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Curing Stress and Compressibility Behaviour of Cement Treated Marine Soil

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Key words

Cement, Marine clay, Deep cement mixing, Curing stress, Constant rate of strain consolidation test

Abstract: Deep cement mixing (DCM) method is a popular method of improving thick deposits of soft clays with high water contents, often close to the liquid limit, for enhancing bearing capacity and reducing settlements. After installation of cement-soil column, the improved ground will be left for curing over a specific period of time, before commencement of construction activities. Therefore, curing takes place under the overburden pressures. Studies on the influence of curing stress on the compressibility characteristics are limited. This paper describes the compressibility characterisitics of a cement treated marine soil cured under stress. The compressibility characteristics were studied using constant rate of strain consolidation (CRS) test for cement contents of 10%, 15% and 20% in the range of deep mixing application. Few tests were also conducted for lower cement contents of 2.5% and 5.0%, which are often used for reclamation purposes. The curing stresses adopted were 50, 100 and 200 kPa representing depths of about 5 m, 10 m and 20 m, respectively. Effects of water contents ranging from 0.8 to 1.5 times the liquid limit on the compressibility characteristics for 15% cement content were also analysed.

Introduction

Due to the growing population and spreading urbanisation, suitable soil conditions are often not available, and the structure has to be founded on poor soils such as saturated, high plastic and soft cohesive soil deposits. These soil formations, especially when the in-situ water contents are high, have low bearing capacity and high compressibility characteristics. Of the many ground improvement methods, cement-soil stabilization has been widely used to improve the engineering performance of clayey soils in various applications. Over the years, cement stabililisation has been developed from surface treatment, such as for road pavements, to greater depths. The in-situ deep mixing technique is an established means for improving the strength and reducing settlement of soft soil deposits. At deeper depths, the treated soil gets cured under stress due to the overburden. However, the laboratory studies in the past did not consider the effect of curing under overburden on the properties of the improved ground.

The improvement of the properties of cement treated soil has been attributed to the soil cement reaction, which produces primary and secondary cementitious materials in the soil cement matrix. The primary cementitious materials are formed by hydration reaction and are comprised of hydrated calcium silicates, calcium aluminates and hydrated lime. A secondary pozzolanic reaction between the hydrated lime and silica and alumina from the clay minerals leads to the formation of additional calcium silicate hydrates and calcium aluminium hydrates. The extent of the strength improvement depends on the mineralogy, environmental conditions of the soft ground, curing period and the type and amount of cement used (Porbaha, 1998). Various investigators have carried out experimental studies to understand the strength improvement in soft soils using cement stabilisation techniques (Uddin et al., 1997, Miura et al., 2001, Tan et al., 2002, Horpibulsuk et al., 2004). Lorenzo and Bergado (2004) established the fundamental parameters such as after-curing void ratio (e_{ot}) and cement content (A_w) to characterize the strength and compressibility of cement-admixed clay at high water contents. The results of laboratory tests conducted by Lorenzo et al., (2006) on soft Bangkok clays have established the existence of an optimum mixing water content at which the resulting cement-admixed clay is expected to give the highest strength compared to those mixed with water contents below or above this optimum value.

Studies on the influence of curing under stress on the compressibility characteristics are limited. Consoli et al., (2000, 2002, 2006 & 2007) and Rotta et al., (2003) carried out some tests on cemented sand reproduced from laboratory and highlighted the importance of curing stress. The samples were isotropically cured in the triaxial cell for a short duration of 48 hrs. It was established that the stress state acting during the cementing process plays a fundamental role in the mechanical behaviour of soils. They suggested that in the case of naturally cemented materials, samples should be taken at different depths, to

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represent different geostatic stresses, and tested under their respective confining stresses for determination of their real mechanical behaviour or else the triaxial tests should be restricted to confining stresses below those that cause bonding degradation, that is, the field yield stress. Chin, (2006) performed tests on cement treated Singapore marine clay, cured under isotropic confining stress for a short duration of 7 days. He concluded that both the compressibility and strength properties of cement treated clay get improved when curing is done under drained conditions, due to the densification of the soil skeleton.

This paper mainly aims to investigate the compressibility characteristics of laboratory prepared cement treated soils under the influence of curing stresses of 50, 100 and 200 kPa, representing depths of about 5 m, 10 m and 20 m, respectively. The cement contents selected were 10%, 15% and 20% in the range of deep mixing application. Lower cement contents of 2.5% and 5% were also used to understand the behaviour. Constant rate of strain (CRS) consolidation tests were carried out on the samples. The results obtained from conventional consolidation test for 10% cement content are also reported. Studies were also made to evaluate the effects of various cement contents and different water contents at a particular cement content of 15%.

Materials

The materials used in this study are marine clay and ordinary Portland cement. The details of the materials are given below.

