Study on Compressibility and Strength Behavior of Cement Stabilized Soil at High Water Content

S. AFRIN[1], I. M. RAFIZUL[2]

[1]Department of Civil Engineering, Khulna University of Engineering & Technology (Email-afrinsalma0072@gmail.com)
[2]Department of Civil Engineering, Khulna University of Engineering & Technology (E-mail: imrafizul@yahoo.com)

ABSTRACT: The in-situ deep mixing technique has been established as a means to enhance the bearing capacity and reduce the settlement into the soft ground. This study was concerned with the stress-strain-strength, stiffness and compressibility properties of cement stabilized soil at high water content. The value of q_u in stabilized soil increases with the increasing of curing time and cement content (lowering wc/c ratio). At a particular curing time and wc/c ratio, c' and φ' was found to decrease with the increasing of mixing water content. In addition, the significant increase in pre-consolidation pressure, reduction in c_c and c_s with the increasing of cement content and increasing of curing time. The swelling behavior of stabilized soils has been found to be very stiff in very low c_s. At a particular wc/c ratio and curing time, values of c_c and c_s increase significantly with the increase of mixing water content.

Keywords: *Stiffness, Compressibility Properties, High water Content, Stabilized soil, Cementing agent.*

1. INTRODUCTION

Various regions of Bangladesh with deep deposits of soft clays at high water content causes special problems associated with engineering design and construction since they have low strength and high compressibility. Thus, suitable ground improvement techniques are needed for deep excavation projects in these soft clays for suitability and deformation control (Sherwood, 1993). Cement stabilization is one of the most commonly used methods. Increase in strength, reduction in compressibility and improvement of swelling characteristics as well as reduction of creep properties of soil are the main aims of cement stabilization method (Keller Inc., 2011). While the conventional cement stabilization is mainly for surface treatment, the use of cement has recently been extended at greater depth in which cement columns are being installed to act as a type of soil reinforcement. These methods are termed as deep cement mixing and cement jet grouting which are currently being used in various countries to improve the strength and deformation properties of soft clay layers for most of the deep excavation projects which was given by(Lee *et al,* 2005). Cement may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required (Sherwood, 1993). Cement hydration is a complex process with a complex series of unknown chemical reactions (Macleran and White, 2003). This study presents stress-strain-strength and compressibility characteristics of cement stabilized soft clays at high water contents so that the state of water contents will simulate the condition realized in deep mixing method. Attempts have also been made to identify the critical factors governing the engineering behavior of cement treated clays, which helps not only to control the input of cementing agent to attain strength development with curing time, clay type and clay- water content, but also to understand the subsequent engineering behavior.

2. Materials and Methods

To conduct this study, the location was selected for the collection of soil samples. Samples were also prepared using several clay-water-cement ratios. The overall procedures are described in the following articles.

2.1 Sample Collection

Soil samples were collected from KUET campus and Dhaka city. The soil samples were collected from depth of 5 ft from existing ground level. In this study, the soil samples of KUET campus and Dhaka city are referred to as C1 clay and C2 clay, respectively. Portland composite cement was used to stabilize soil. The physical and index properties of soil samples were measured in the laboratory through the ASTM standards methods. The plasticity index (%), liquidity index (LI), in-situ water content (w_n%), specific gravity (G_S) and degree of saturation (S_r%) were found as 32, 0.50, 26, 2.77 and 73 as well as 18, 0.34, 23, 2.91 and 68 for C1 clay and C2 clay, respectively. The stabilized soil samples were prepared in the laboratory with clay-water cement ratio (wc/c) of 5, 10, and 15 at varying mixing water contents of 100, 150, 250 and 300%.

2.2 Sample preparation

The clay paste was passed through a 2-mm sieve for removal of shell pieces and other bigger size particles. The cement slurry was prepared with the required amount of cement with water. The mixing of the hardening agent and the clay was done until the mixture was uniformly mixed, the mixing done within 10 minutes. Such a uniform paste was transferred to a cylindrical mold 75 mm diameters x 100 mm height and 44 mm diameter x 120 mm height. Cylindrical mold of 75 mm diameter x 100 mm height were used for the preparation of samples for direct shear and consolidation tests and 44 mm diameter x 120 mm height were used for the preparation of samples for unconfined compression tests. Sample preparation procedure is similar to that reported by (Chin *et al.,* 2004). After 48 hours the cylindrical samples were dismantled. All the cylindrical samples were wrapped in thick polythene bags and these were stored in room temperature until the lapse of different planned curing times. Then the sample was trimmed to the size required for the specific tests to be conducted, i.e., to 6o mm diameter x 25.4 mm high for the shear tests and to 63.5 mm diameter x 25.4 mm high samples for the consolidation tests.

