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RESEARCH ARTICLE

ENGINEERING BEHAVIOR OF CEMENT STABILIZED SOIL: NEW STATISTICAL MODEL

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ABSTRACT
Soft soils are well known for their low strength properties, high compressibility and high swell-shrinkage characteristics. Thus, they are inappropriate for building foundation or for other geotechnical works. Deep cement mixing has recently been used to face these problems by improving the strength and reducing the deformation of soft soils. The present study examines the parameters which influence significantly the strength of cement stabilized soil. These are: water content, liquid limit, amount of the added cement and curing time. A comprehensive laboratory work was carried out in order to study the compressive strength of clayey-silt soil, stabilized with various quantities of cement. The laboratory results were used for the development of a non-linear regression equation that best relates the compressive strength of a stabilized soil to the aforementioned parameters considered as descriptor variables.

KEYWORDS: Soil stabilization, compressive strength, liquid limit, water content, regression model, Khulna.

INTRODUCTION

Site feasibility study for geotechnical projects is far most beneficial before a project can take off. Site survey usually takes place before the design process begins in order to understand the characteristics of subsoil upon which the decision on location of the project can be made. When the bearing capacity of the soil is poor, the options are to change the design to suit site condition, to remove and replace the in situ soil or to abandon the site. However, in most geotechnical projects, it is not possible to obtain a construction site that will meet the design requirements without ground modification [1]. Nowadays, soils such as, soft clays and organic soils can be improved to the civil engineering requirements [2]. This study focuses on soil stabilization method which is one of the several methods of soil improvement. Soil stabilization aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two [3]. The simplest stabilization processes are compaction and drainage (if water drains out of wet soil it becomes stronger). The other process is by improving gradation of particle size and further improvement can be achieved by adding binders to the weak soils [4].

Cement is the oldest binding agent since the invention of soil stabilization technology in 1960's. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required [3, 5]. Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil [5]. Hydration process is a process under which cement reaction takes place. The process starts when cement is mixed with water and other components for a desired application resulting into hardening phenomena. The hardening (setting) of cement will enclose soil as glue, but it will not change the structure of soil [5]. Cement hydration is a complex process with a complex series of unknown chemical reactions [6]. However, this process can be affected by (i) presence of foreign matters or impurities; (ii) water-cement ratio; (iii) curing temperature; (iv) presence of additives and (v) specific surface of the mixture.

The strength of soil-cement mixture is influenced from many parameters like physicochemical properties of the soil, geological and hydrogeological conditions of the area, the properties and the quality of the used binder or the additive, the mixing method and consequently the mechanical equipment, the curing conditions [7]. The measurement of the strength of soil-cement mixtures in laboratory and the determination of the parameters which affect is still very important for the estimation of strength of mixture in situ [7]. However, the quality of cement was not taken into account on the proposed model, since previous studies has shown that it has a limited influence on the strength of the stabilized soil [8]. Soil stabilization can be accomplished by several methods. All these methods fall into two broad categories namely mechanical stabilization (soil stabilization can be achieved through physical process) and chemical stabilization (soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect). However, a chemical stabilization method is the fundamental of this study and, therefore, throughout the rest of this report, the term soil stabilization will mean chemical stabilization. Soil stabilization involves the use of stabilizing agents (binder materials) in weak soils to improve its geotechnical properties such as compressibility, strength, permeability and durability. The components of stabilization technology include soils and or soil minerals and stabilizing agent or binders (cementitious materials). This method is often applied on many geotechnical and foundation applications such as the stabilization of deep excavations or high embankments, the reduction of settlement or the increase of soil strength for building foundation, the slope stability, the tunnel support, the water retention etc [9].

LABORATORY INVESTIGATIONS

Material used in this Study: The soil type can affect significantly the efficacy of cement stabilization [10]. In this study one type of soil was stabilized with different quantities of cement. The cement used was Portland cement (King Brand Cement). The soil sample used in this study is characterized in the laboratory provided in Table 1.

