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CONTROLLED SOFT CLAY ENGINEERING BEHAVIOR AT HIGH WATER CONTENT

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ABSTRUCT

In-situ deep mixing has gained widespread acceptance as a method of increasing bearing capacity and preventing settlement in soft ground. Cemented soft clays with high water content were studied for their compressive and tensile strength, stiffness, and expansion. This research examines a wide range of factors in order to get a better understanding of the engineering behaviour of cement-stabilized soft clays. As a result, the geotechnical engineering behaviour of stabilised soft clays and the quantity of cementing agent that is required to achieve the appropriate strength development may be explained. The cementation binding strength increases as the wc/c ratio decreases. We discovered that for low wc/c ratios and longer curing durations, stress-strain curves of the treated samples climbed rapidly to peak values, then promptly declined. As wc/c ratio is reduced (or cement content is increased), both C and rise, according to this research, but C climbs and falls with increasing curing time. Increasing the quantity of cement and the curing time resulted in an increase in pre-consolidation pressure and a drop in the compression and swell indexes. In order to improve fine grained soil, the clay-water/cement ratio (wc/c) is the most significant element.

Keywords: It is important to know the properties of soft clays such as stress-strain, unconfined compressive strength, and compressibility.

INTRODUCTION

The low strength and extreme compressibility of Bangladesh's soft clays provide unique challenges to engineering design and construction in various locations of the country. For deep excavation operations in soft clays, proper ground improvement methods are required for suitability and deformation control. It is possible to increase the intrinsic shear strength and lessen the compression of such clay deposits by preloading them with vertical drains (e.g., PVD or sand drain) (Siddiquej et al., 2002). Admixtures such cementing agents may be used to increase the cementation bond level as an alternate method. In this cemented condition of clay, the resistance to compression and subsequent strength growth increases as curing time increases.An in-situ soft clay mix with a cementing agent is not feasible. DMMs have been created over the last three decades in order to create columnar inclusions in the soft ground and so alter the whole soft ground to composite grounds. The Port and Harbour Research Institute in Japan began researching and implementing this technology in 1975. (Nagaraj et al., 1998; Miura et al., 2001). (Hashizume et al., 1998) explored the behaviour of the enhanced ground of the group column type DMM (Probaha et al., 2000). Soil-cement columns were experimentally and statistically investigated to see whether the surrounding clay increased in strength over time (Nagaraj et al., 1998; Miura et al., 2001).Using cementing agents and high water content clays, researchers (Nagaraj et al., 1998) and (Miura et al., 2001) investigated the fundamental factors of strength development. Several studies have examined the laboratory strength and deformation properties of stabilised soft clays at certain clay-water contents (Hashizume et al., 1998) and (Kamaluddin et al, 2002). There are no works in Bangladesh that use the deep mixing approach to enhance the water content of soft clays by distributing cement additive using the wet method. As a result, it is impossible to understand the behaviour of the stabilised clay material under different circumstances by studying it at a certain water content. Engineers need to investigate Bangladeshi soft clays at high water content and utilise them to explain some of the observed engineering behaviour for the deep mixing approach in a well-controlled laboratory environment before applying it to the field.To mimic the conditions of deep mixing, this research examines the stress-strain-strength and compressibility properties of cement stabilised soft clays at high water contents. To better understand the engineering behaviour of cement-treated clays, efforts have been made to determine the essential parameters that influence the strength development with curing time, clay type, and clay-water concentration, as well as to manage the input of cementing agent.

EXPERIMENTAL INVESTIGATION

Soil Sample: Sample of Soil On the KUET campus, an undisturbed clay sample was taken at a depth of 5 feet from the present ground surface. Table 1 lists its index characteristics. In this experiment, the cement utilised was Portland composite cement.

Methodology of Testing: These clays and cement slurries were used to create test specimens for the study.A framework for analysing data

Parameters : Using a 2-mm screen, the clay paste was filtered to remove shell bits and other larger particles. In order to make the cement slurry, water and the correct quantity of cement were mixed together. It took about 10 minutes for the hardening agent and clay to be combined thoroughly, and the mixing was complete. Molds with diameters of 75 and 44 mm, respectively, were used to deposit the homogenous paste. For direct shear and consolidation testing, cylindrical moulds of 75 mm diameter x 100 mm height were employed, while 44 mm diameter x 120 mm height were used for unconfined compression tests. The cylindrical samples were disassembled after a period of time, usually 48 hours. Curing durations for each cylindrical sample were kept at room temperature in thick polythene bags, which were then stored until the time had elapsed. Afterwards, the sample was cut to the appropriate size for the various tests to be done, such as the shear and consolidation tests, which required a diameter of 6o mm and height of 25.4 mm, respectively.