2.3Parameters

Clay-water cement ratio, (wc/c), is the ratio of initial water content of the clay, wc(%) to the cement content, c(%). The cement content, c is the ratio of cement to clay by weight both reckoned in the dry state. To obtain the same value of wc/c, it is possible to vary the water content of the clay, or the amount of cement, or both as the case might be. In order to examine to what extent the applicability of wc/c is varied the water content of clay is varied over a wide range in this study.

3. Results and Discussions

The strength and compressibility behavior of cement stabilized soil at high water content were analyzed and hence discussed in the following articles.

3.1 Strength Behavior

The unconfined compressive strength test measures the compressive strength of a soil. The test results provide an estimate of the relative consistency of the soil. Almost used in all geotechnical engineering designs (eg. design and stability analysis of foundations, retaining walls, slopes and embankments) to obtain a rough estimate of the soil strength and viable construction techniques. The shear strength is taken equal to half the compressive. The stress-strain behavior of C1 and C2 clay samples are shown in Figure 1 and Figure 2, respectively.

Figure 1 and Figure 2 reveals that the higher curing time, the higher strength and the lower strain. Shear types of failures were observed. In general, stress-strain curves of the stabilized samples were found to increase abruptly to peak values, then suddenly decreased to low residual values at low clay-water/cement ratio and long curing time. In addition, the shear strength parameters (c', φ') for stabilized clays in drained direct shear tests are shown in Table 1. The effective cohesion and friction angle of samples contained higher cement (lower wc/c ratio) were greater than those of samples contained lower cement (higher wc/c ratio).This is possibly due to disappearance of cluster and lubricating effect of water due to larger spacing of fabric.

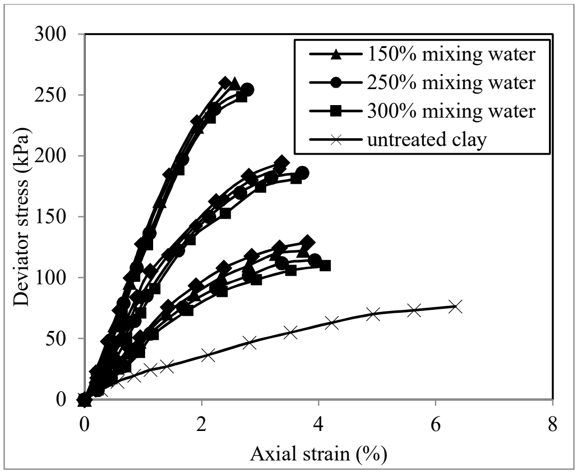

Figure 1.Stress-strain behavior of C1 clay at 3 week test.

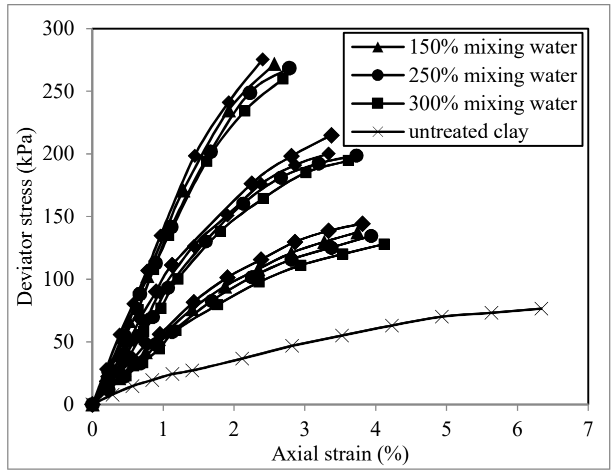

Figure 2.Stress-strain behavior of C1 clay at 5 week test.

Table1. Shear Strength Parameters (c' and φ') for Cement Stabilized Clay

Parameters	w_i (%)	wc/c ratio	Curing time Clay 1		Curing time Clay 2	
			3 w	5 w	3 w	5 w
c' in kPa	100	5	111	124	120	150
		10	104	113	112	139
		15	101	111	109	127
	150	5	109	120	112	141
		10	102	114	106	120
		15	95	107	98	118
	250	5	106	116	111	127
		10	98	110	102	122
		15	85	95	86	106
	300	5	102	113	106	117
		10	95	104	97	114
		15	82	97	83	99
φ' in degree	100	5	45.34	44.83	42.87	35.89
		10	44.27	42.76	41.70	35.04
		15	41.08	40.29	39.68	35.10
	150	5	41.73	39.04	41.04	33.26
		10	39.86	38.83	39.37	32.81
		15	38.69	37.19	38.72	31.83
	250	5	40.40	38.94	41.63	32.50
		10	39.39	37.31	39.39	31.66
		15	38.09	35.33	38.13	30.05
	300	5	39.35	37.45	38.68	31.66
		10	38.62	33.22	37.92	30.23
		15	36.20	31.13	36.98	30.32
c'	Untreated clays		21		33	
φ'	Untreated clays		15		13	

The Figures 3 and 4 show that the friction angle is decreased but the cohesion is increased with increasing curing time because soil slippage and frictional movement are less prevented due to hydration of cementation at high water content. The cohesion of treated clays is decreased with increasing clay-water content because stiffness and non-lubrication are decreased due to hydration of cementation at high water content. The friction angle of treated clays is abruptly decreased with increasing wc/c ratio because slippage sand frictional movements are less prevented due to less cement content.