Table 1 Various Properties of untreated soil sample

Property		Standard method [11]
USCS	MH	ASTM D 2487
Unit weight of solids (gm/cm^3)	1.60	ASTM D 698
Liquid limit, w_L(%)	51	ASTM D 4318
Plastic limit, w_L (%)	28	ASTM D 4318
Plasticity index, Ip (%)	23%	ASTM D 4318
Clay content (%)	26.0	ASTM D 422
Silt content (%)	70.5	ASTM D 422
Sand content (%)	3.5	ASTM D 422
pH (at 28.9 degree c)	7.87	--
Sulphate (mg/L)	0.64	--
Specific gravity, G_s	2.55	ASTM D 854

Table 2 Curing time of specimens and amount of water-cement addition

Water addition (ml)	Cement addition (% by weight of dry soil)	Curing period (days)
155	5	
165	10	
165	15	3
180	20	
175	30	
147	5	
155	10	
154	15	7
180	20	
178	30	
151	5	
160	10	
140	15	28
170	20	
162	30	
145	5	
140	10	90
145	15	
170	20	
175	30	

Methodology Adopted

Soil sample was collected from KUET campus (near mosque).After initial tests, cement-soil specimens tested in unconfined compression were prepared by initially mixing the relevant quantities of dry soil and water for required amount of time by hand; the cement was then added to the mixture and further mixing was performed until it was homogeneous in appearance. Table 2 shows the curing time of soil-cement mixture specimens and the percentage of water-cement addition. Cylindrical specimens were prepared by pouring the soil-cement material into modulus, 35.5mm in diameter and 71mm height [12].Then curing was done for 3 ,7,28 and 90 days. On stabilized soil, compressive strength tests were performed under a constant strain rate of 0.6604 mm/min. Water content and liquid limit of stabilized soil were also determined.

RESULTS AND DISCUSSIONS

The engineering properties of stabilized soil were evaluated in the laboratory and hence discussed the following articles.