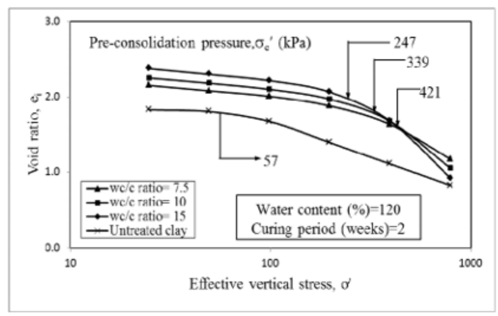
Parameters It is the ratio of the initial water content of the clay (wc) to the cement content (c), which is expressed as w c/c (percent). The dry weight ratio of cement to clay is used to calculate the cement content, or c. The water content of the clay, or the quantity of cement, or both, may be varied to get the same w c/c value. Water content of clay is adjusted in this research to see how wc/c may be used to a broad variety of situations.

TEST RESULTS

Consolidation test

Samples with varying wc/c values, but the same or varied clay-water content (wc) and cement content, are shown in Table 2 as compressibility data (c). The (e, logv') relationship of clay-cement mixes at wc/c ratios of 15, 10 and 7.5 after 2 and 4 weeks of curing was used to derive compressibility parameters. Presented in Table 2 are the compression index (Cc), swell (Cs) and yield stress (y'). The slopes of the loading and unloading curves are represented by the Cc and Cs, respectively, in the equation. the junction of the two straight lines extended from the linear parts of the compression curve represented as e versus logv' is used to calculate the yield stress (Horpibulsuk et al,. 2000).

The initial clay-water content (wi) was 120 percent, 150 percent, 200 percent, and 250 percent with the clay in the clay-cement combinations. In order to account for the influence of the void ratio difference for vertical stresses smaller than the yield stress, the (e, logv') is displayed as illustrated in Figs. 1 and 2.



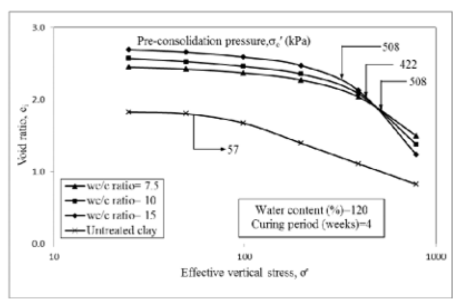


Figure1: Effect of wc/c ratio on e - logσ_v' 2 weeks
Figure2: Effect of wc/c ratio on e - logσ_v' 4 weeksof curing of curing

Figures 3 and 4 show how the compression index and swell index change with wc/c. To withstand compression in this range, cementation is the most important component. All samples with the same wc/c had almost comparable yield stress and deformation behaviour at pre-yield stress. samples with higher clay water levels are more stable and produce greater compressive index values beyond yield stress, particularly for

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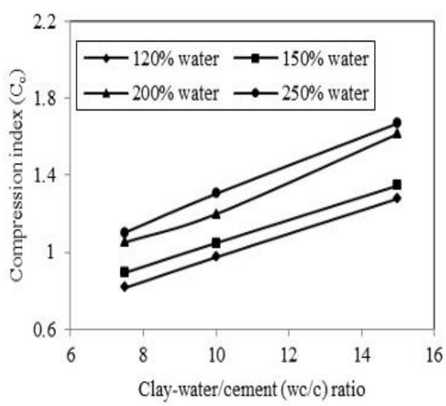
samples built up with a high water content of 250 percent, as demonstrated in Table 2 (see Fig. 4). Natural clay behaves in a similar way as a cementation bond that breaks down.

In the post-yield condition of clay-cement mixes with similar starting clay-water content, the compression indices are nearly in the same order, regardless of the cement amount. As shown in Table 2, wc/c has an effect on yield stress and compression and swell indexes when it is reduced. The hydration and pozzolanic processes of hardening are influenced by the clay-water/cement ratio. In general, the longer the curing period, the lower the compression index and the swell index. Higher water content and longer curing durations result in lower yield stress and greater compression and swell indexes for same wc/c and wc/c. A closer look at the relationship between improved compressibility qualities and wc/C reveals that the former plays a prompter, more proactive, and more effective function.