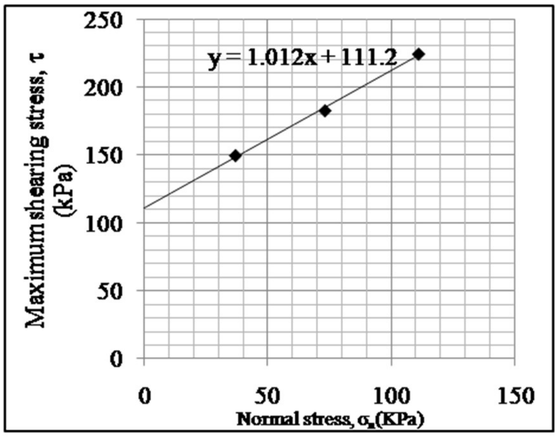

Figure3. Variation of shear stress with normal stress for 100% clay-water content (wc) and 5 clay-water/cement ratio (wc/c) (3 week)

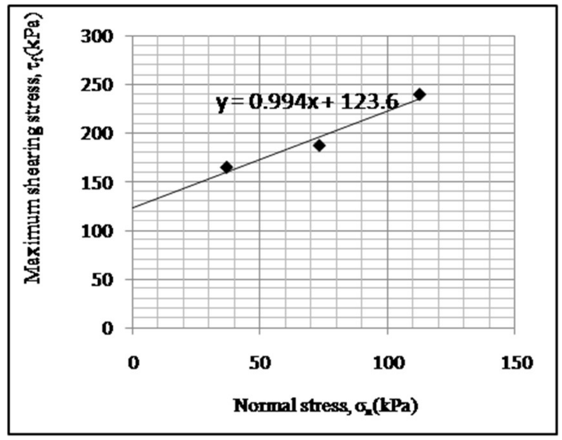

Figure4. Variation of shear stress with normal stress for 100% clay-water content (wc) and 5 clay-water/cement ratio (wc/c) (5 week)

Table2. Compressibility parameters for cement stabilized clays

Curing (weeks)	wc (%)	wc/c Ratio	Clay 1			Clay 2		
			σ_y'(kPa)	C_c	C_s	σ_y'(kPa)	C_c	C_s
3	100	5	425	0.815	0.037	506	0.855	0.007
		10	343	0.974	0.041	418	0.886	0.008
		15	250	1.279	0.042	306	0.964	0.009
	150	5	416	0.894	0.043	502	0.912	0.009
		10	352	1.048	0.044	427	0.943	0.011
		15	245	1.347	0.047	309	0.995	0.013
	250	5	406	1.052	0.047	511	1.065	0.014
		10	338	1.199	0.049	412	1.121	0.016
		15	249	1.616	0.051	312	1.148	0.018
	300	5	398	1.103	0.048	517	1.188	0.018
		10	333	1.304	0.052	415	1.201	0.020
		15	233	1.671	0.055	307	1.213	0.022
5	100	5	512	0.78	0.03	585	0.822	0.004
		10	426	0.908	0.033	481	0.856	0.005
		15	320	1.157	0.037	355	0.933	0.006
	150	5	505	0.834	0.037	593	0.893	0.008
		10	420	0.956	0.039	471	0.906	0.009
		15	313	1.246	0.041	351	0.968	0.011
	250	5	503	0.946	0.041	577	0.992	0.010
		10	414	1.104	0.042	467	1.111	0.012
		15	316	1.419	0.043	348	1.126	0.014
	300	5	496	1.016	0.042	581	1.155	0.014
		10	418	1.159	0.043	479	1.188	0.015
		15	314	1.501	0.044	352	1.194	0.017
Untreated clay			57	0.803	0.162	65	0.781	0.127

3.2 Compressibility Behavior

Table 2 presents the compressibility data of the cement stabilized samples having the same and different wc/c values but with different combinations of clay-water content (wc) and cement content (c). Compressibility parameters were calculated from the (e, logσ_v') relationships of clay-cement mixtures at wc/c ratios of 15, 10 and 5 after 3 and 5 weeks of curing. The C_c and C_s are the slopes of the loading and unloading curves, respectively. The yield stress is obtained as the point of intersection of two straight lines extended from the linear portions on either end of the compression curve plotted as e against logσ_v'.