Marine clay

Marine clay used in the present study was collected from a coastal site at Ennore, near Chennai. The sample was taken from a depth of 1.5 m. As per the borehole charts available at the sampling site, the soil stratification consists of 3 m thick soft clay, followed by 5 m thick sand and 2 m stiff clay. The water table is at a depth of 0.7 m below the ground level. The raw soil sample brought from the site was crushed and sieved through 4.75 mm sieve to remove shell pieces and other bigger sized particles. About 500 kg of samples was prepared and stored. Prior to cement treatment, the properties of the untreated clay were determined as per relevant Indian Standard specifications and are given in Table 1. The soil is classified as CH as per Indian Standard Classification system.

The Unconfined compressive strength of the untreated clay at natural moisture content was found to be 17 kPa. The chemical composition of the clay obtained from the X-ray fluorescence study is shown in Table 2.

Table 1 Physical Properties of the Marine Soil

Property	*Value*
<u>Atterberg limits</u>	
Liquid Limit (%)	56
Plastic Limit (%)	25
Plasticity index (%)	31
<u>*Grain size distribution :*</u>	
Sand (%)	9
Silt size (%)	47
Clay size (%)	44
pH value	7.2
Organic matter (%)	5.5
Specific gravity	2.62
Free swell index (%)	45
Activity	0.7

Table 2 Chemical Composition of the Marine Soil

Chemical Composition	*Values (%)*
Silicon dioxide (SiO_2)	50.8
Calcium Oxide (CaO)	3.27
Aluminium Oxide (Al_2O_3)	13.7
Iron Oxide (Fe_2O_3)	22.21
Phosphorous Oxide (P_2O_5)	0.997
Titanium dioxide (TiO_2)	2.01
Potassium Oxide (K_2O)	5.35

Cement

Ordinary Portland cement of 53 grade was used for the study. The cement was packed in 1 kg and 2 kg polythene bags and placed in airtight containers to preserve the freshness. To ensure that the cement used throughout the study had consistent physical properties and chemical composition, cement from the same batch of production was used. X-ray Fluorescence results shows that the major concentration is that of Calcium oxide and it is about 77%.

Sample preparation and Test Procedure

For a given cement content, the shear strength of the cement treated soil depends on the total clay water content. There exists an optimum clay water content at which the shear strength is the maximum (Lorenzo et al., 2006). The optimum clay water content is the total clay water content present in the marine soil including water from the cement slurry at which maximum strength is achieved. The overall water content of the clay-water-cement paste just at the time of mixing will be the total remoulding water plus the water in the cement slurry. The overall water content is hereinafter called as the total clay water content (C_w), which is defined as (Lorenzo and Bergado 2004):

$$C_w = w^* + (W/C)(A_w) \quad (1)$$

where C_w is the total clay water content of the clay-water-cement paste (in %) reckoned from the dry weight of soil only; w* is the remoulding water content of the untreated clay (in %) before mixing the cement slurry; (W/C) is the water-cement ratio by weight of the slurry and A_w is the desired cement content (in %). Cement content (A_w) is defined as the percentage ratio of the weight of cement to the dry weight of soil.

In order to determine the optimum clay water content for cement treated samples, experiments were conducted for water contents ranging from 0.8 to 1.8 times the liquid limit water content. The untreated clay was mixed with remoulding water content in the Hobart mixer for ten minutes. The prepared remoulded clay was then mixed with cement slurry at a water-cement ratio of 0.6 for another ten minutes in the Hobart mixer at a speed of 61 rpm until a homogeneous clay-water–cement paste was attained. Specimens with 10, 15 and 20% cement contents were made at different water contents for performing unconfined compression test to determine the optimum total clay water content. Before the tests, the samples were kept in the mist room for 28 days for curing. From the UCC tests performed on samples treated with cement contents of 10%, 15% and 20%, the optimum clay water content was taken as 1.25 times the liquid limit irrespective of the cement content (Bushra and Robinson, 2010).

The specimens for the consolidation tests were prepared by placing the clay-water–cement paste directly into the oedometer ring by thumb kneading. Care was taken to ensure that the sample prepared is free of air voids. This technique was adopted to avoid possible disturbance during the subsequent sample cutting and fitting into the oedometer ring. The oedometer rings together with the specimen were wrapped in layers of cling film and placed in a mist room and samples were subjected to atmospheric curing for 28 days. Another set of samples placed in the oedometer rings were subjected to curing stresses of 50, 100 and 200 kPa in the consolidation test set- up. Literature review suggests that the post-yield compression line was not much affected with curing time in excess of the optimum curing period of 28 days (Uddin et al., 1997). Therefore, in the present study a curing period of 28 days was adopted. The samples taken from the mist room after 28 days of curing were directly placed in the consolidation cell of the equipment.