Figure 1: Preparation of sample during this study

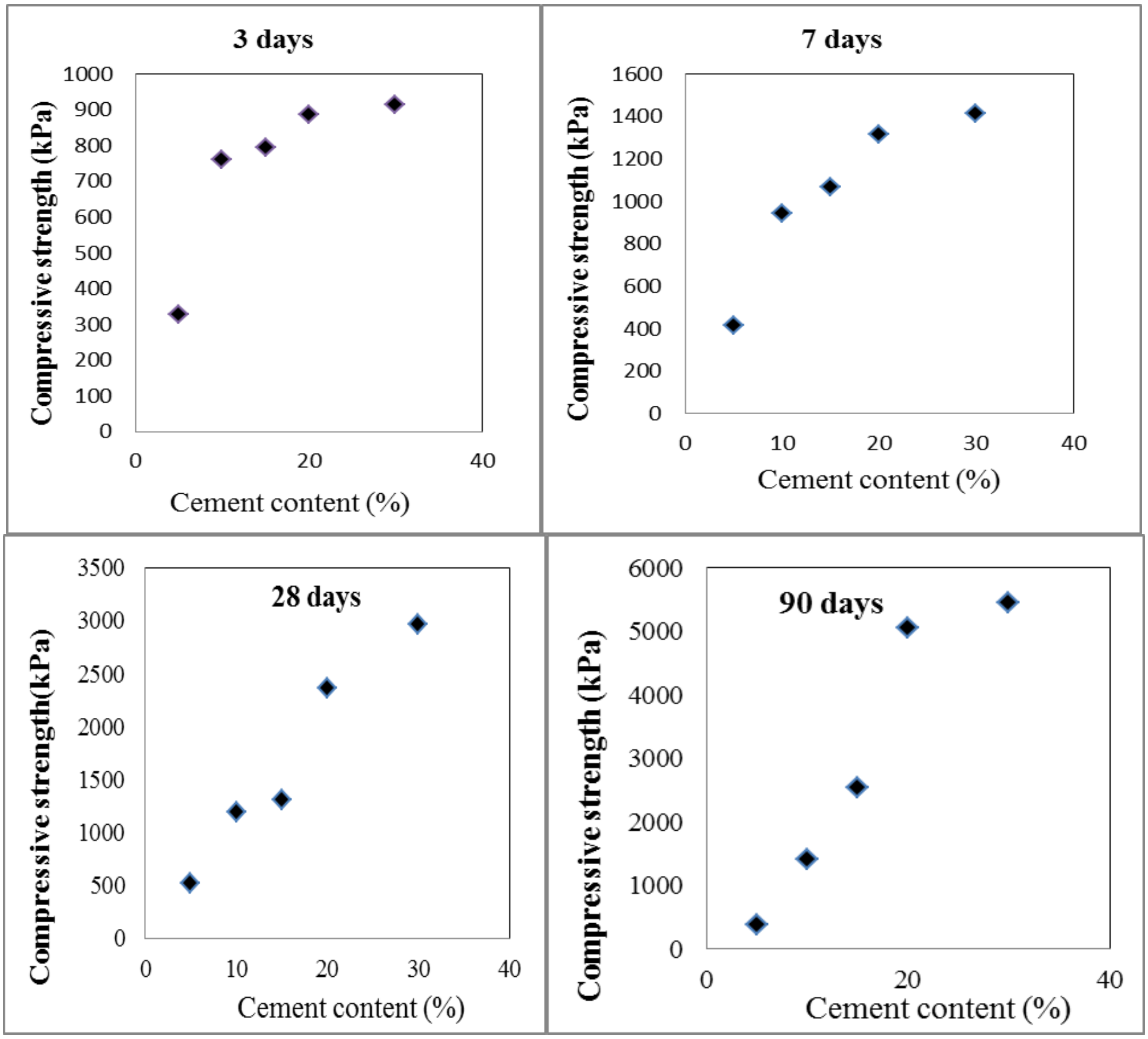


Figure 2: Variation of compressive strength of soil specimens stabilized with different amounts of cement: (a) 3 days; (b) 7 days and (c) 28 days and (d) 90 days.

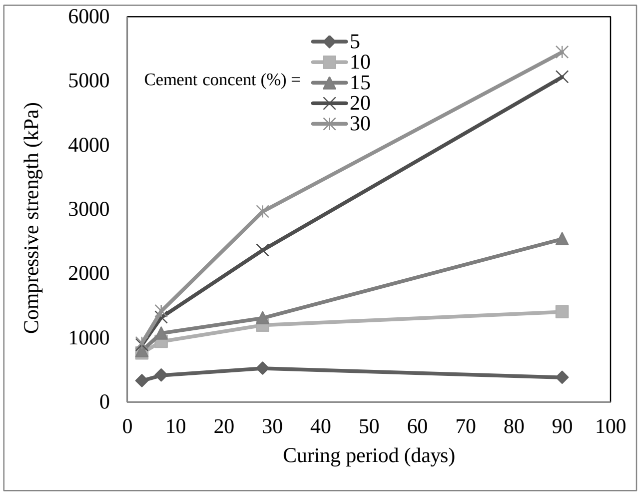


Figure 3: Compressive strength of cement stabilized soil at varying curing periods

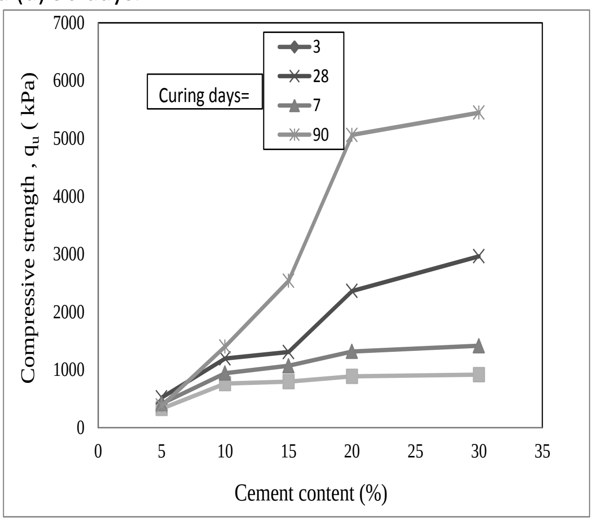


Figure 4: Compressive strength of cement stabilized soil at varying cement content

