Study on Suction Swell Characteristics of Expansive Clays

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Abstract—**The objective of the proposed study is to obtain the relationship between soil suction and swell pressure based on drying soil water characteristics curve. To understand the relation between suction and swell characteristics of clays of high and intermediate permeability detailed laboratory investigations were carried out. The percent swell and swell pressure is low for CI clay than CH clay and are higher for solid state than semisolid state and plastic state. The percent swell of soil compacted for maximum dry density and selected dry of optimum density are lower than that of semisolid state. The swell pressure of clay compacted at maximum dry density and selected dry of optimum density are higher than that of solid state. Air entry value and residual suction value are higher for liquid state than plastic and solid state. The dewatering rate also decreases from liquid state to solid state. The relationship between suction and swell vary as the state of soil varies. The relationship between initial water content and percent swell as well as suction and swell pressure are nonlinear for both CH and CI type of clays. The influence of initial state is dominant for CH type clay than CI type clay.**

Keywords— Suction; air entry value; soil water characteristic curve

I. INTRODUCTION

Active clay soils undergo volume change upon wetting and drying. They are also called expansive soil. This volume change occurs in active zone which starts at the ground surface down to the saturated part of the zone of capillary rise above the ground water table. Usually lower the shrinkage limit (W_S) and wider the range of plasticity index (I_P), the more likely is the volume change to occur and greater the amount of suction change. The parent materials that are associated with expansive soil can be placed in two groups. The first group comprises of the basic igneous rocks such as the basalts of the Deccan plateau in India, the dolerite sills and dykes in the central region of South Africa and the gabbros and norities west of Pretoria north, Transvaal etc. In these soils, the feldspar and pyroxene minerals of the parent rocks decompose to form montmorillonite and other secondary minerals. The second group comprises of secondary rocks that contain montmorillonite as a constituent which breaks down physically to form expansive soils. Examples of these types of rocks are bed rock shale found in North America, marls and stones in Israel and the shale of South Africa.

The swelling of soils of India have their origin in subaqueous decomposition of basalts rocks or weathering in-situ. The mineral montmorillonite is formed under alkaline environment. This soil is popularly known as black cotton soil in India. The soil is mostly residual in character and the thickness of deposits is less than 5m in most cases. However, transported soil deposits are black cotton soils that are known to exist and they may be much thicker up to 8.0m or more. The marine deposits present in the narrow tidal coastal planes along the east and west coast of India have undergone desiccation over a period of time and these desiccated clays also exhibit characteristics similar to expansive soils.

II. LITERATURE REVIEW

Agus et al (2013) investigated the relationship between swelling pressure and suction of heavily compacted bentonite- sand mixtures and bentonite specimens. A series of suction controlled constant volume swelling pressure tests were performed using multi-step constant volume method where suction of the specimens tested was reduced in a stepwise manner toward a zero value. The test results revealed that suction decrease did not contribute to a reduction in the swelling pressure to indicate a collapse of macrostructure of the specimens tested. The influence of dry density on the development of swelling pressure was found to be distinct only at small applied suctions.

Mokhtari and Dehghani (2012) studied the behaviour of expansive clays and summarized the factors influencing the swell shrink behaviour of soil. Conditions affecting swell potential were also briefed. Control and Mitigation of the swell-shrink behaviour of expansive soil was also investigated in this article. Methods of improving expansive soil are also suggested.

Chittoori Bhaskar and Puppala Ananth J (2011) performed X-ray diffraction study on 20 soils to identify the minerals present in the soil. As a part of the experimental program, three chemical properties of clays, cation exchange capacity (CEC), specific surface area (SSA), and total potassium(TP) were determined for mineral identification analysis. The primary finding was that higher amounts of stabilizers are needed for treating native soils with high amounts of montmorillonite, i.e., when the percentage of montmorillonite exceeds 40% weight.

Vanapalli et al., (2011) determined the soil-water characteristic curve relationship of a single specimen from a fully saturated condition in the laboratory using pressure plate equipment. Initial water content had a considerable influence on the resulting structure of fine grained soils. The dry of optimum specimens were found to act more like a coarse grained soil with a highly aggregated macro structure. The conclusions of this study should be valid for fine grained soil of relatively stiff consistency.