Experimental set-up

Compressibility characteristics of soils are conventionally evaluated by performing one-dimensional consolidation tests. The required consolidation pressures are normally applied in steps with a load increment ratio of 1.0. Deformation under a particular load is usually recorded for a period of 24 hours. Therefore, completion of this type of consolidation test requires very long time exceeding more than 10 days. When testing stabilised soils, the time-dependent effects of stabilisation can alter the compression characteristics unless tests are performed rapidly in relation to the rate of stabilisation (Kassim and Clarke, 1999). Therefore, conventional consolidation test is not suitable for stabilised soils, as the properties may change with time. The yield stress of cement treated soils is also very high, often exceeding 1000 kPa. Therefore, special consolidation loading frames are needed for applying high consolidation pressures in excess of 800 kPa.

In order to overcome the above limitations, Constant Rate of Strain (CRS) tests were conducted in the present study. In this type of test, consolidation test time is considerably reduced, as the sample is loaded continuously at a constant rate of strain. Very high consolidation pressures, of the order of 9000 kPa can be easily imposed on the soil sample.

In the CRS test, drainage is allowed only from the top of the sample. This allows the excess pore pressure to be measured and controlled at the bottom of the sample, which is undrained. In the present study, the conventional oedometer cell was modified so that a pore pressure transducer can be mounted at the base of the cell. Schematic diagram of the cell is shown in Figure 1. The diameter of the consolidation ring is 60 mm with a height of 20 mm. A thin rubber gasket of about 0.2 mm thickness was placed at the bottom edge of the consolidation ring so as to make the base leak proof. The pore pressure transducer is connected to the base of the cell as indicated in the figure.

The pore pressure line in the CRS test set-up was flushed with de-aired water so as to remove all the entrapped air bubbles in the drainage line. A saturated, de-aired porous stone was placed at the base of the cell. A wet filter paper separator was placed above the porous stone. The ring, with the sample, was then assembled carefully ensuring that air bubbles are not entrapped in the system. The set- up was then placed in the conventional digital triaxial frame of 50 kN capacity, which has the capability of applying deformation rates varying from 0.00001 mm/min to 9.99999 mm/min.

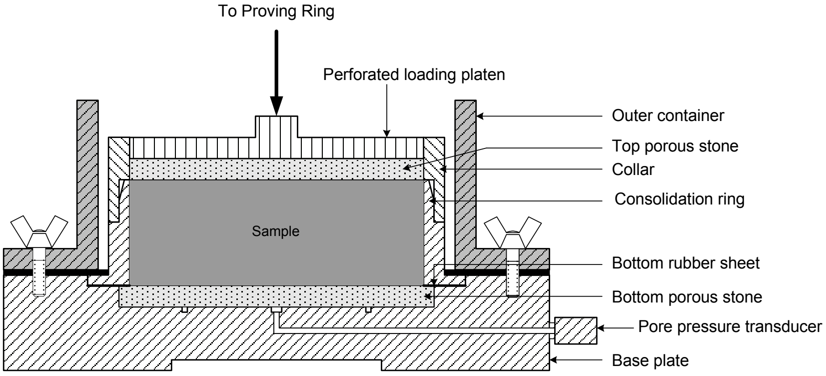

Fig. 1 Schematic of the Consolidation Cell Used for CRS Test

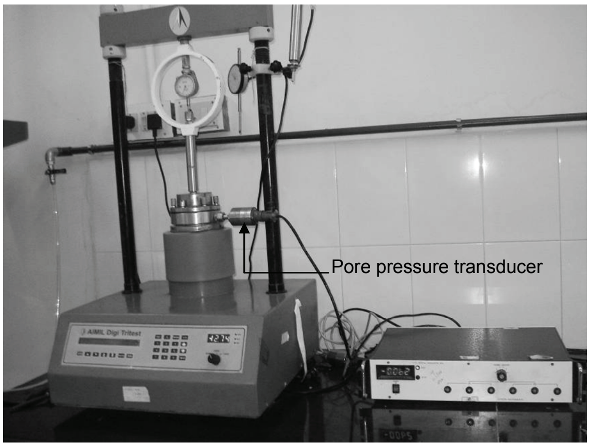

Fig. 2 Photograph of CRS Consolidation Test Set-Up

The pore pressure transducer is connected to the digital read-out unit. The load imposed on the sample was measured using a proving ring. The photographic view of the complete set-up is shown in Figure 2. A deformation rate of 0.05 mm/min. was adopted that was calculated as per the procedure given by Smith and Wahls (1969) based on the following equation:

$$R = \frac{c_v c_c (u_b / \sigma_1)}{m^2 H_0 (1 + e_0)[1 - 0.7(u_b / \sigma_1)]} \qquad (2)$$

where, R is the deformation rate and m is a proportionality constant that would normally range between 0.6 and 0.8. The values of coefficient of consolidation (C_v) and compression index (C_c) are taken from 1-D consolidation test, previously conducted. H_o and e_o are initial height and initial void ratio, respectively. The values of (u_b/σ_1) are taken as 0.5, where u_b is the pore pressure at the undrained boundary and σ_1 is the applied vertical pressure.