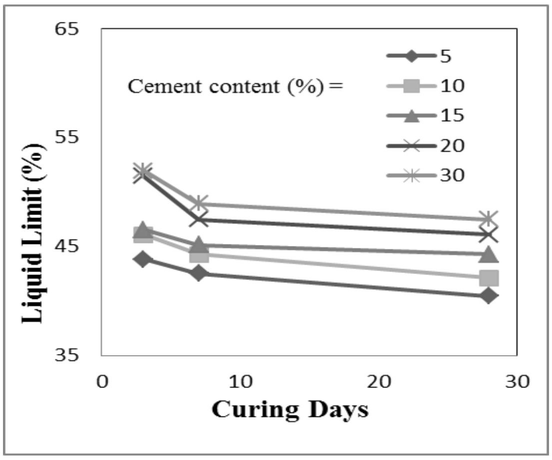


Figure 5: Liquid limit of cement stabilized soil at varying days

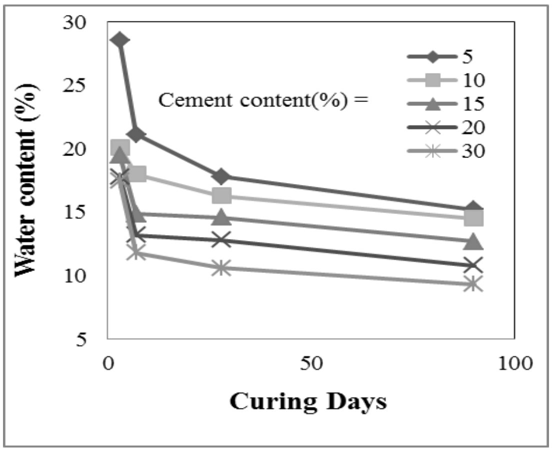
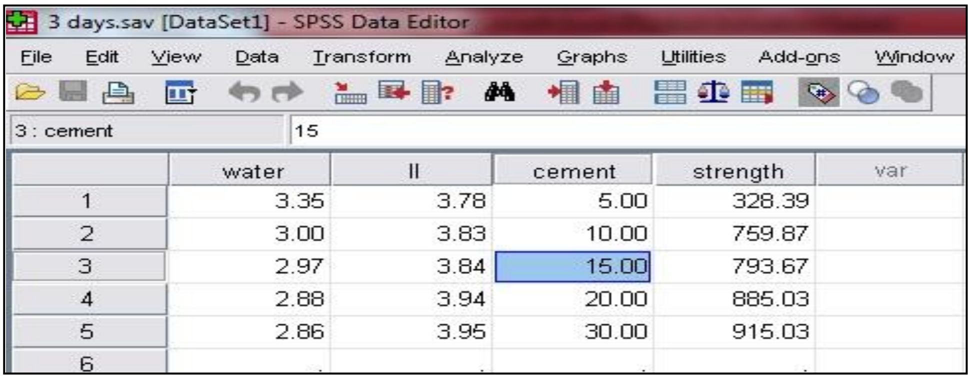


Figure 6: Water content of cement stabilized soil at varying curing days



	water	ll	cement	strength	var
1	3.35	3.78	5.00	328.39	
2	3.00	3.83	10.00	759.87	
3	2.97	3.84	15.00	793.67	
4	2.88	3.94	20.00	885.03	
5	2.86	3.95	30.00	915.03	
6	.	.	.	.	

