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Soil Water Characteristics Curve of Lime Stabilized Soil

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Abstract: ***Expansive clays are problematic deposits to civil engineering constructions as these deposits exhibit swelling and shrinkage during wet and dry seasons respectively. Therefore stabilization of expansive clay is of interest to engineers who deal with this soil. Among various stabilizing agents addition of lime with clay is considered more effective. The research work on Soil Water Characteristics Curve (SWCC) of lime stabilized soil cured at various curing conditions are limited. Towards understanding this aspect an attempt is made in the present investigation to bring out the effect of curing conditions and lime contents on SWCC of lime stabilized clayey soil. In the present investigation, a black cotton soil, classified as clay of high plasticity, CH, is used for all the experiments. Laboratory grade hydrated lime was used for the stabilization of soil. Based on the experimental results, efforts were made to establish empirical relations between SWCC parameters with curing condition, lime content etc. The SWCC of lime treated soil with different lime content, curing period and curing temperature were plotted. The SWCC parameters a, m, n were affected by lime treatment. The average value of parameter "a" increased with increase in lime content and curing temperature. As far as curing period was concerned "a" increased upto 14 days curing and slightly reduces thereafter.***

Keywords: Expansive clay, SWCC, lime content, curing period

1. Introduction

Expansive soils are commonly found in arid and semiarid regions of the world. They have potential for volume change (swelling and shrinkage) upon change in moisture content. Lime stabilization is one of the oldest techniques adopted to improve the engineering behavior of expansive soils.

Soil suction is a quantity used to study the behavior of unsaturated soils. Soil suction is a potential energy quantity which is responsible for soil water retention. The two components of soil suction are matric suction and osmotic suction. Matric suction arises from the capillary forces, soil texture, and adsorption forces of clay particles. Osmotic suction is due to the differential concentration of salts and the development of an osmotic gradient that attracts even more water.

Engineering behaviour of collapsible residual compacted and expansive soils that are typically in a state of unsaturated condition can be better interpreted if the influence of matric suction is taken into account (Fredlund 2000). The direct measurements of properties of unsaturated soil by experiments are expensive and time consuming. Hence, soil water characteristics curve has been used to predict the engineering behavior of unsaturated soil by researchers in the recent past (Barbour 1998). Since lime stabilization is one of the popular techniques used to improve the engineering behavior of expansive soil, in this chapter, the Soil Water Characteristic Curves (SWCC) of natural soil and thermally cured lime treated expansive soils are presented and discussed to bring out the effects of lime treatment on the SWCC of soil.

2. Background of SWCC

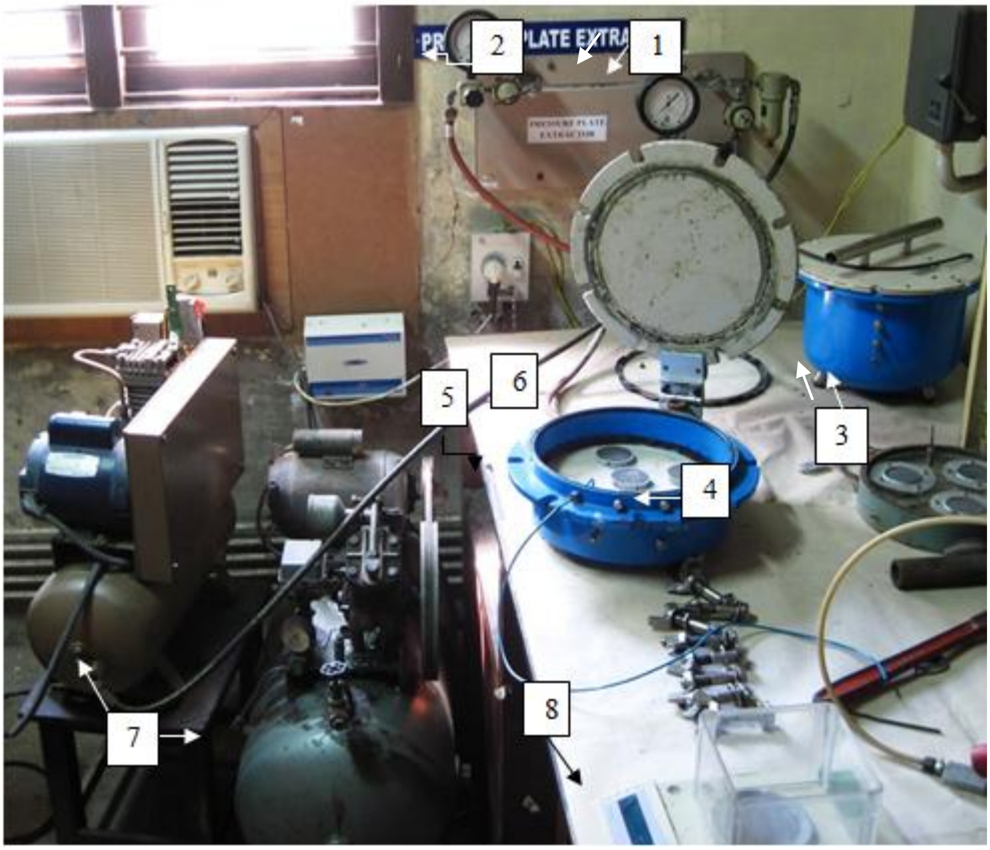
Leong and Rahardjo (1995) and Sillers et al. (2001) showed based on their comprehensive study that experimental data for various soils over a wide soil suction range can be well fitted using the Fredlund and Xing (1994) equation. Further Puppala (2006) used the Fredlund and Xing (1994) equation for the analysis of SWCC's of stabilized soils. Therefore, in the present study the Fredlund and Xing (1994) equation is used for the analysis.