Hung et al., (2007) illustrated the prediction of seasonal soil suction changes and is critical to the analysis of volume change in unsaturated expansive soils. A one dimensional moisture flow model was developed to study the boundary flux and suction conditions in a soil profile at a test site in Regina, Saskatchewan. A parametric study was performed to evaluate the soil properties and initial suction conditions on the actual evaporation.

From the literature survey it is observed that there is no attempt to find out the relation between suction and swell characteristics of expansive clay at different state. This kind of relationship is essential when the expansive clay is used for the construction activity with and without stabilizers.

The objective of the present study is to find out the relationship between the suction and swell characteristics of expansive clays at different initial state.

III. MATERIAL AND METHODS

Expansive clay from two different locations, namely Anna Nagar and Tambaram is procured and the methodology that is to be adopted in the present study is listed below.

Stage-1: Determination of Index properties and Compaction Characteristic of soils

(i) Collection of soil samples
(ii) Determination of index properties
(iii) General classification of soil
(iv) Expansive soil classification of collected soil
(v) Determination of Compaction Characteristics

Stage-2: Determination of SWCC of soil for different initial condition

(i) Liquid limit water content
(ii) Plastic limit water content
(iii) Shrinkage limit water content
(iv) Maximum dry density state
(v) Dry of optimum state

Stage-3: Determination of swell pressure for different initial condition as listed in stage-2

Stage-4: Examination of the suction and swell pressure value at identical condition to obtain the relationship between them.

The general procedure that is adopted to determine the SWCC and swell pressure are described in the following section.

PROCEDURE FOR DETERMINATION OF SWELL PRESSURE

The one-dimensional consolidation apparatus (i.e., oedometer) has been widely used for testing the swelling characteristics of swelling soils. The more commonly used testing procedures for determining the swelling pressure of the soil can be described as

(i) Swell oedometer test
(ii) Double oedometer test
(iii) Constant volume oedometer test

Among the above stated test methods, due to high swell and swell pressure results obtained from the swell oedometer test, it is chosen to be conducted for this study.

Swell oedometer Method

This method is also called as free swell method or expanded loaded method. An oedometer with ring 60mm in internal diameter and 20mm in height made of stainless steel was used. The ring was packed with soil at different initial condition. The oedometer ring was placed in the consolidometer with a nominal seating load of 3.5kPa and connected to a water column. Later, swelling of the sample was recorded over a period of time without any loading. After completion of the swelling cycle, the final heights(H_f) of these corresponding to the seating load have been obtained. Conventional loading was continued until the sample was restored to its initial heights (H_i). The swelling pressures (P_s) that correspond to the pressure applied to restore the initial sample heights, i.e., zero percent deformation, have been obtained. From these observations the percentage swelling can be calculated. It is the ratio of change in the height of the sample due to swelling(H_f) to its initial height(H_i).

PROCEDURE FOR DETERMINATION OF SWCC USING PRESSURE PLATE EXTRACTOR

The pressure plate extractor uses the axis-translation technique which reverses the reference air pressure from atmospheric pressure to above atmospheric pressure causing the pore water pressure to change as it comes to equilibrium with the pore air pressure. In a closed system, the air pressure was varied and the soil water pressure varied by some magnitude so the matric suction remained constant. No water flow occurred. This behaviour is used to verify that the axis-translation technique is valid. In an open system, the high pore air pressure forces the water to flow from the soil to the ceramic disk until the soil pore water pressure, equal to the pressure in the disk, comes to equilibrium with the soil air pressure. A ceramic plate was saturated and soil sample(s) was placed on it. The soil was allowed to reach a desired state of equilibrium. The air pressure in the pressure cell was varied until the equilibrium was reached again. The soil matric pressure is the difference between the applied air pressure and the water pressure where the water pressure is usually close to atmospheric pressure.

