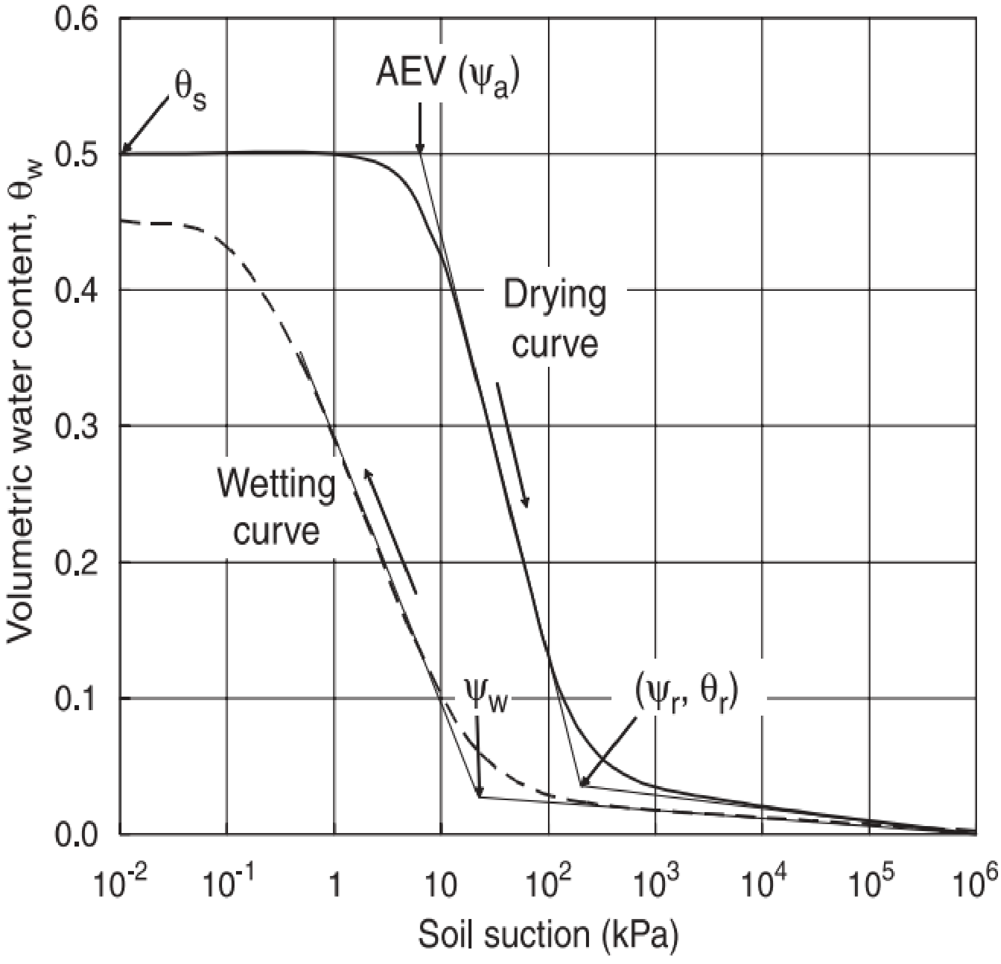

Fig.1.1: Idealized soil water characteristic curve (Fredlund and Xing 1994)

Either gravimetric or volumetric water content, θw (defined as the ratio of volume of water in the soil and the total volume of the soil, Vw/V), and soil suction are linked by a SWCC. The SWCC's form is determined by the soil type. Figure 1 shows typical SWCCs for drying and wetting. During the drying phase, the air-entry value, AEV or ψ_a, is specified as the matric suction at which air first enters the largest pores of the soil (Brooks and Corey 1964, 1966). The volumetric water content of the soil, θw, is fairly steady as matric suction rose from zero to the AEV of the soil. As matric suction exceeds the AEV, the water content gradually dips to the residual water content, θr. Water content in the residual state, where the water process is discontinuous, is known as residual water content. The residual soil suction(ψ_r), is the soil suction that corresponds to the residual water content. In the wetting SWCC, the water entry value (ψ_w), is specified as the matric suction at which the water content of the soil begins to substantially rise during the wetting phase.

To represent the highly nonlinear SWCC, a variety of empirical models or equations have been developed (e.g., van Genuchten 1980; Mualem 1986; Rossi and Nimmo 1994; Fredlund and Xing 1994; Assouline et al. 1998; Aubertin et al. 1998). Many researchers have used the van Genuchten (1980) equation among these equations (e.g Stormont and Anderson, 1999). As per Leong and Rahardjo (1997), the van Genuchten equation and the Fredlund and Xing (1994) equation are the best SWCC models for a variety of soils . Therefore, the van Genuchten equation was employed in this research. The equation was used with the least square algorithm in the RETC software to fit the SWCC.