3. Results and Discussions

The clayey soil collected from Siruseri, Tamil Nadu, India was dried in air and pulverized and passed through 425 μm sieve prior to use for SWCC tests. The specific gravity of natural soil is 2.72. The soil composed of 30% sand fractions, 34% silt fractions and 36% clay fractions. The soil exhibited liquid limit and plastic limit of 80% and 25% respectively. The plasticity index of the soil is 55% and its shrinkage limit is 12%. Based on USCS soil classification system, the soil is classified as Clay of High plasticity (CH).

The samples for SWCC tests were prepared at a maximum dry unit weight and moisture content of 15.5 kN/m^3 and 23% for natural soil and 14.5 kN/m^3 and 26% for lime mixed soils respectively. The samples were prepared for the lime contents of 3%, 5% and 7%. The test specimens for SWCC were prepared by static compaction in a mound of diameter 60mm and height of 10mm.

The pressure plate apparatus used in the present study is shown in Figure 1. Two pressure chambers of 5 bar and 15 bar capacities were engaged for the study.



1) 5 Bar Pressure regulator set up
2) 15 Bar Pressure regulator set up
3) 5 Bar pressure chamber
4) 15 Bar pressure chamber
5) 15 Bar ceramic plate
6) Specimen
7) Air compressor
8) Weighing balance (0.0001 g accuracy)

Figure 1: Pressure Plate Apparatus

The SWCC of natural soil, 3% , 5% and 7% lime treated soils cured at 15°C, 30°C and 40°C for 7, 14 and 28 days are obtained using pressure plate apparatus. The samples for suction tests are prepared to get the required unit weight at the specified water content by applying static compactive energy using predetermined weight of soil-lime-water mix. For each condition at least 9 identical samples were prepared. Enough care was taken to avoid the moisture fluctuation and was ensured by taking the weight of the specimens at each stage that is after compaction, curing, saturation and at the end of the test. The sample with greater than ±1% weight change is rejected and the one with less error is taken for the analysis.

Figures 2 to 5 plot SWCC of 3% and 7% lime treated soil cured at 30°C and 40°C for 7, 14 and 28 days.