In order to conduct the test, the specimen ring was prepared by packing the required amount of soil, so as to achieve the initial condition. Six specimen rings were 60mm in internal diameter and 10mm in height made of poly vinyl chloride (PVC) materials. These specimens were submerged in water allowing access to drainage at top and bottom for about 24 hours. The degree of saturation of these specimens was checked using waxed trail samples that were weighted in air and water. The degree of saturation was greater than 99% for all the samples. The prepared specimens were placed on a high air-entry ceramic disk of 15 bar in sealed air pressure

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 11, November-2019

chamber. Water in the compartment beneath the disk was maintained at zero water pressure while an applied air pressure induces a matric suction under which the specimen is allowed to come to equilibrium.

IV. RESULTS AND DISCUSSION

The gradation characteristics, consistency limits tests and standard proctor compaction tests were conducted for the two soil samples as per relevant I.S code recommendation. To study the soil-water characteristics curves of the different soil samples at a known compacted density, the standard proctor compaction test was carried out on the two samples. The index and compaction characteristics of expansive clays obtained from these tests are listed in table 1.

TABLE 1 INDEX PROPERTIES AND COMPACTION CHARACTERISTICS OF THE ANNA NAGAR AND TAMBARAM SOIL

S. No.	DESCRIPTION	ANNA NAGAR	TAMBARAM
1	**Specific gravity**	2.72	2.62
2	**Gradation characteristics**		
	Gravel	0	0
	Sand	2	15
	Silt	20	35
	Clay	78	50
3	**Liquid limit (%)**	60	46
4	**Plastic limit (%)**	28	22
5	**Shrinkage limit (%)**	13.5	16
6	**Plasticity index (%)**	32	24
7	**Differential free swell index(%) as per BIS**	82	62.5
8	**Classification of soil free swell index(%)**	CH	CI
9	**Expansive classification of soil based on IS 1498**	Critical	Marginal
10	**Standardproctor compaction test results**		
	Maximum Dry Density (g/cc)	1.560	1.750
	OMC(%)	29.18	26.09

From table 1, it can be observed that the optimum moisture content of Anna Nagar clay is 29.08% and that of Tambaram clay is 26.09%. The maximum dry density of Anna Nagar clay is 1.56 g/cc and Tambaram clay is 1.75g/cc. From the above data, it is inferred that increase in percentage of fines, percentage of clay, plasticity index, increase in liquid limit, decrease in shrinkage limit decreases the maximum dry density and increases the optimum moisture content. Anna Nagar clay is classified as CH, clay of high plasticity and Tambaram clay is classified as CI, clay of intermediate plasticity. The swell classification of the soils as per IS 1498 are critical and marginal as listed in table 1.

The swell and soil-water characteristics curve is determined for different initial conditions as summarised in table 2.

TABLE 2- DIFFERENT INITIAL CONDITIONS OF SWELL AND SUCTION TEST

Sample Location	**Water Content %**	**State Of Soil**	**Density (g/cc)**
Anna Nagar	59	Liquid	-
	34	Plastic	1.728
	23	Semi solid	1.728
	13	Solid	1.728
	29	OMC	1.560
	26	Dry of OMC	1.320
Tambaram	46	Liquid	-
	22	Plastic	1.728
	17	Semi solid	1.728
	14	Solid	1.728
	29.19	OMC	1.750
	22.09	Dry of OMC	1.695

The SWCC and swell curve of Anna Nagar is shown in the figure 1 and 2 respectively. The same type of curves is obtained for Tambaram also.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 11, November-2019