Figure 7: Screen shot of input data in SPSS for 3 days

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5473.762	274.142		19.967	.032
	water	-1251.090	15.394	-1.048	-81.271	.008
	ll	-252.857	66.250	-.079	-3.817	.163
	cement	.576	.464	.023	1.241	.432

a. Dependent Variable: strength

Figure 8: Coefficients for model of SPSS analysis

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-9651.070	3894.037		-2.478	.089
	LI	2685.488	1006.584	.839	2.668	.076
a. Dependent Variable: strength						

Figure 9: Coefficients for model of SPSS analysis

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	4331.171	67.132		64.517	.000
	Water	-1193.408	22.248	-.999	-53.640	.000
a. Dependent Variable: strength						

Figure 10: Coefficients for model of SPSS analysis

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	417.031	151.190		2.758	.070
	Cement	19.960	8.323	.811	2.398	.096
a. Dependent Variable: strength						

Figure 11: Coefficients for model of SPSS analysis

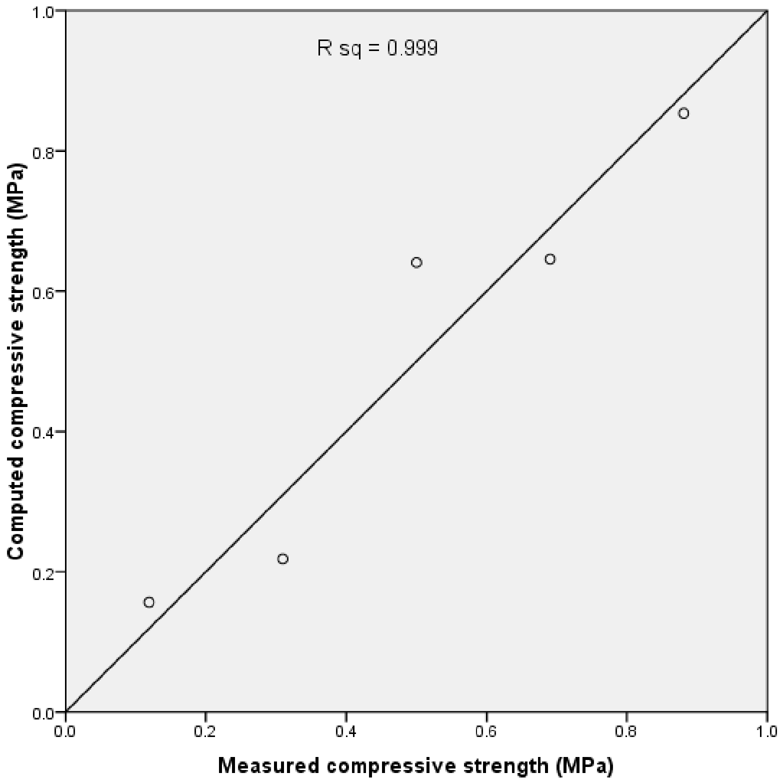


Figure 12: Variation of measured strength with computed strength

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	5477.953	686.917		7.975	.004
	Water	-1624.309	250.154	-.966	-6.493	.007