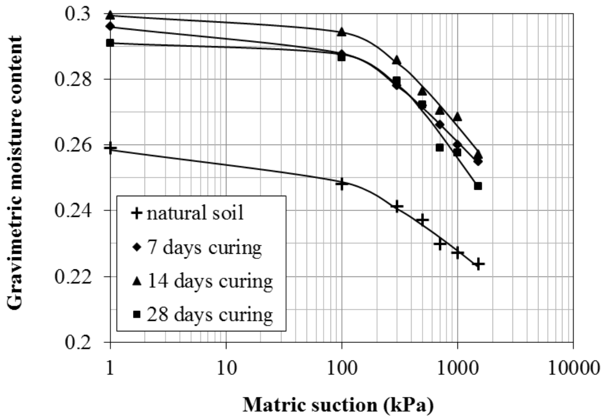


Figure 2: SWCC for 3% Lime Treated Soil Cured at 30°C

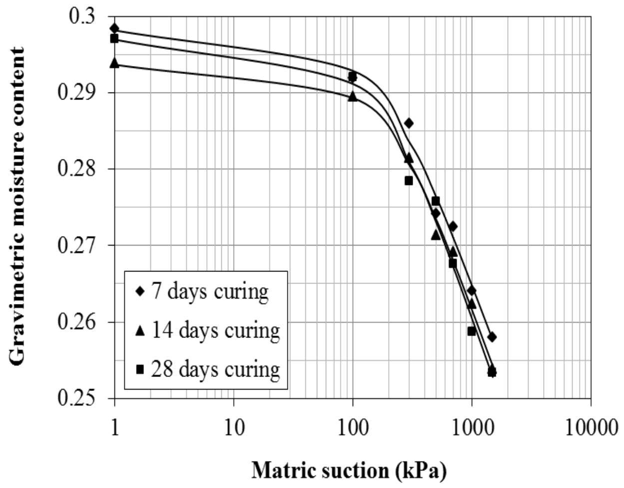


Figure 3: SWCC for 3% Lime Treated Soil Cured at 40°C

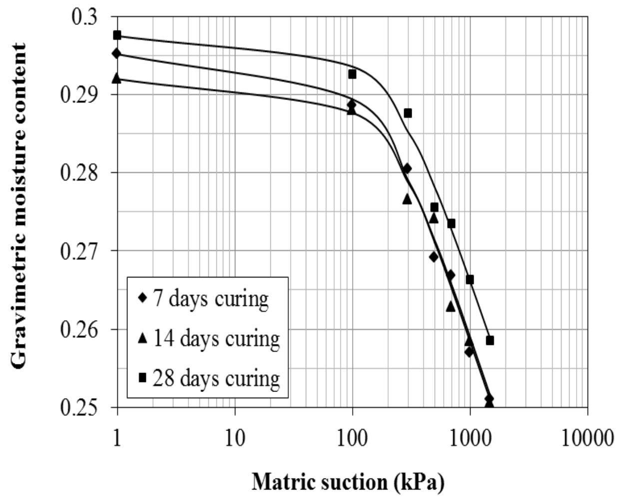


Figure 4: SWCC for 7% Lime Treated Soil Cured at 30°C

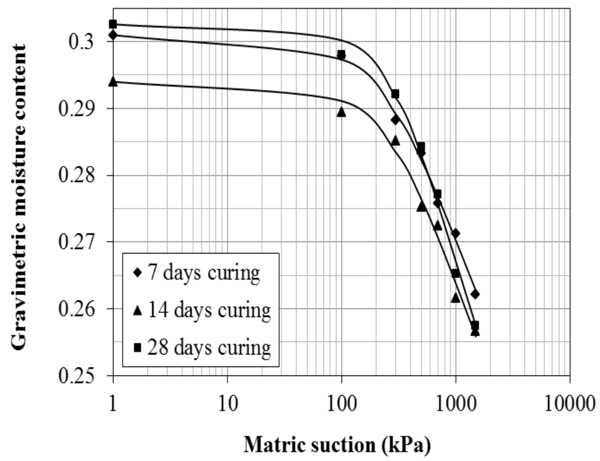


Figure 5: SWCC for 7% Lime Treated Soil Cured at 40°C

The parameter a, n, m for various lime treated soils are summarized in Table 1. The Corresponding data for natural soil is also included in the Table 1. To have a feel about the effect of lime content, curing temperature and curing period on various parameters of SWCC, the mean of value of parameter "a" for a given lime content, curing temperature and curing period are analysed against the different variables. The mean value of 'a' is observed to increase with increase in lime content curing temperature and curing period.

Table 1: SWCC Parameters for Natural Soil and Lime Treated Soil

Lime Content (%)	Curing temp(°C)	Curing per(day)	SWCC parameters		
			a	m	n
Nil (Natural soil)	-	-	283.7	0.2638	0.6851
3	15	7	277.3	0.2203	0.9345
		14	303.1	0.2104	1.170
		28	292.8	0.209	0.9768
	30	7	262.0	0.2119	0.9192
		14	337.5	0.2021	1.122
		28	355.6	0.1964	1.369
	40	7	315.8	0.1937	1.114
		14	341.1	0.1895	1.185
		28	305.9	0.2088	1.125
5	15	7	317.2	0.1821	0.968
		14	327.4	0.1998	1.008
		28	326.3	0.2002	1.176
	30	7	347.0	0.1866	1.203
		14	363.4	0.1798	1.273
		28	349.5	0.1859	1.259
	40	7	328.8	0.206	1.133
		14	281.9	0.2121	1.049
		28	332.1	0.207	1.155
7	15	7	343.5	0.1906	1.120
		14	298.5	0.2101	1.102
		28	312.8	0.2011	0.9678
	30	7	297.4	0.2067	1.143
		14	348.2	0.1972	1.203
		28	362.2	0.1863	1.218
	40	7	369.6	0.1806	1.236
		28	385.9	0.1849	1.555
		14	390.0	0.1778	1.351

The increase in the value of "a" upon decrease in lime content may be attributed to the combination of CSH, CAH gel which coats the soil particles upon soil-lime reaction, which retards the extraction of water from the pores.