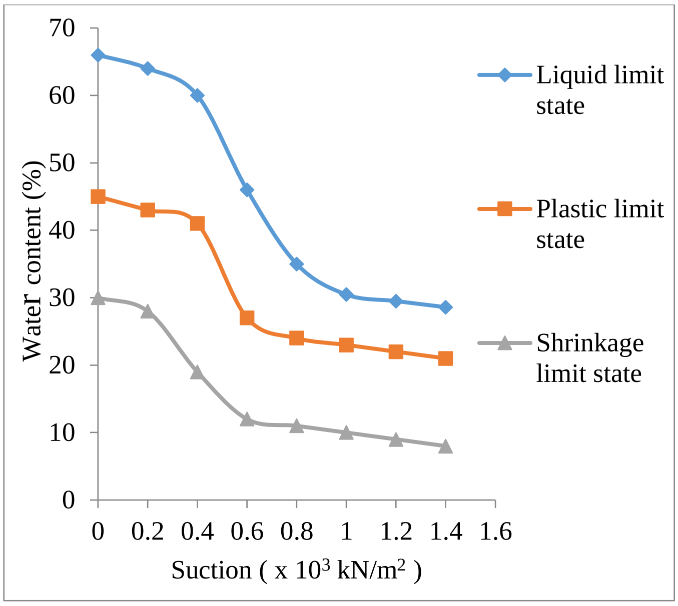

Fig.1 Water Content Vs Suction of Anna Nagar Clay at Different Initial Condition

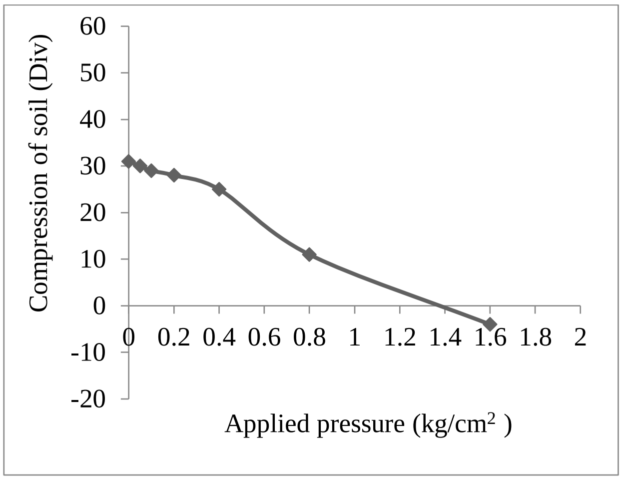

Fig. 2 Applied Pressure Versus Compression of Soils, Anna Nagar Clay at Maximum Dry Density Moisture Content

Swell and Swell Pressure Results

Based on the swell tests conducted as per procedure stated in section III, the results obtained are presented in table 3 and 4.

TABLE 3 PERCENT SWELLING AND SWELL PRESSURE OF ANNA NAGAR CLAY

Sl. No	State of the samples	Dry density g/cc	Initial water content %	Final water content %	Percent swelling %	Swell pressure (Ps) kN/m²
1	*Solid state*	1.728	13.5	36.50	2.80	36
2	*Semi- solid state*	1.728	20.75	32.0	1.65	19
3	*Plastic state*	1.728	28.0	30.05	1.05	16
4	*Maximum dry density*	1.560	29.18	36.03	1.55	140

TABLE 4 PERCENT SWELLING AND SWELL PRESSURE OF TAMBARAM CLAY

Sl. N o	State of the samples	Dry density g/cc	Initial water content %	Final water content %	Percent swelling %	Swell pressure (Ps) kN/m²
1	*Solid state*	1.728	16	35.50	2.05	32
2	*Semi-solid state*	1.728	19	28.3	1.25	24
3	*Plastic state*	1.750	22	25.20	0.95	12
4	*Maximum dry density*	1.726	26.09	32.50	2.10	72

The observations made from tables 3 and 4 are summarized in the following paragraphs.

It can be observed from the results obtained that the percent swell is low for CI clay than CH clay. The CH type clay exhibits high swell pressure than CI clay. The percent swell and swell pressure are higher for solid state than semisolid state and plastic state. The percent swell of soil compacted for maximum dry density and selected dry of optimum density are lower than that of semisolid state. The swell pressure of clay compacted at maximum dry density and selected dry of optimum density are higher than that of solid state. Increase in initial water content irrespective of different density decreases the initial swelling.

The clay in solid state exhibits higher initial swell and primary swell than secondary swell. The clay in plastic and semi solid state exhibits higher secondary swell than primary and initial swell for CH type soil. Time versus swell relation of CH and CI type of soil at solid state are same. At semi solid and plastic state of CI type soil exhibits higher primary swell than initial and secondary swell. At plastic state the initial swell is zero for CH type soil and secondary swell is zero for CI type soil. The secondary swell percent is same for soil compacted for maximum and dry of optimum density and water content for CH type soil respectively.