a. Dependent Variable: strength

Figure 13: Coefficients for model of SPSS analysis

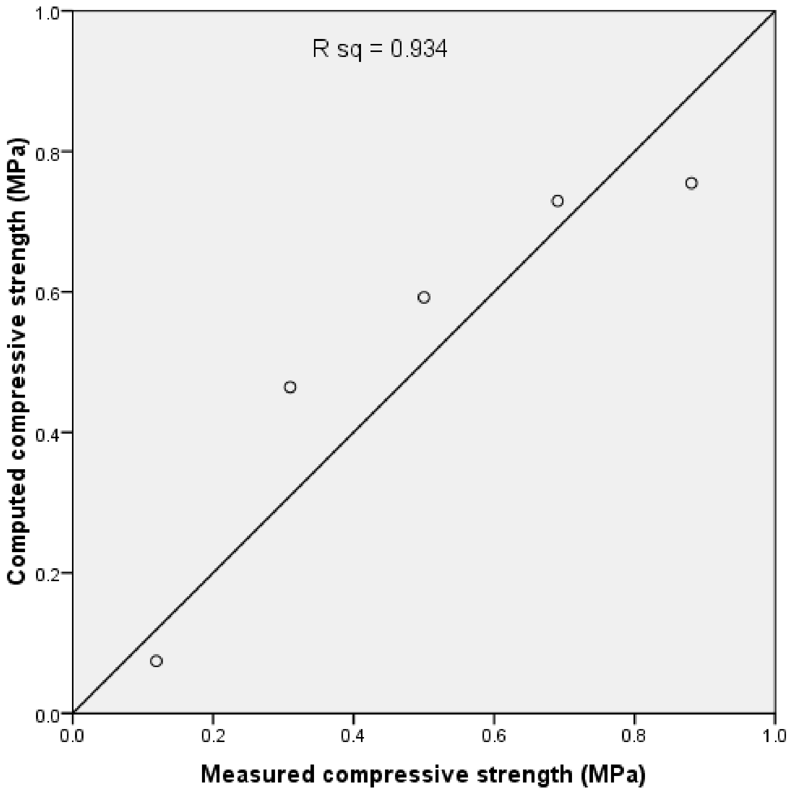


Figure 14: Variation of measured strength with computed strength

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	14112.689	1410.410		10.006	.002
	Water	-4692.097	530.567	-.981	-8.844	.003

a. Dependent Variable: strength

Figure 15: Coefficients for model of SPSS analysis

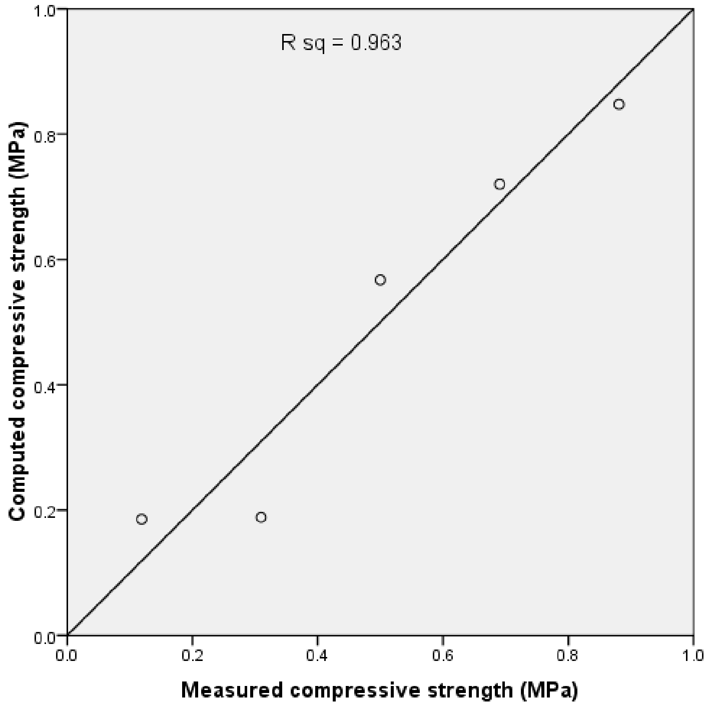


Figure 16: Variation of measured strength with computed strength

Compressive Strength: Figures 2(a)-(d) present the compressive strength values of stabilized soil with cement content ranging from 5 to 30% by dry weight of soil at 3, 7, 28 and 90 days of curing, respectively. A significant variation of strength values for all ages of curing and for all cement dosages is observed.

Liquid Limit and Water Content

Figure 5 shows the liquid limit of cement stabilizes soil at varying curing periods. It is observed that liquid limit decreases with time for different cement contents. But, it increases with the increase of cement content. Here, liquid limit for 20% and 30% of cement contents at 90 days of curing could not be performed .The values of liquid limit for 5, 10 and 15% of cement content at 90 days curing are 49.8, 42.76 and 37.6 %, respectively.

In Figure 6, water content of cement stabilized soil at varying curing periods is observed it is seen that water content has decreased as the curing days increased. This value also decreased with the increase of cement content. In addition cement treatment causes immediate decrease in water content [13]. Cement treated materials behave in a more brittle manner than non-treated materials.