Figure 3: Effect of clay-water/cement (wc/c) ratio oncompression index

2 weeks curing



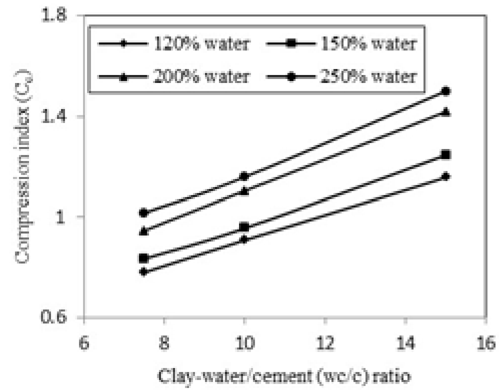


Figure 4: Effect of clay-water/ cement (wc/c) ratio on swell index

4 weeks curing

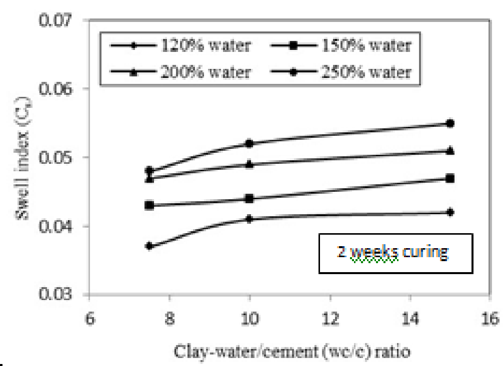


Table 1: Physical and index properties of the untreated clay sample

Property Name	Value	Property Name	Value
Initial moisture content w (%)	38	Liquidity Index, LI	0.49
Liquid limit, LL (%)	55	Sand % (4.75-0.075mm)	15
Plastic limit, PL (%)	21	Silt % (0.075-0.002mm)	60
Plasticity index, PI	34	Clay % (<0.002->0.001mm)	25
Specific Gravity	2.77	USCS	CH

Table 2: Compressibility Parameters for Cement Stabilized Clays

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Curing (weeks)	wc (%)	wc/c Ratio	σ_y' (Kpa)	C_c	C_s
		7.5	421	0.815 0.974	0.037
	120	10	339	1.279	0.041
		15	247		0.042
		7.5	412	0.894 1.048	0.043
	150	10	348	1.347	0.044
		15	241		0.047
		7.5 10	402	1.052	0.047
2	200		334	1.199	0.049
		15	235	1.616	0.051
		7.5 10	394	1.103 1.304	0.048
	250		329		0.052
		15	229	1.671	0.055
		7.5	508	0.78	0.03
	120	10	422	0.908	0.033
		15	315	1.157	0.037
		7.5	501	0.834 0.956	0.037
	150	10	415	1.246	0.039
		15	309		0.041
		7.5 10	498	0.946 1.104	0.041
4	200		410		0.042
		15	312	1.419	0.043
		7.5 10	492	1.016	0.042
	250		414	1.159	0.043
		15	310	1.501	0.044
	Untreated clay		57	0.803	0.162

Table 3: Unconfined Compressive Strength (q_u) in kpa for Cement Stabilized Clays

Admixture	w_i (%)	wc/c Ratio	Curing Time	
			2 w	4 w
		7.5	259.952	383.592
	120	10	194.461	243.026
		15	129.053	147.185
		7.5	259.525	369.911
	150	10	189.452	236.156
		15	122.184	140.214
		7.5 10	254.480	356.379
Cement	200		186.154	226.237
		15	114.356	126.647
		7.5 10	248.315	352.283
	250		181.294	225.549

Table 4: Shear Strength Parameters (c' and φ') for Cement Stabilized Clays

Parameters	w_i (%)	wc/c ratio	Curing time	
			2 w	4 w
		7.5	111	124
	120	10	104	113
		15	101	111
		7.5	109	120
	150	10	102	114
		15	95	107
		7.5 10	106	116
c' in Kpa	200		98	110
		15	85	95
		7.5 10	102	113
	250		95	104
		15	82	97
		7.5 10	45.34	44.83 42.76
	120	15	44.27	40.29
			41.08	
		7.5	41.73	39.04 38.83
	150	10	39.86	37.19
		15	38.69	
		7.5 10	40.40	38.94 37.31
φ' in degree	200		39.39	
		15	38.09	35.33
		7.5 10	39.35	37.45
	250		38.62	33.22
		15	36.20	31.13
c'	Untreated clays		21.33	
φ'	Untreated clays		15	