The equation proposed by van Genuchten (1980) is as follows:

$$\theta_w = \theta_r + (\theta_s - \theta_r)[1 + (h * a)^n]^{-m} \quad [1.1]$$

Which can be re-written as,

$$\theta_w = \theta_r + (\theta_s - \theta_r)[1 + (\psi/a_0)^n]^{-m} \quad [1.2]$$

where θ_w is volumetric water content; h is pressure head; θ_s is water content at saturation phase; a is soil parameter (cm^{-1}); a_0 is soil parameter (kN/m^2); θ_r is water content at residual state; ψ is soil suction; n is a soil parameter linked to rate of water extraction from soil; and m is linked to residual water content.

The shape of the SWCC is defined by the fitting parameters in eq. {1.1} (i.e a , n , and m). These parameters are obtained by using a least-squares algorithm to best-fit test data into the calculated SWCC. Fredlund and Xing (1994) and van Genuchten (1994) provide more information (1980).

The water content of soil given at a matric suction is not exclusive. The water content in the drying curve is always higher than that in the wetting curve for a given matric suction (Fig. 1). In other words, during the drying and wetting processes, soil follows various SWCCs. This phenomenon is known as hysteresis. Several authors have researched and proposed different models to predict the SWCC's hysteretic behaviour, primarily to predict the wetting curves and secondary curves (e.g., Parlange 1976; Mualem 1977, 1984; Jaynes 1985; Hogarth et al. 1988; Nimmo 1992; Pham et al., 2000).

Here, SWCC of sand mixed with different proportions of Bentonite clay, were determined and best fitted using van Genuchten equation with the help of RETC software. The obtained points were correlated with grain size distribution.

CHAPTER 2

LITERATURE REVIEW

Yang et al. (2004) investigated drying and wetting soil water characteristic curves of five different soil specimens with the help of tempe cell and capillary rise tube. Test data points were fitted to two soil water characteristic equations using least squares algorithm. Fitting parameters were obtained and hysterical behaviour was described. Obtained SWCC was correlated with SWCC estimated from particle size distribution. They observed that the soil water characteristic curve of uniform soil had steeper slopes and not much total hysteresis. They also observed that soils with coarser grain had a lesser air-entry value, residual suction and water entry value. Predicted SWCC from particle size distribution was fairly accurate enough.

Fredlund et al. (2011) examined the reliability of SWCC for the determination of in situ soil suction. It presented the limitations of estimating soil suctions from SWCC and also suggested circumstances at which estimates should be used. The estimated suction values vary because of hysteresis between drying and wetting SWCC's. Hence, it is not often encouraged to estimate suction values due to the mentioned reasons. They showed the percentage error in estimated suction value is much less in sandy soils than clayey soils.

Elkady et al. (2013) evaluated the soil water characteristic curves of sand mixed with different proportions of Al-Qatif clay. Soil sample was prepared by taking sand as base and adding different proportions of clay (0%, 5%, 10%, 15%). They concluded that an increase in clay content caused the unimodal form of SWCC to become bimodal form.

Hong et al. (2016) estimated several cycles of water retention curve by employing volumetric pressure plate extractor (VPPE). For determining the SWCC with VPPE, four samples with different particle sizes and void ratios were selected. The hysteresis observed in the first cycle was largest and almost identical after 1.5 cycles.

The air entry value increased as the void ratio decreased. They finally concluded VPPE might fairly estimate several cycles of SWCC of soils.

X. Yang et al. (2018) analysed the effects of sodium chloride solutions on soil water characteristic curve of MX-80 Bentonite. This experiment showed that the concentration of salt in pore water had a major influence on Bentonite. The total suction of the samples gradually increased as the NaCl content increased, whereas the matric suction decreased. Total suction increased with addition of solution, when soil saturation is greater than 50%.

Van Genuchten et al. (1991) described RETC computer software to analyse soil water characteristic curves as well as hydraulic conductivity function of soil. Software uses the Van Genuchten equation to determine the soil water characteristic curve. The report gives detailed information on different analytical expressions used for quantifying soil water characteristic curves. The software also allows one to fit analytical functions to viewed soil water characteristic curve data. The report doubles as a user handbook and reference guide.

Y. Lins et al. (2009) determined an extensive database for sand with the help of a modified pressure plate apparatus. This database helps to derive conclusions on hydraulic properties. Results were derived from homogeneous element tests and initial boundaries considering varying hydraulic loading path directions. Finally, outputs are shown for soil water characteristic curves including scanning curves, main curves and initial curves.

A.Taban et al. (2017) used genetic programming to represent equations determining Van Genuchten's fitting parameters for sand. For both wetting and drying, new equations for estimating Van Genuchten modelling parameters are presented. Finally, the GP findings are assessed and verified in several ways to determine the accuracy of the proposed estimation equations.