The initial swell percent is same for soil compacted for maximum and dry of optimum density and water content respectively for CI type of soil. The percent swell of CI type of soil is comparatively lower than CH type soil at the same density.

Since the maximum dry density and optimum moisture content of CI type of clay is higher than CH type of clay, the percent swell of CI type of clay is higher than CH clay at their respective density and water content. The secondary swell percent is same for soil compacted for maximum and dry of optimum density and water content respectively for CI type of soil. The initial swell percent is same for soil compacted for maximum and dry of

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 11, November-2019

optimum density and water content respectively for CI type soil. The percent swell of CI type of soil is comparatively lower than CH type soil at the same density.

Swell and Suction Results

Based on the suction test conducted as per procedure stated in section III, the results obtained are presented in table 5 and 6. The results obtained from swell and suction tests are plotted to compare the percent swell and swell pressure with suction for different states of soil from Anna Nagar and Tambaram which is shown in figure 3 to 6.

TABLE 5 SUCTION Vs SWELL PRESSURE OF ANNA NAGAR CLAY AT DIFFERENT INITIAL CONDITION

Water content (%)	**Swell pressure (kN/m²)**	**Swell (%)**	**Suction at different initial condition of soil**		
			Liquid state	***Plastic state***	***Solid state***
16.0	32.0	2.05	>1300	>1300	>1000
19.0	24.0	1.25	>1300	>1100	>800
22.0	12.0	0.95	>1300	1000	500
OMC	90	-	-	-	-
Dry of OMC	72	-	-	-	-

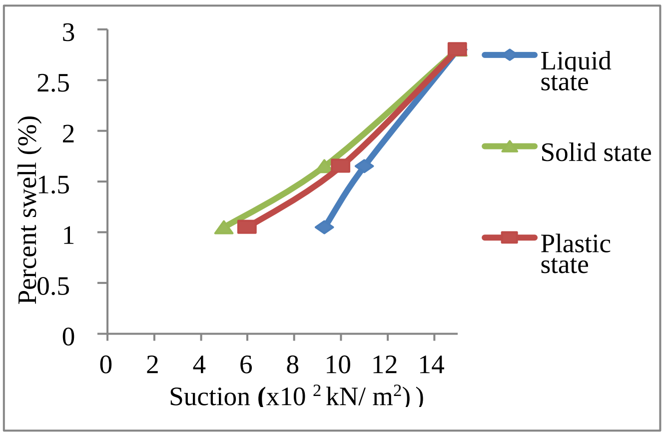

Fig 3. Suction Vs Percent Swell of Anna Nagar Clay at Different State of Soil

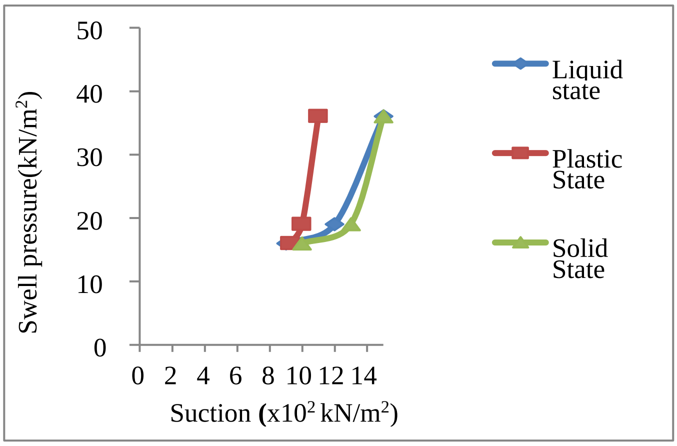

Fig 4. Suction Vs Swell Pressure of Anna Nagar Clay at Different State of Soil

TABLE 6 SUCTION Vs SWELL PRESSURE OF TAMBARAM CLAY AT DIFFERENT INITIAL CONDITION

Water content (%)	**Swell pressure (kN/m²)**	**Swell %**	**Suction at different initial condition of soil**		
			Liquid state	***Plastic state***	***Solid state***
13.5	36.0	2.8	>1000	>1000	>930
20.75	19.0	1.65	>1100	>1000	930
28.0	16.0	1.05	>1000	600	500
OMC	140	-	-	-	-
Dry of OMC	110	-	-	-	-