Unconfined compression test

As shown in Table 3, samples with varying beginning water contents and varying degrees of cementing agent but the same WC/C ratio at 2 and 4 weeks curing time for stabilised clays had variable unconfined compression strengths. 7.5, 10 and 15 are the values contained in the wc/c table. Figures 5.1 and 5.2 demonstrate the stress-strain behaviour of stabilised samples for a typical clay sample with the same clay-water/cement mix. According to this study, a greater amount of curing time results in greater strength and reduced strain. We saw a lot of shear failures. Stabilized samples showed stress-strain curves that rose quickly, then fell quickly for low clay-water/cement ratios and extended curing times, in general. Cementation bond strength improves with decreasing wc/c (Fig. 6), and as a result, higher strength is achieved. Fig. 5.1 and 5.2 indicate that with the same wc/c but differing water content, the cementation bond strength is enhanced to the same extent. Stabilized soft clays, on the other hand, have wc/c as a structural characteristic.

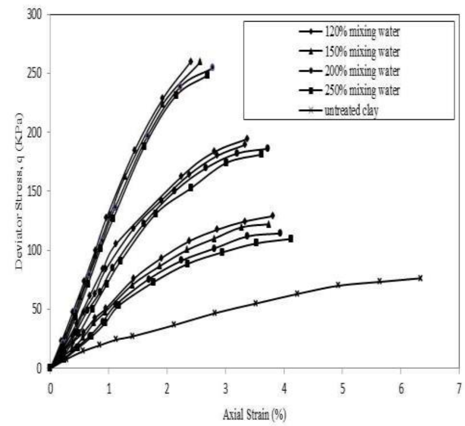

Figure 5.1: Stress-strain variations of clay at different wc/c for curing 2 week

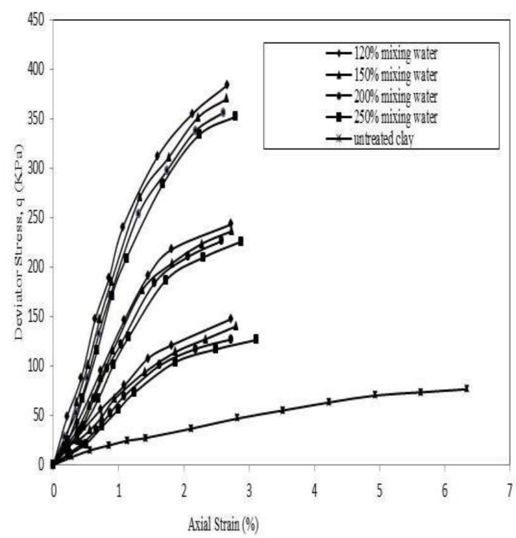

Figure 5.2: Stress-strain variations of clay at different wc/c for curing 4 week

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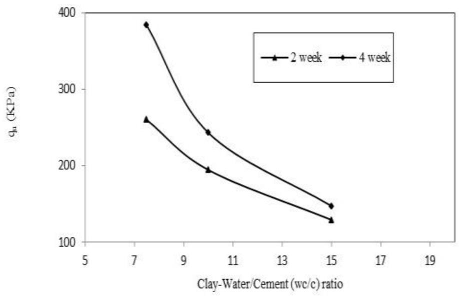

Figure 6: Strength variations with wc/c for stabilized clay Direct shear test

Direct shear test: Table 4 displays the results of drained direct shear tests on the stabilised clays' shear strength characteristics (c', '). There were larger effective cohesiveness and friction angles in samples that had more cement (lower wc/c ratio) than those that contained less of it. This may be because the rigidity and increased lubricating action of cement stabilised soil minimises soil slippage and frictional movement. Because cement hydration at high water content reduces the ability of cement to resist soil slippage and frictional movement, the friction angle decreases while the cohesiveness increases. The stiffness and nonlubricity of treated clays diminish with increasing clay-water concentration owing to the hydration of cementation at high water content, which reduces their cohesiveness.

Figures 7 and 8 demonstrate the influence of the clay-water/cement ratio and curing duration on effective cohesiveness and friction angle for stabilised clays at wi = 120 percent with curing times of 4 and 12 weeks. Because the stiffness and non-lubricity of treated clays are reduced as the wc/c ratio increases, the cohesion of the treated clays decreases rapidly. Because less cement prevents slippage and frictional movement, the friction angle of treated clays decreases sharply as the wc/c ratio rises.