H.Bilsel et al.(2000) studied the effects of climatic changes on the structure of calcareous marine clay. They found that repeated wetting and drying caused macro and micro fabric changes. The role of structural changes in soil water characteristic curves and permeability functions were investigated. Brooks and Corey, and Van Genuchten models were employed to describe soil water characteristic curves. The best fit to the data points were determined by variable m,n and m=1-1/n constraint. The repeated drying-wetting caused a reduction in pore size distribution and in turn increased water capacity. However, at lower suction values, the relative coefficient of permeability is about the same, and it decreases with repeated wetting.

CHAPTER 3

MATERIALS AND TEST METHODS

3.1 MATERIAL USED

Sand was obtained from a local construction site and was light grey to white. The sand was sieved and the size ranged from 4.75mm to 0.425mm was opted for the study. Total 5 samples were prepared by adding different proportions of Bentonite clay (0%, 5%, 10%, 15%) by weight. Bentonite clay was commercially obtained and was dark brown in colour.

3.2 BASIC PROPERTIES OF SOIL

The basic properties of the soil were determined by following indian standard codes. Specific gravity was determined with the help of a pycnometer using IS -2720 (part 3) : 1980. Grain size distributions were performed on soil with the help of IS - 2720 (part 4) : 1985. Atterberg's limit test was performed on Bentonite clay using IS - 2720 (part 5) : 1985. Free swell index was determined for Bentonite clay using IS - 2720 (part 40) : 1970.

Following are some basic properties of soil:

Table 3.1: Properties of soil specimen

DESCRIPTION	SAND	SAND + 5% BC	SAND + 10% BC	SAND + 15% BC
Specific gravity	2.68	2.683	2.681	2.683
Dry density of soil (g/cc)	1.39	1.44	1.46	1.46
Void Ratio	0.92	0.863	0.836	0.837
Porosity	0.48	0.463	0.455	0.455

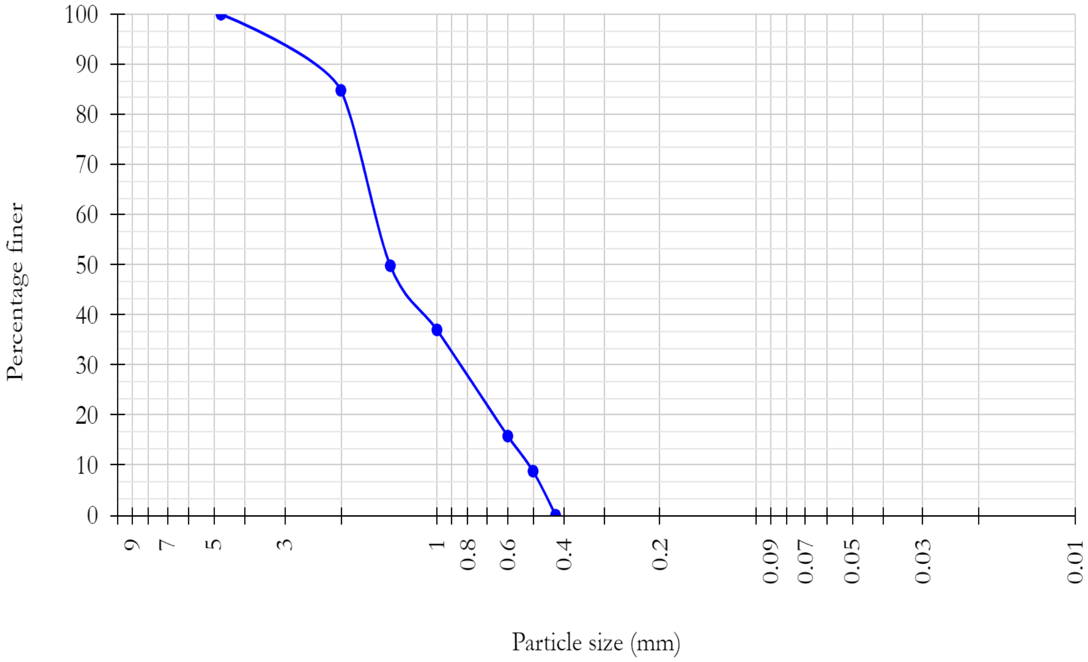

Fig. 3.1: Particle size distribution of sand

Table 3.2: Sand properties

DESCRIPTION	SAND
Unified Soil Classification System	SP
Specific gravity, Gs	2.68
Grain size analysis results	
D_{60} (mm)	1.55
D_{30} (mm)	0.84
D_{10} (mm)	0.5
Coefficient of uniformity, Cu	1.5
Coefficient of curvature, Cc	0.96

Table 3.3: Bentonite clay properties

DESCRIPTION	BENTONITE CLAY
Shrinkage limit	15.2%
Plastic limit	41.3%
Liquid limit	170%
Plasticity Index	128.7%
Specific gravity	2.66
Free swell index	652%

CHAPTER 4
METHODOLOGY

A negative column was used to obtain wetting soil water characteristic curves. In this test, soil specimen is placed in column and compacted. This setup is placed in a tray where a water table is maintained at the bottom of the column (Fig. 4.1).