To bring out the relative impact of various factors affecting the behavior of lime treated soil viz lime content, curing temperature, and curing period on the suction parameter 'a' an attempt is made using SPSS to evaluate the impact of each of the variables on 'a' by using general linear model. The summary of analysis is presented in Table 2. It is noticed that out of the variables considered only lime content exhibits a significance level of 0.049, which is less than 5%. The other factors viz. curing temperature and curing period shows significant levels higher than 5%, which shows that they are not better related to 'a'.

Table 2: Summary of ANOVA

Source of variation	Degree of freedom	F-value	Significant levels
Lime content	2	3.516	0.049
Curing temperature	2	2.651	0.095
Curing period	2	1.057	0.366

Unsaturated soils represent a classical example of three-phase media, as they are constituted at equilibrium by soil skeleton, pore water and pore air. A fourth phase could be represented by the interface existing between the pore fluids, as it behaves as a contractile skin submitted to a uniform state of stress generated by the surface tension (Fredlund and Rahardjo 1993). The complex interaction among the phases co-existing at equilibrium explicates in different mechanisms which modify soil response as the degree of saturation changes. The main interaction mechanisms are represented by adsorption and capillarity (Hillel 1982). In fine-grained soils both the mechanisms are important, because of the presence of the diffuse double layers and of the intense ionic exchange taking place between clay minerals and pore water (chemical adsorption), but also of the small dimension of capillary pores.

So, the abovementioned observations may be due to different rules of lime in forming of a new structure in the soil. Four major changes are happen when lime is added to clayey soil.
(i) Cation exchange
(ii) Flocculation and agglomeration
(iii) Forming various cementitious compounds such as the CSH and CAH in gel form initially then crystallization
(iv) Unreacted lime as a filler material

The first two changes are obtained by minimum requirement of lime (ICL) whereas the amount of new components (i.e. CSH and CAH) depends upon the amount of lime content and silicate and aluminate that are produced by clay particles and other factors such as initial moisture content. All abovementioned factors effects on amount and distribution of pores in soil that effect on engineering behaviors of soil such as hydraulic conductivity and SWCC. The main rule of curing temperature in lime-soil reaction is accelerating the reaction and also the solubilities of silica and alumina are greatly increased at elevated pH levels and high temperatures (Thompson 1967). But the main rule of curing period is after the initial 7 days of curing, increase in crystallinity of reaction products rather than from the continued formation of additional pozzolanic compounds (Transportation Research Board 1987).

4. Regression Analysis

Based on the experimental results presented in the previous sections stepwise regression analysis has been performed in three categories using SPSS:
1) Regression analysis between "a" parameter as a dependent variable and all linear and nonlinear combinations of lime content (L), curing temperatures (T) and curing period (t) as independent variables.
2) Regression analysis between "a" parameter as a dependent variable and UCS strength (q_u) as an independent variable.
3) Regression analysis between "a" parameter as a dependent variable and CBR value as an independent variable.

From the first category of analysis among all variables only L.T.ln(t) (where, L- lime content in %, T – Temperature in ˚C and t – curing period in days) was selected by stepwise method that the goodness of fit is presented in Figure 6.

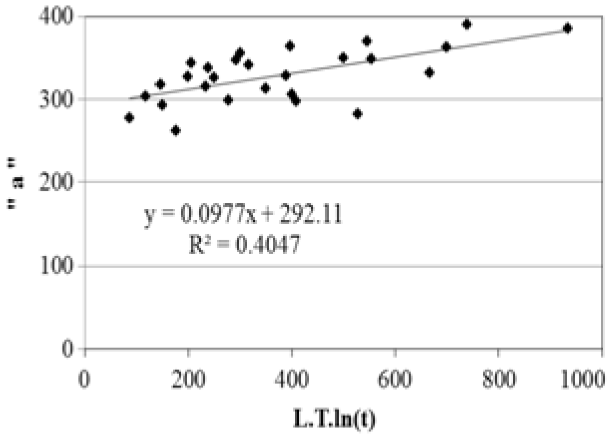


Figure 6: Relationship Between "a" and L.T.ln (t)

5. Summary and Conclusion

To examine the soil water characteristics of lime trended expansive clay, SWCC tests were conducted in this study. The soil water characteristics curves of thermally cured lime treated soils thus obtained reflect that the SWCC parameters a, m and n are affected by lime treatment. The increase in lime content and curing temperature increase the average value of 'a', but the increase is seen upto 14 days curing only. The relationship of parameters 'n' and 'm' with 'a' showed an increasing trend for 'n' and decreasing trend for 'm'. Regression analysis was also carried out on the experimental data viz. SWCC parameter 'a', lime content, curing period and curing temperature.

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