A continuous record of pore water pressure (u_z = H) and a corresponding record of σ (total stress applied at the top of the specimen) are obtained from the test. Average effective stress was computed as per Eqn. 3 (Das, 1987).

$$\sigma'_{av} = \sigma - \left[\frac{\frac{1}{3} - \frac{1}{24}\left(\frac{b}{r}\right)}{\frac{1}{2} - \frac{1}{12}\left(\frac{b}{r}\right)} \right] u_{z=H} \qquad (3)$$

The value of b/r~1.

Change in void ratio that has taken place during time t,

$$\Delta e = \frac{\Delta H}{H_f}\left(1 + e_f\right) \qquad (4)$$

$$e = e_f - \Delta e \qquad (5)$$

Where, ΔH, H_f, e_f and Δe are the change in thickness, final thickness, final void ratio and change in void ratio, respectively.

The validity of the CRS test results were verified by comparing the results of one-dimensional consolidation test conducted on identical samples. Typical plot is shown in Figure 3 (Bushra and Robinson, 2009). The difference in the results is negligible, within the range tested, suggesting the validity of the CRS tests. It may be also noted that one-dimensional consolidation tests could not be conducted beyond a consolidation pressure of 800 kPa due to the limitations of the capacity of the consolidation frame. Guided by the

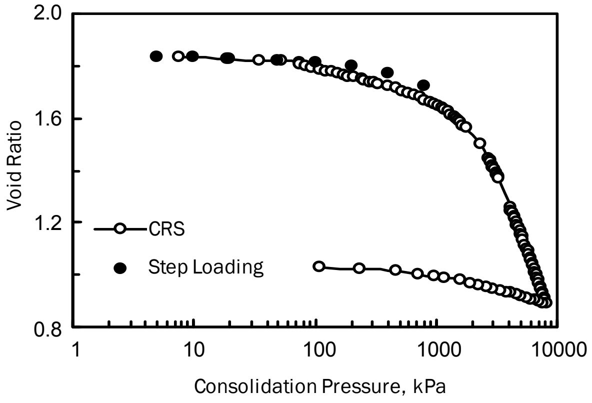

Fig. 3 Comparison of Step Loading and CRS Test Results

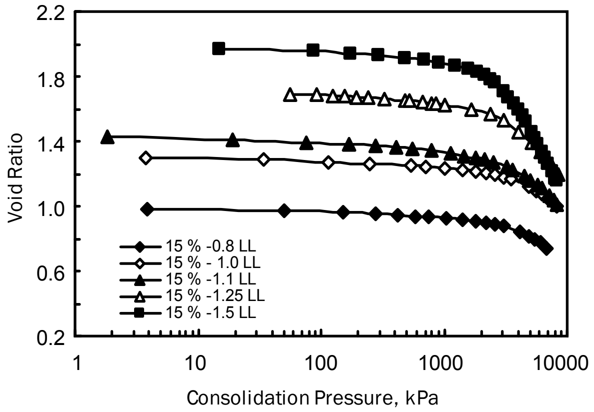

Fig. 4 e-Log σ_v' Plots for Different Water Contents

above, all the tests on the cement treated soil were conducted using the CRS set-up.

The yield stress was obtained as the point of intersection of two straight lines extended from the linear portions on either end of the compression curve plotted as log (1+e) against log σ'_v (Sridharan et al., 1991). The value of compression index (c_c) is calculated from the slope of the *e*-log *σ_v'* plot beyond the yield stress.

Results and Discussion

Effect of clay water content on the yield stress

Research on the behaviour of cement treated clay indicated that the mixing water content plays a major role. The unconfined compressive strength of cement treated soil gives a maximum value, when the clay water content is about 1.2 to 1.3 times the liquid limit water content (Bushra and Robinson, 2010). Therefore, the optimum clay water content for the sample was selected as 1.25 times the liquid limit water content, irrespective of cement content. This is consistent with the findings of Lorenzo et al., (2006), conducted on soft Bangkok clays, that there exists optimum clay water content for achieving maximum strength for cement treated soil.