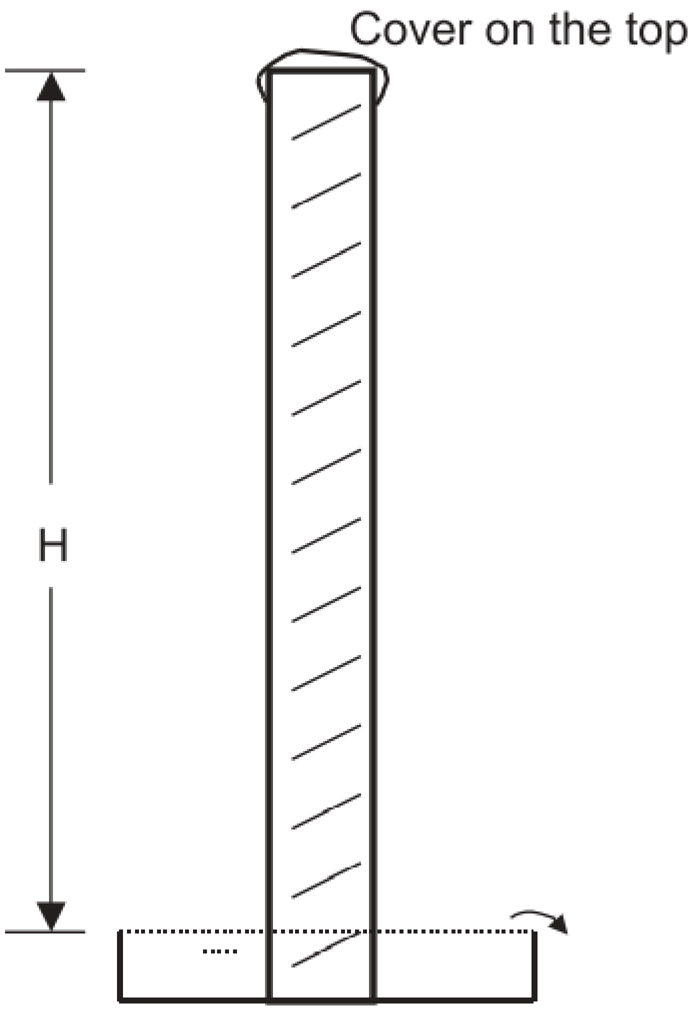

Fig. 4.1: Schematic diagram of Negative column (H.Yang 2004)

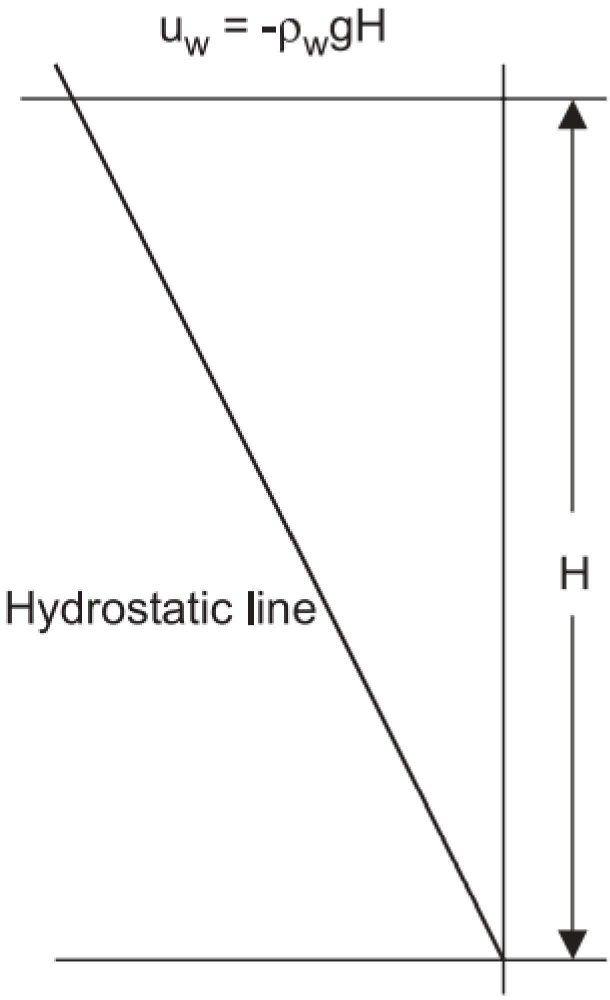

Fig. 4.2: Matric suction of soil specimen in Negative column (H.Yang 2004)