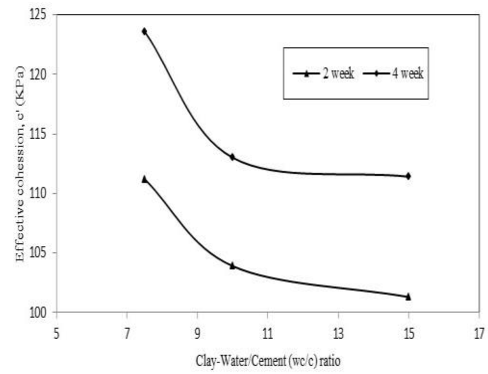

Figure 7**:** Effective cohesion variations with wc/c of stabilized clays for curing 2 and 4 weeks

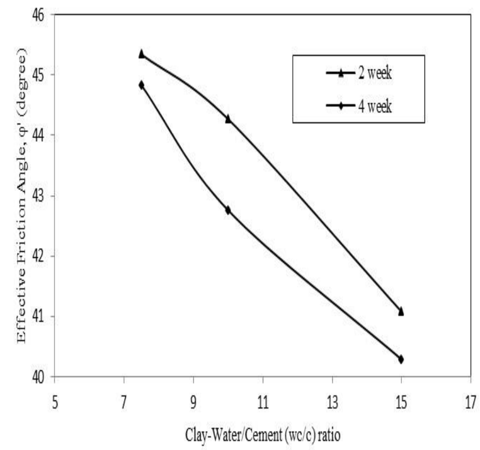

Figure 8**:** Effective friction angle variations with wc/c of stabilized clays for curing 2 and 4 weeks

ANALYSIS AND DISCUSSION

These tests demonstrate that wc/c is an important factor in cement-stabilized soft clays' engineering performance. Clays are often treated traditionally in roadway stabilisation by combining the clay with cement and the water content required for compaction while it is still reasonably dry. When water and cementing chemicals are present, the clay is converted into a modified clay because of physicochemical interactions with clay - cement - water interactions, which results in particle grouping (Chew et al,. 2004). There is no way to create a homogenous mass that can demonstrate the appropriate levels of strength at the particle level. In order to use this changed soil as an engineering material, an

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external compaction effort is necessary. Clays with a high water content do not mix well with cement in the same way that dry cement does. The admixture is not made accessible to the clay itself, but rather to a clay-water system that interacts. In order to identify the clay-water system, one must look at the water content. This topic has been thoroughly covered by the authors (Nagaraj et al., 1998; Miura et al., 2001).The microstructure of cement-stabilized clay may be used to explain its engineering properties. Structure of clay type is the preferred term to describe the soil fabric, which is made up of an arrangement of soil particles, particle groups, and pore spaces. Particles or aggregates are grouped together into enormous fabric units to form a cluster, and a fabric is made up of clusters. Due to the electro-chemical nature of the interaction, the cementing agents may be thought to drift to the space between clusters and weld the fabric by gel as the following hydration of cement takes place. As a result, the final structure created as flocculated and reticulated clusters of clay and cement has a clay-water/cement ratio. An important part of this structure's performance is its mix of fabric and cementation.There are several soft clays, each of which has a particular liquid limit state, which is the condition in which the micro fabric will develop such that the addition of cement doesn't change the liquid limit. A modified soil's abundance may be seen when dried clay is blended with water and cement to a consistency closer to that of plastic. The plastic limit will rise as a result of the creation of clay clusters that may retain water as a result of cementation. Because the plasticity index is utilised as the denominator, the clay-cement mixture's fluidity index immediately after mixing with cement rises, but the clay-water content decreases insignificantly. The therapy has a negligible effect on the liquid limit. However, as cement amount and cure time rise, so does the plastic limit. As a result of this, the plasticity index of the combination decreases since the plastic limit of the mixture significantly increases. The change in water content is insignificant. Adding cement admixture results in an increase in the liquid index.

MICRO-MECHANISTIC EXPLANATION

The compressibility and strength properties and microstructure of soft clay have allowed us to deduce that the fabric of soft clay in both un-cemented and induced cemented states is the same. ' Because they assumed that all soils in this stage had the same fabric pattern, Yamadera et al. (2007) used water content as a limit water content when analysing strength data. For a given cement amount, the previous research showed that the strength produced decreases with increasing water content in the clay (Yamadera et al., 1997) because of an increased distance among particles as well as clusters. The cement content must be raised in order to maintain the same degree of strength. Although it is crucial to identify prospective cementation locations, the identification of the fabric pattern alone is not sufficient since the structural condition (fabric and cementation) cannot be expressed by the parameter water content alone. According to these findings, it would be beneficial to include cement into this parameter since it would help with the state's bonding component, which is represented by water content. wc/c, the clay-water-cement ratio, measures the structural condition of soft clay in its induced cemented form as an integrated metric. To attain the same amount of strength and cure time with the same cement content in water, this is a helpful parameter to use (Nagaraj et al., 1998; Miura et al., 2001).