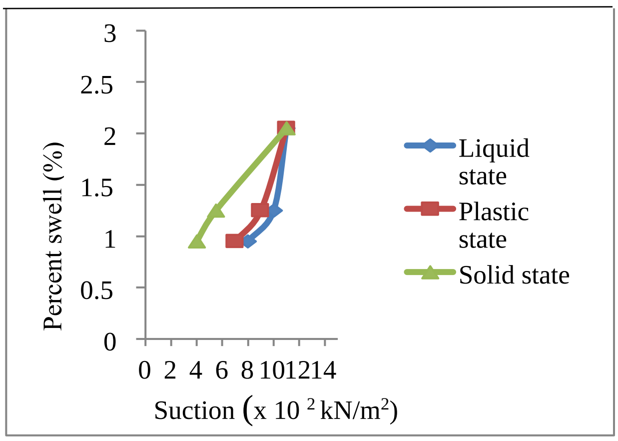

Fig. 5 Suction Vs Percent Swell of Tambaram Clay at Different State of Soil

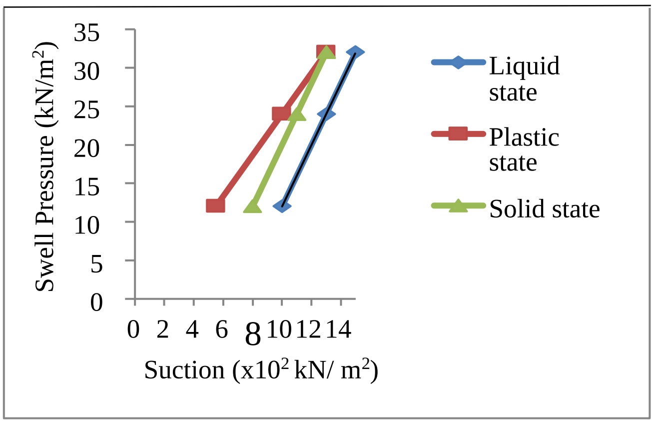

Fig.6 Suction Vs Swell Pressure of Tambaram Clay at Different State of Soil

The observations from table 5 and 6 are, the relationship between suction and swell vary as the state of soil varies. Both CH and CI type clay have suction values greater than 1000kPa for solid and semi solid state. The relationship between initial water content and percent swell is nonlinear for both CH and CI type clays. The relationship between initial water content and swell pressure is also nonlinear for both CH and CI type of clays. The relationship between suction and swell pressure is also nonlinear for both CH and CI type of clays at different initial state. The relationship between suction and percent swell is almost linear for both CH and CI type of clays at different initial state.

VI. CONCLUSIONS

To understand the relation between suction and swell characteristics of expansive clays, clays of CH and CI type are collected and detailed laboratory investigations were carried out. The important observations made from this laboratory investigation are summarized below.

Percent Swell and Swell Pressure

i) The percent swell and swell pressure are higher for solid state than semisolid state and plastic state.
ii) The percent swell of soil compacted for maximum dry density and selected dry of optimum density are lower than semisolid state.
iii) The swell pressure of clay compacted at maximum dry density and selected dry of optimum density are higher than solid state.
The above observations are very well within the observations reported in literatures.

Swell suction relationship

i) The relationship between suction and swell vary as the state of soil vary. Both CH and CI type clay, suction values are greater than 1000kPa for solid and semi solid state.
ii) The relationship of initial water content with percent swell and swell pressure are nonlinear for both CH and CI type clays.
iii) The relationship between suction and swell pressure are also nonlinear for both CH and CI type of clays at different initial state.
iv) The relationship between suction and percent swell are almost linear for both CH and CI type of clays at different initial state.
v) The influence of initial state is dominant for CH type clay than CI type clay.

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