The top opening of the column is closed to avoid evaporation. Water present in the tray starts to seep into the specimen immediately as a column is placed on the tray. After some days, equilibrium of capillary water in the column is attained. Soil specimens are collected from each level in the column and used to determine water content. The following equation is employed to obtain volumetric water content:

$$\theta_w = \left(\rho_d/\rho_w\right) \times w \qquad [4.1]$$

Where; θ_w is volumetric water content

ρ_w is density of water

ρ_d is dry density of soil

The negative pore water pressure head is assumed to be the height of soil specimen from the water table. Matric suction is the difference between pore air pressure and pore water pressure. Whereas, in this case, negative pore water pressure is equal to matric suction, since air pressure is atmospheric in the column. The plot of volumetric water content versus matric suction gives the wetting soil water characteristic curve. Scatter points were best fitted with the help of different equations given by Van Genuchten. RETC software was employed to best fit the data.

Fig.4.3: Test setup of negative column

In this study, an acrylic column of 100mm diameter was used. Columns were kept undisturbed for 60 days. Equilibrium was attained during this period.

CHAPTER 5
RESULTS AND DISCUSSIONS

5.1 RESULTS OF WETTING SOIL WATER CHARACTERISTIC CURVES OF SOIL

A negative column was used to determine wetting soil water characteristic curves of soil specimens. The obtained test data were best fitted using the Van Genuchten equation. The test data were also best fitted by employing constraints m=1-1/n and m=1-2/n. The above constraint provides better fits for lesser known test data. RETC version 6.02 software was employed to determine water entry value, volumetric water content corresponding to water entry value and fitting parameters (such as a, m and n) as shown in table 5.1.

Table 5.1: Results of SWCCs and fitting parameters of Van Genuchten equation

DESCRIPTION		SAND	SAND + 5% B.C	SAND + 10% B.C	SAND + 15% B.C
Sat. water content (θ_s)		0.47	0.463	0.455	0.45
Water entry value (ψ_w)		1.847 kPa	3.5 kPa	3.84 kPa	4.633 kPa
Vol. water content ψ_w (θ_w)		0.007	0.027	0.032	0.046
V.G best fit parameters	a_0(kPa)	0.629	0.823	0.834	0.845
	m	0.823	0.61	0.58	0.51
	n	1.65	1.59	1.56	1.53
V.G best fit parameters m=1-1/n	a_0(kPa)	0.415	0.637	0.7	0.705
	m	0.497	0.459	0.455	0.418
	n	1.99	1.85	1.835	1.72
V.G best fit parameters m=1-2/n	a_0(kPa)	0.33	0.456	0.467	0.471
	m	0.302	0.256	0.245	0.218
	n	2.868	2.69	2.65	2.56

The best fit SWCC and test data results of soil specimens are shown in fig 5.1 to 5.5. The results show that the best fit of soil water characteristic curves using the Van Genuchten equation with variable and constrained fitting parameters are quite close and accurate enough to predict SWCC.