In order to evaluate the influence of water content on the compressibility characteristics, CRS tests were conducted, typically for the case of cement content of 15%. The water content was varied from 0.8 LL to 1.5 LL. The void ratio-pressure relationship is shown in Figure 4. The values of yield stress determined by the log (1+e) versus log σ_v' plot are listed in Table 3. Typical plots of log (1+e) versus log σ_v' are shown in Figure 5. The values of compression index are also listed in Table 3. It can be observed that the yield stress is

Table 3 Yield Stress for Different Water Contents

Water content	*Yield stress (kPa)*	*Compression index C_c*
0.8 LL	2900	0.226
LL	2900	0.316
1.1 LL	2900	0.435
1.25 LL	3000	1.052
1.5 LL	2500	1.417

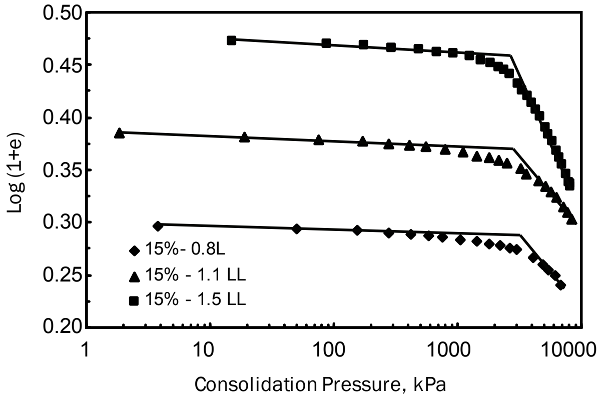

Fig. 5 Typical Plots of Log (1+e) Versus Log σ_v'

maximum for the mixing water content of 1.25 times the liquid limit water content, very similar to the case of UCC test results. The reasons for this is that a particular water content called optimum total clay water content equal to or greater than the liquid limit is necessary for proper hydration of cement and for efficient mixing of soil with cement. If the water content is above or below the optimum, the strength is reduced.

If the mixing clay water content is too high, the resulting cement-admixed clay will show very low shear strength and possess high compressibility due to the consequence of high void ratio. Apart from that, due to the presence of too much of water, there is also a tendency for the clay particles to lose their electrostatic attraction. Thus the number of clay-to-clay contact surfaces to be cemented or bonded by the pozzolanic products reduces, thereby limiting the strength of the resulting cemented soil matrix. On the other hand, if the clay water content is too low, the air can occupy some portions of the voids. The presence of air spaces can eventually reduce the ability of cementing ions to disperse because the air spaces can block them. Consequently, some of the cementing agents may remain unmixed, reducing the effectiveness of the admixture. Also, the lack of water can somehow cause some of the clay-to-clay contact surfaces to remain unbonded or uncemented, due to the inefficient mixing and poor dispersion of cementing agents (Lorenzo et al., 2006). The optimum clay water content varies with the type of soil. Guided by the fact that the optimum clay water content for the particular soil under study is about 1.25 times the liquid limit water content, all the tests reported in the present study are conducted at water content of 1.25 times the liquid limit water content.

Effect of cement content on the e-log σ_v' relationship:

The void ratio-effective stress relationships of the soil for cement contents varying from 1% to 20% are shown in Figure 6. For comparison, the result of untreated soil is also shown. At very small cement contents (cement content < 2.5%), the curves are close to the untreated soil. This is attributed to the fact that the quantity of cement available is not sufficient to initiate pozzolanic reactions. Calcium hydroxide reacts with silicates and aluminates (pozzolans) in the clay, to form cementing materials or binders, consisting of calcium silicates and aluminium hydrates. A certain minimum value of A_w (Cement-soil ratio) is important for complete interaction between cement with clay in order to form the required order of primary and secondary cementitious material which are said to be the principal strength producing compounds of cement treated clay. Tests conducted on Hong Kong marine deposits by Yin and Lai, (1998) showed that no significant improvement was obtained if the cement-soil ratio is less than 5%. The studies conducted on soft Bangkok clays by Uddin et al., (1997) arrived at the conclusion that higher cement content of as much as 10% to 25% is needed to reduce the compressibility of the clay. Therefore, higher percentage of cement is needed for getting improvement in the soil. At cement contents of more than 5%, the soil started gaining strength which is reflected in the pre-yield region of the void ratio-effective stress relationship. The yield stress values obtained for all the cement contents are tabulated Table 4. The yield stress increase significantly beyond 5% cement content. However, the difference in the yield stresses for 15% and 20% cement contents is not very significant.

The curves are flat with negligible compression up to the yield point, as expected. Beyond the yield point, sudden compression was observed. This is