It is also clear from Table 2 that the lower the value of wc/c, the greater enhancement of yield stress and the lower compression index and swell index. The clay-water/cement ratio affects not only the deformation characteristic, but also the rate of hardening related to hydration and pozzolanic reactions. The higher the curing time, the greater the enhancement of the yield stress and the lower compression index and swell index. Results for same wc/c and curing periods, the higher the water content, the lower the enhancement of the yield stress and the higher the compression index and swell index. The variations of compression index and swell index with wc/c are explained in Figures 5 and 6 respectively. In this range, the cementation component is the dominant factor to resist compression. But samples with a higher clay water contents are stable at higher void ratios and provide a higher compression indices beyond yield stress, especially for samples made up at a high water content of 300% as shown in Table 2. This is due to the breakup of cementation bond, which is similar to the behavior of naturally cemented clay.

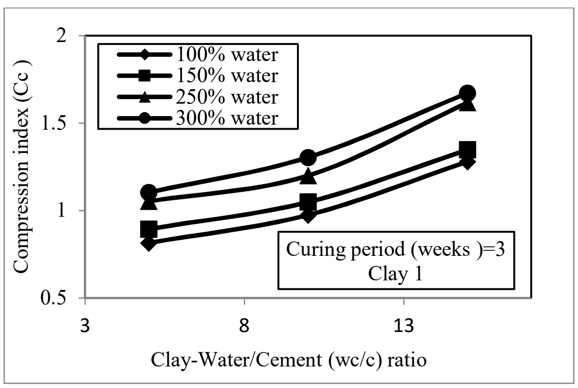

Figure5. Effect of clay-water/cement (wc/c) ratio on compression index (3 week)

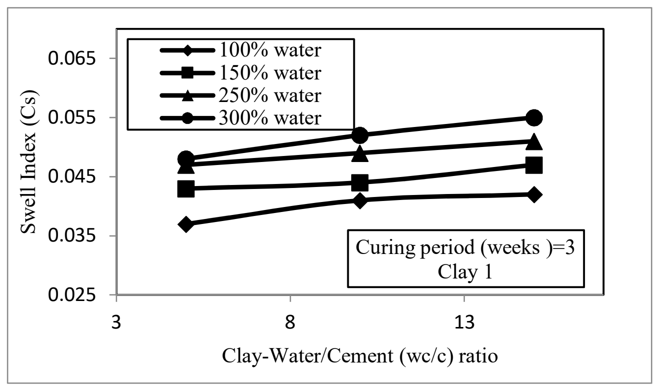

Figure6. Effect of clay-water/cement (wc/c) ratio on swell index (3 week)

5. Conclusion

This study aims to investigate the effect of cement content on soft clays at high water content. The value of q_u in stabilized soil increases with the increasing of curing time and cement content (lowering wc/c ratio). Both the values of c' and φ' of stabilized soil increases with the increasing of cement content; however, c' increases and φ' decreases with the increasing of PI. At a particular curing time and wc/c ratio, c' and φ' was found to decrease with the increasing of mixing water content. At higher stress beyond the pre-consolidation pressure, the e-logσ' curves of the treated clays shift at higher void ratio than those of the untreated clays having the same consolidation pressure .The significant increase in pre-consolidation pressure, reduction in C_c and C_s have been observed with the increasing of cement content and increasing of curing time. The swelling behavior of stabilized soils has been found to be very stiff in very low C_s. At a particular wc/c ratio and curing time, values of C_c and C_s increase significantly with the increase of mixing water content.

REFERENCES

Lee, F.H., Lee, Y., Chew, S. H., and Yong, K.Y., “Strength and Modulus of Marine Clay-Cement Mixes,” J. Geotech. Geoenviron. Eng., ASCE, vol. 131, no.2, pp.178-186, 2005.

Keller Inc., (2011). Improvement of Weak Soils by the Deep Soil Mixing Method. Keller Bronchure, 32-01E: http://keller-foundations.co.uk/technique/deep-dry-soilmixing.

MacLaren, D.C and White, M.A. (2003). Cement: Its Chemistry and Properties. Journal of Chemical Education, Vol.8,(No.6), 623.

Sherwood, P. (1993). Soil stabilization with cement and lime. State of the Art Review. London: Transport Research Laboratory, HMSO.

Chin, K.G., Lee, F.H., and Dasari, G.R. (2004). "Effects of Curing Stress on Mechanical Properties of Cement-treated Soft Marine Clay," in Proc. Int. Symp. On Engineering Practice and Performance of Soft Deposits, Osaka, pp. 217-222.