Based on the laboratory results and using SPSS 16.0 statistic program a non- linear regression model was developed which correlates the compressive strength (q_u) of cement stabilized soil to the four variables (water content, w (%), liquid limit, w_L (%), cement content, C (%) and curing time, CT (days)), where, a_1, a_2, a_3, a_4, and a_5 are coefficient of regression line as follows

$$q_u=a_1+a_2 \ln(w)+a_3\ln(w_L)+a_4(C)+a_5\ln(CT) \quad (1)$$

In order to obtain a more accurate regression model, the curing time was left out as a descriptor variable in the regression equation. The model that gives the best correlation is of the following from again.

$$q_u=a_1+a_2 \ln(w)+a_3\ln(w_L)+a_4(C) \quad (2)$$

The reliability and accuracy of the model were checked by comparing the predicted values of compressive strength from this model and the measured values, and computing the correlation coefficient. The correlation coefficient (R^2) at 95% confidence interval all values are nearly same. In this study, water content, liquid limit and cement content are consider as independent variables, measured strength are consider as a dependent variable.

Regression Model of cement Stabilized Soils at 3 Day Curing Period: To depict the validity of the measured compressive strength against the computed values, the Equation 3, was developed using the unstandardized coefficients shown in Figure 7.

Figure 8 reveals that in case of liquid limit and cement content the values of significance level are greater than

0.05. Therefore, the obtained coefficient of independent variable is not significant at 95% confidence level. So, the equation achieved using these coefficients is not valid.

Then independent variables were used individually in SPSS. While using only liquid limit, coefficient obtained is shown Figure 9. Here significance level exceeded 0.05. So, this coefficient cannot be used to form equation.

Using only Water content as independent variable in SPSS the output obtained is shown in Figure 10. Here, significance level is less than 0.05. So the equation developed using these coefficients are valid.

Using cement content as independent variable, obtained coefficients from SPSS are shown in Figure 11. As significance level is beyond limit, these values are not acceptable to form equation.

The cross plot of the values of computed compressive strength obtained from the application of equations 3 against the measured values using the linear regression model. Figure 12 illustrates a plot of the values of computed compressive strength with measured values using the linear regression model. The black straight line in the figure represents the line of perfect equality, where the values being compared are exactly equal. The correlation coefficient (R^2) at 95% confidence interval was 0.999, meaning roughly that 99.9% of the variance in compressive strength is explained by the model. This value is statistically significant and therefore suggests that the measured and calculated values of compressive strength are comparable.

Regression Model of cement Stabilized Soils at 7 Day Curing Period

As represented before same process was repeated for the data of 7 days curing period using SPSS. Several trials were made to check the accepted significant level of coefficients. Thus, the accepted coefficient is shown in Figure 13.

The equation obtained from these coefficients is

$$q = 5477.95 - 1624.31 \ln (w)$$

In figure 14, the correlation coefficient (R^2) at 95% confidence interval was 0.934, meaning roughly that 93.4% of the variance in compressive strength is explained by the model. This value is statistically non significant and therefore suggests that the measured and calculated values of compressive strength are not comparable.

Regression Model of cement Stabilized Soils at 28 Day Curing Period

Obtained coefficients using SPSS for 28 days is shown in Figure 15.

Equation developed from these coefficients is given, and the outcome is shown in Figure 16.

$$q = 14112.69 - 4692.1 \ln (W)$$

For 28 days of curing period, the correlation coefficient (R^2) at 95% confidence interval was 0.963, meaning roughly that 96.3% of the variance in compressive strength is explained by the model. This value is statistically significant and therefore suggests that the measured and calculated values of compressive strength not comparable. It should be noticed that regression model for 90 days of curing period could not be done as the liquid limit cement stabilized soil with 20% and 30% cement content for 90 days of curing could not be performed in laboratory.

CONCLUSIONS

In this study soft soil was stabilized with cement at five contents and curing was done for 3, 7, 28 and 90 days. Result reveals that compressive strength increases with the increase of cement content and curing period. However, liquid limit has decreased with the increasing curing days but it has increased with the increasing cement content. Again, water content is decreasing with the increasing curing days and cement content. Based on SPSS analysis it is seen that regression model for 7 days is not acceptable to the desired confidence level with the obtained data. Regression model for 3 and 28 days is acceptable as it reached the desired confidence level. So, these obtained results from various tests and SPSS analysis on this cement stabilized soil can be used for further research and also for field application.

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