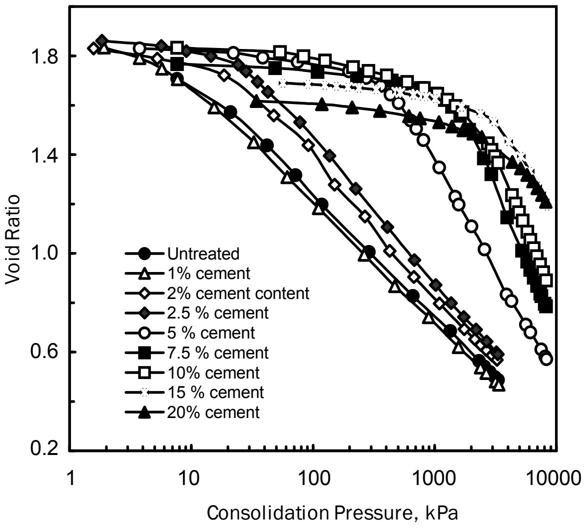

Fig. 6 e-Log σ_v' Plots for Different Cement Contents

Table 4 Yield Stress for Different Cement Contents

Cement content (%)	*Yield stress (kPa)*	*Compression index C_c*
0	0	0.484
1	25	0.457
2	40	0.461
2.5	50	0.554
5	500	0.912
7.5	1600	1.121
10	2500	1.282
15	3000	1.052
20	3100	0.768

attributed to the breakage of cementation bonds. The values of compression index are also listed in Table 4. The compression index values are the slope of the linear part of the void ratio versus log pressure relationship curve beyond yield. The c_c values increased with increase of cement content at lower percentage of cement (cement content < 10%). Beyond a cement content of 10%, the compression index decreases. This may be due to the sudden breakage of bonds at the contacts at lower percentage of cement. At higher cement contents, the bond strength is strong that sudden reduction in compressibility has not occurred leading to lesser compression index values. It was also noted that Cc of treated clay is higher than that of untreated clay and this observation is consistent to the findings of Kamruzzaman et al., (2009) and Liu and Carter (1999), which showed that during virgin yielding, the structured soil is more compressible than the reconstituted soil. Thus, beyond the yield stress, the treated samples seem to exhibit normally consolidated behaviour.

Effect of curing stress on compressibility

As brought out earlier, the soil in the field, after deep cement mixing will be left for curing under the overburden pressure. The effect of the curing stress on the compressibility is mainly studied through CRS test. The void ratio-effective stress relationship showing the effect of curing stresses for 10% cement content by conventional consolidation test are shown in Figure 7. It can be seen that e-log σ_v' plots of treated sample shows less compressibility due to cementation bonds. Sufficient data points beyond 800 kPa are required for establishing the yield stress. This was achieved by performing CRS tests. The void ratio-effective stress relationship of all the soils after curing under different stress levels for various cement contents are shown in Figures 8a to 8e. The effect of curing under stress is to

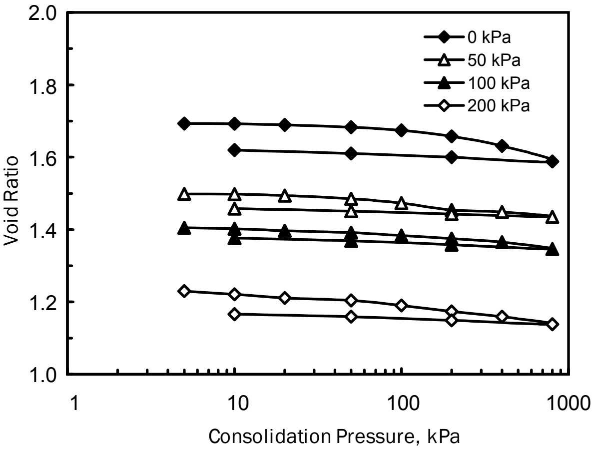

Fig. 7 e-Log σ_v' Plots of 10% Cement Content for Different Curing Stresses (Conventional Consolidation Test)