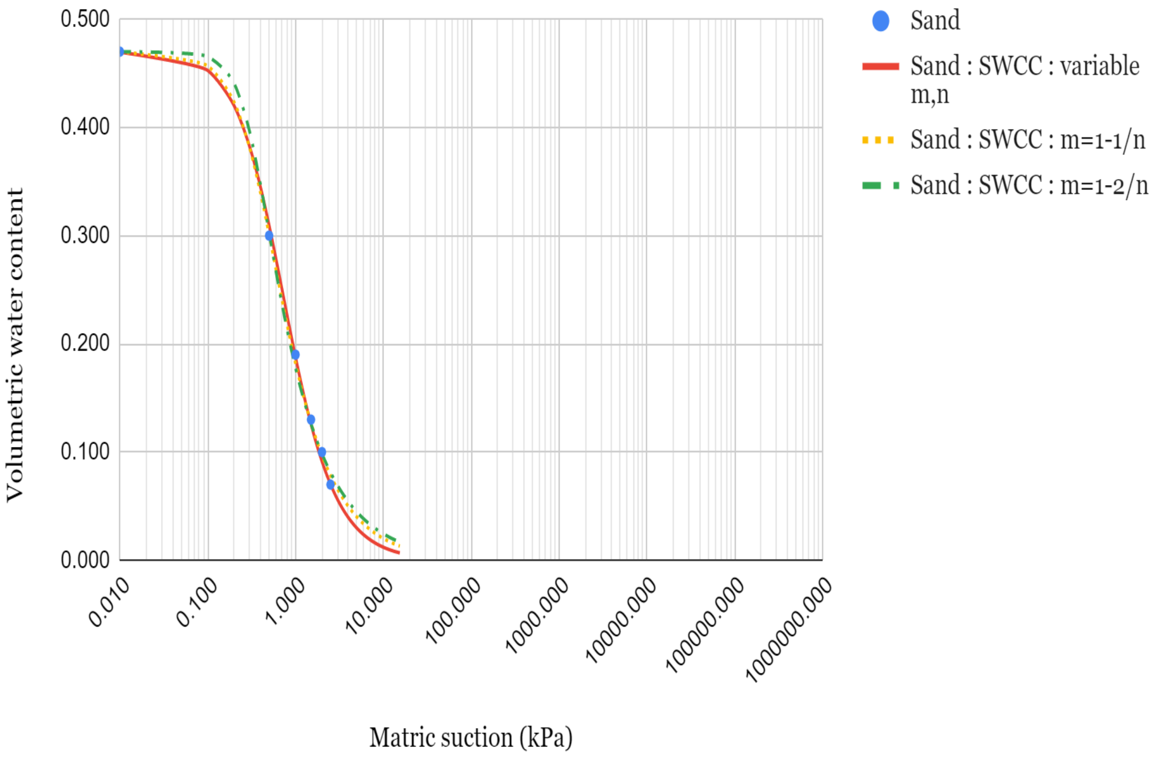

Fig.5.1: Wetting soil water characteristic curves of pure sand

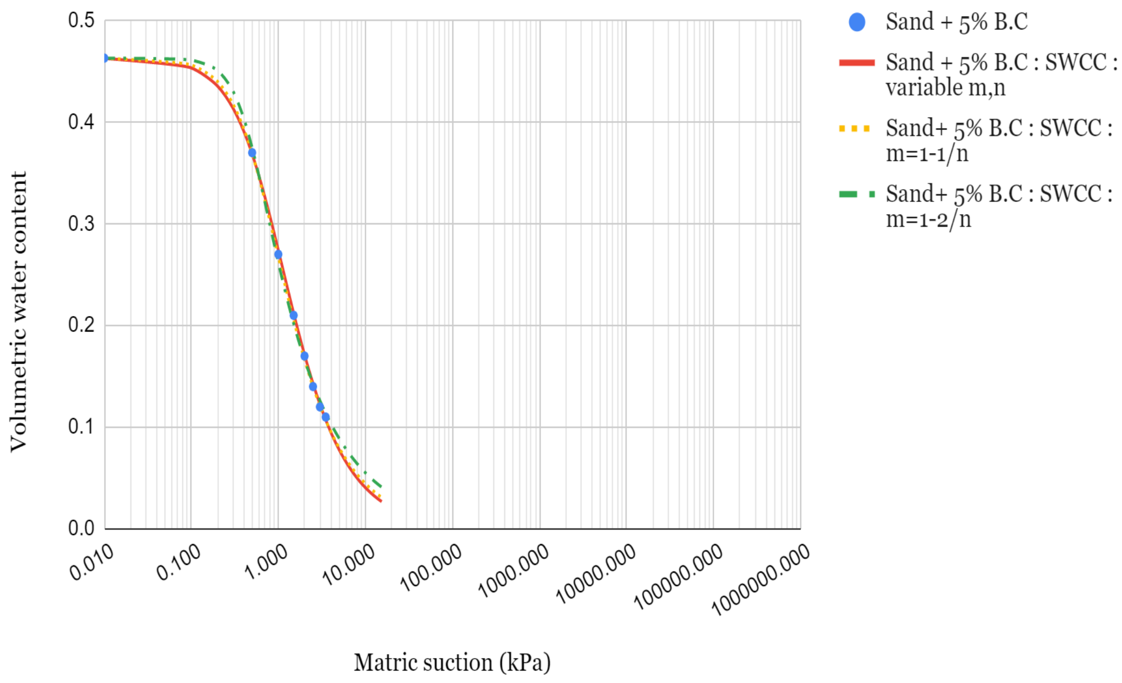

Fig.5.2: Wetting soil water characteristic curves of sand mixed with 5% of Bentonite clay