ANALYSIS OF COMPRESSION BEHAVIOR IN CONSOLIDATION

Pre-compression resistance is considerably increased when vertical pressure rises in Figs. 1 and 2. This is due to the cement-induced cementation bond, which is a result of the material itself. The yield stress decreases as the clay-water/cement ratio rises, implying a lower cement content. The yield stress rises as the curing period for the same input condition increases. According to Table 2, increasing curing time and decreasing wc/c both enhance the yield stress of stabilised clay. The yield stress is almost the same for all four water content levels of Bangladesh clays, i.e., 120 percent, 150 percent, 200 percent, and 250 percent, as long as the wc/c value is same; the fabric is not taken into consideration for this study. After the cementation link is broken down, the compressibility of the material is greatly influenced by the fabric's influence. Results reveal that larger clay-water levels in clay-cement mixes result in more settling at

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the post-yield condition, supporting this theory. As a result, the cement admixture plays the job of increasing the consolidation yield stress. The fabric, on the other hand, controls the material's resistance to plastic deformation (Nagaraj et al., 1998; Miura et al., 2001).

ANALYSIS OF STRESS-STRAIN AND STRENGTH CHARACTERISTICS

Cement-stabilized clay's geotechnical engineering behaviour is influenced by the clay-water/cement ratio and the ratio of cement to water. The lower the wc/c, the higher the yield stress, resulting in an increase in the yield surface, which indicates that the failure envelope grows larger, and therefore the strength rises. wc/c The clay-water content, on the other hand, dictates the stress-strain behaviour. A drop in shear strength and an increase in volumetric strain result when the water content is higher, resulting in more space between clusters. The clay-cement mixture with a lower wc/c produces a larger deviator stress when exposed to low effective cell pressures compared to the combination with a higher wc/c. Based on the effective cell pressure and the degree of cement content, wc/c play a significant impact in the engineering behaviour of clays with high water content (200 to 250 percent).Post-peak stress decreases with strain when the treated specimen has a larger cement content, which is more like the impact of the structuration and destructuration processes involved in the cementation bond formation and destructuration processes (Chew et al,. 2004). The cementation bond is mostly responsible for this. So, for combinations with the same water content/cementation ratio, the stress-strain characteristics aren't affected by clay water content as much as they would be.As a consequence, the strength of the clay-cement mixture decreases significantly when the water content of the clay is high and the clay-water/cement ratio is low (e.g. wi=200 percent to 250 percent and wc/c = 7.5) because the distance between clusters is great, resulting in less shearing resistance. Nevertheless, this fabric effect is diminished when the clay-cement mixes are built up with low cement concentration, such as at wc/c of 15. In an unconfined compression test, all samples fail inside the yield surface because the confining pressure equals zero; hence, all samples display the same modulus of stress-strain.

CONCLUSIONS

The direct shear test and analysis of the stress-strain behaviour of soft clays treated with or without cement. This study's major findings and conclusions are as follows: Shear failures were discovered during unconfined compression studies. It has been demonstrated that curing time and cement concentration have a substantial influence on the value of the quarried stone increased curing time and lower wc/c ratios resulted in higher qu values. The index of strength growth is greatly influenced by cement content and cure time.

Cement concentration raised the effective cohesiveness (c) and effective angle of internal friction () of treated samples, whereas the plasticity index lowered c and. When curing was finished at a certain time and wc/c ratio, it was found that the c and values declined as the mixing water content increased. At higher stress than the pre-consolidation pressure, the treated clay e-log curves shift with a greater void ratio than those of the untreated clays. This displacement happens approximately parallel to the initial consolidation line of the untreated clay as cement amount and cure time increase and the clay hardens.

The pre-consolidation pressure, compression index (Cc), and swell index (Cs) all rose considerably when cement content and curing time were increased, respectively. Even at very low Cs, clays are able to retain their stiffness and elasticity even after treatment. In order to get the best results, the wc/c ratio and curing time must be changed.

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