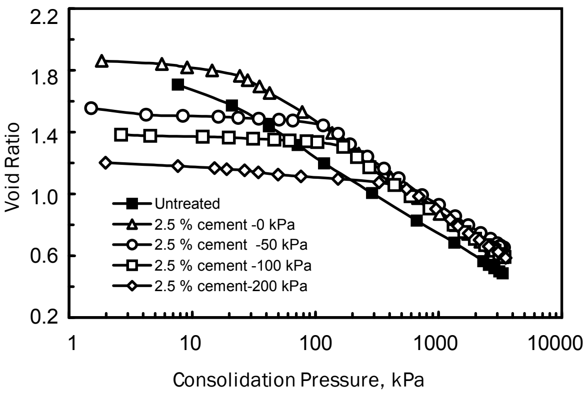

Fig. 8a e-Log σ_v' Plots for 2.5% Cement Content at Different Curing Stresses

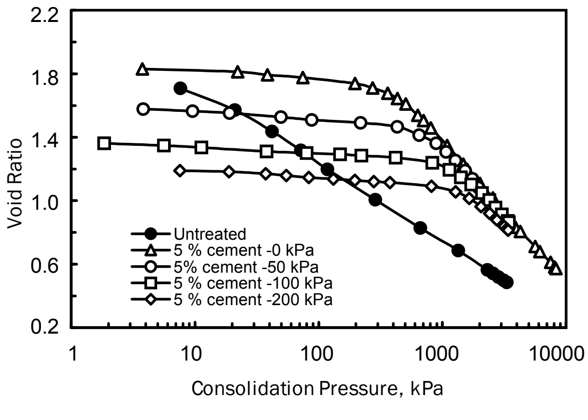

Fig. 8b e-Log σ_v' Plots for 5% Cement Content at Different Curing Stresses

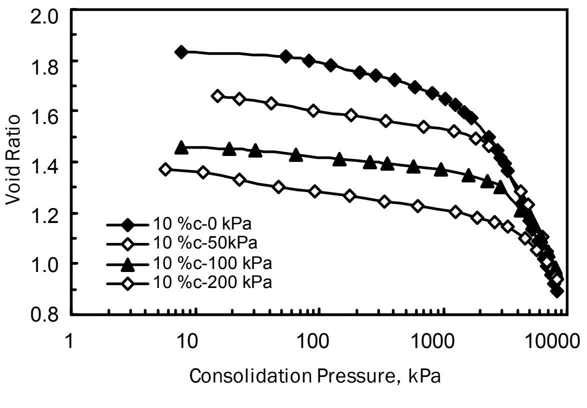

Fig. 8c e-Log σ_v' Plots for 10% Cement Content at Different Curing Stresses

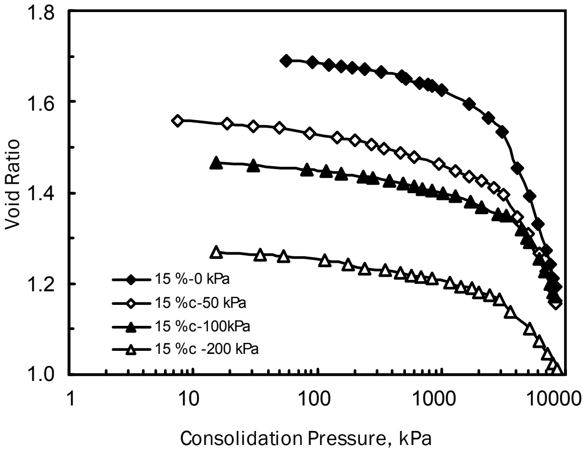

Fig. 8d e-Log σv' Plots for 15% Cement Content at Different Curing Stresses

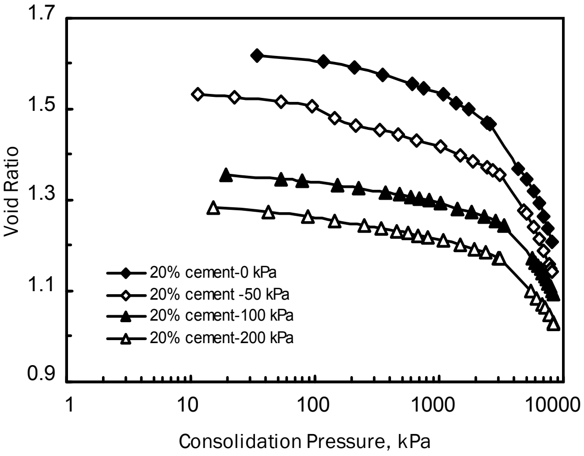

Fig. 8e e-Log σv' Plots for 20% Cement Content at Different Curing Stresses

shift the position of the curves downwards due to lesser initial void ratio. The initial void ratio decreases as the curing stress increases. This is mainly due to the consolidation that is taking place during the curing period. The values of compression index for different curing stresses for cement contents of 2.5%, 5%, 10%, 15% and 20% are tabulated in Table 5. It can be seen from the table that the Cc values decreases with curing stresses and the effect is significant for cement contents greater than 10% and negligible for 2.5% cement content.

The yield stress values computed for different cement contents with curing stresses are shown in Figure 9. At zero curing stress, the magnitude of yield stress depends on the cement content. However, the difference between 15% cement content and 20% cement content is not very significant. Therefore, 15% cement content is very effective than the 20% cement content considering the fact that the additional 5% of cement has not increased the yield stress significantly. Similar conclusions were drawn by Uddin et al. (1997).

The increase in yield stress is due to a coupled effect of cementation and densification due to consolidation under the curing stress (Huang and Airey 1998). The effect of curing stress alone is evaluated by separating the yield stress corresponding to the yield stress obtained for the case of samples cured without curing stress and plotted in Figure 10. The effect of curing stress is clearly visible. Up to a curing stress of 100 kPa, the effect of curing stress is to increase the yield stress. This may be attributed to the densification

Table 5 Compression Index for Different Curing Stresses at Various Cement Contents

% of cement	*Curing stress (kPa)*	*Compression Index (C_c)*
2.5	0	0.554
	50	0.53
	100	0.512
	200	0.533
5	0	0.912
	50	0.946
	100	0.857
	200	0.704
10	0	1.282
	50	1.274
	100	1.154
	200	0.844
15	0	1.052
	50	0.581
	100	0.530
	200	0.496
20	0	0.768
	50	0.554
	100	0.502
	200	0.450