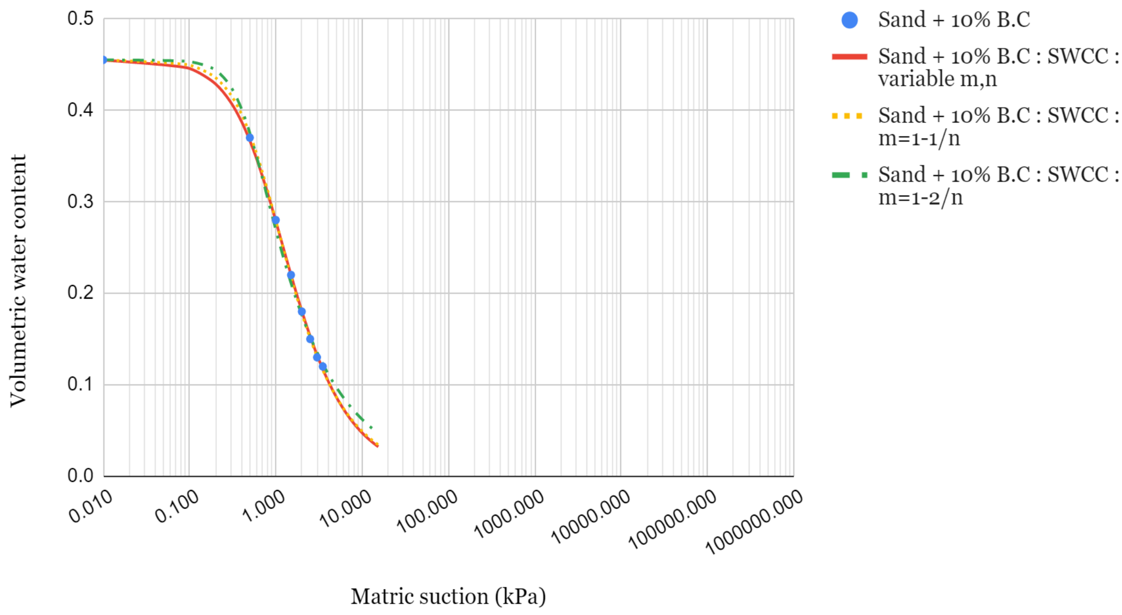

Fig.5.3: Wetting soil water characteristic curves of sand mixed with 10% of Bentonite clay

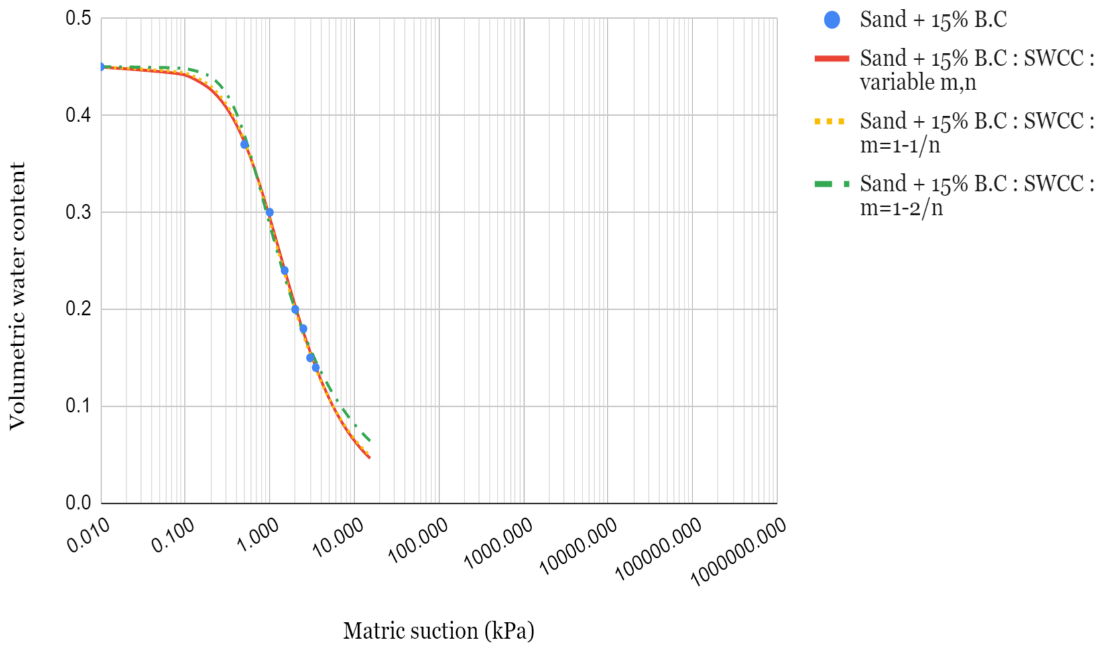

Fig.5.4: Wetting soil water characteristic curves of sand mixed with 15% of Bentonite clay

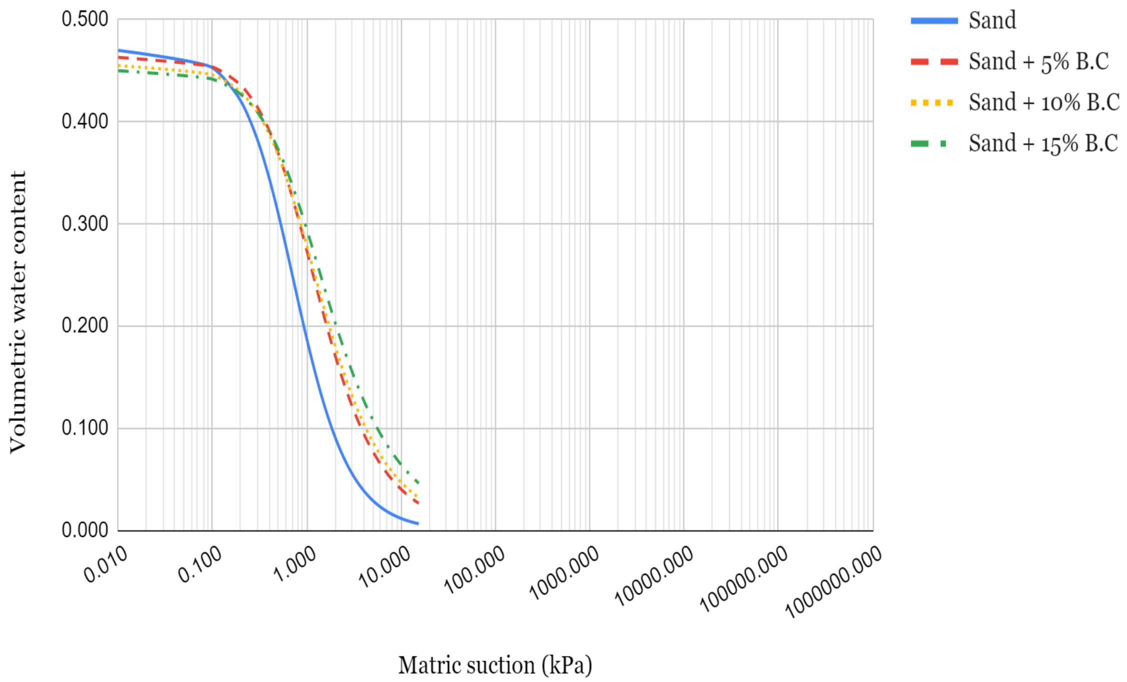

Fig.5.5: Best-fit wetting soil water characteristic curves of soil specimens

5.2 ANALYSIS OF WETTING SOIL WATER CHARACTERISTIC CURVES OF SOIL

The wetting soil water characteristic curve of pure sand differs noticeably from sand containing Bentonite clay. A slight difference is noticed among the SWCCs of sand mixed with different amounts of Bentonite clay. It is interesting to note that slight addition of clay can considerably affect the curve.The shape of the curves are controlled by fitting parameters such as a, m and n. The water entry value of wetting soil water characteristic curve is closely related to the amount of Bentonite clay present in sand. The presence of clay in sand reduces the pore size. It can be said that as the percentage of finer particles increases, the water entry value too increases.

The rise in negative column containing sand particles is due to capillary action. Smaller pore size encourages the capillary action. This phenomenon can be explained by considering pipes of different diameters partially submerged in water. Pipe with a smaller diameter shows much more rise in water level than a pipe with a larger diameter. This explains the shift of SWCC towards the right with an increment in clay content. Clay content reduces the pore size of sand. Clay shows much more water entry value than sand due to the fact that clay exhibits Diffuse Double Layer. Diffuse Double Layer too promotes the rise in water level in the negative column, in addition to capillary action. This leads to a sharp difference in SWCC of sand and sand with clay. Further increment in clay content doesn't change the SWCC by much.

CHAPTER 6
CONCLUSIONS AND SCOPE FOR FUTURE WORK

Wetting soil water characteristic curves were studied for 4 soil specimens which were pure sand,and sand with 5%, 10% and 15% of Bentonite clay. The test data were obtained with the help of a negative column. The Van Genuchten equation was used to best fit the SWCC test data. The variable m,n, m=1-1/n constraint and m=1-2/n constraint were used. The changes caused due to clay particles in sand were noticed. The following points can be concluded by present experiment:

1. The water entry value increases with increase in clay content.
2. The slope of SWCC of pure sand is much steeper than sand with clay particles.
3. Water entry value increases upto 90% with initial addition of clay particles.
4. Not much change is observed in SWCC of sand with different proportions of clay.
5. The increment in clay content, increases matric suction for given volumetric water content since clay particles fill up the pore space. Smaller pore promotes the capillary rise. This phenomenon can be understood by considering two tubes having diameter d_1 and d_2 ($d_1 > d_2$) respectively, which are partially submerged in water, capillary rise in the second tube will be higher due to the smaller diameter than the first tube.
6. Addition of clay content also introduces the phenomenon called diffuse double layer, which in turn promotes the rise in water level in the negative column.
7. Further, increase in clay content causes slight change in SWCC, since rise is caused only due to reduction in pore size.

The following are some recommendations for further study:

1. Different types of clay can be considered instead of Bentonite clay to study the behavior of SWCC.
2. The effect on the unsaturated coefficient of permeability can be shown due to the presence of Bentonite clay, since SWCC is related to it.
3. The change in drying soil water characteristic curve due to addition of Bentonite clay can be obtained with the help of axis translation method.

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