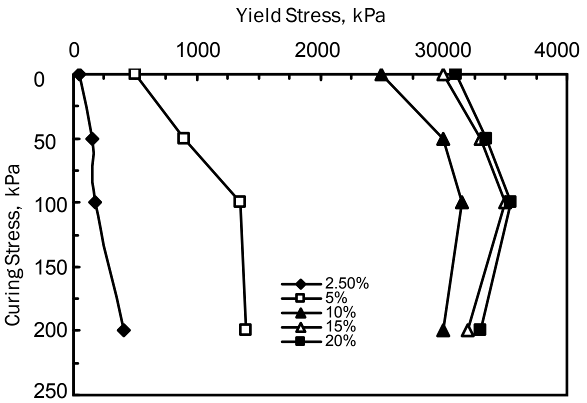

Fig. 9 Variation of Yield Stress with Curing Stress for Different Cement Contents

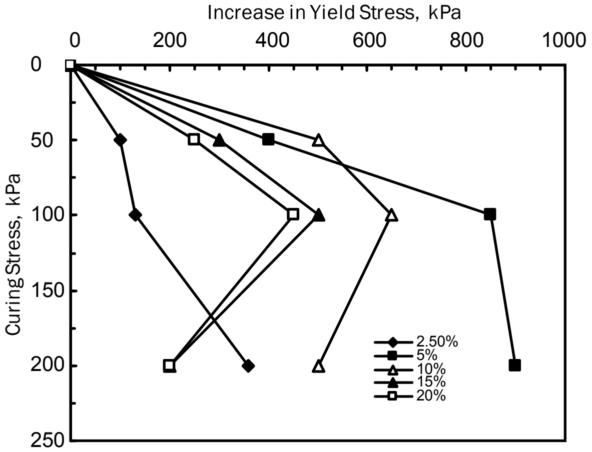

Fig. 10 Increase in Yield Stress with Curing Stress at Various Cement Contents

Table 6 Water Content Reduction due to Consolidation for Curing Stress 200 kPa

Percentage cement	*Water content reduction due to consolidation (%)*
2.5%	27.29
5%	24.58
10%	17.44
15%	16.26
20%	12.88

effect. However, at a curing stress of 200 kPa, the increase in yield stress has decreased. This may be attributed to the combined effect of the following two aspects:

1. The increase in yield stress of cement treated soil primarily depends on the cementation bonds. Formation of cementation bonds is a time dependant process due to pozzolanic reactions. When the curing stress is very large, particle slippage occurs continuously due to consolidation that occurs along with cementation. Therefore, the bond strength may get reduced at higher curing stresses.
2. For effective formation of cementation bonds, sufficient quantity of water is needed for hydration. However, when the curing stress is large, large quantity of water is squeezed out of the sample. Typically, the reduction in water content from the initial water content of 70% due to consolidation under 200 kPa are listed in Table 6. The quantity of water squeezed out is quite significant. Therefore, water available may not be sufficient for full formation of cementation bonds.

In order to see the effect of curing stress further, the values of unconfined compressive strength with curing stresses are shown in Figure 11. Very similar to the case of yield stress, the unconfined compressive strength also decreases at a curing stress of 200 kPa, further confirming the reasons outlined above.

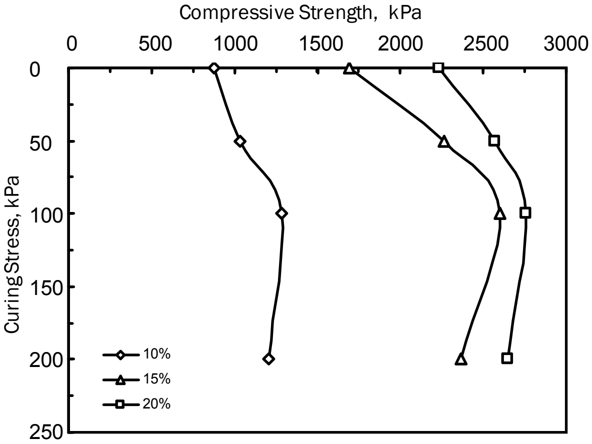

Fig. 11 Variation of Unconfined Compressive Strength with Curing Stress

Conclusions

Following conclusions are drawn from the constant rate of strain consolidation test conducted on cement treated marine clay:

1. The CRS test results are comparable to the conventional consolidation test results by incremental loading. Therefore, the conventional consolidation apparatus may be slightly modified and used to conduct CRS tests, by connecting a pore pressure transducer at the base of the cell.
2. The yield stress of the cement treated clay depends on the mixing water content. The yield stress is the maximum when the clay water content is about 1.25 times the liquid limit water content.
3. The behaviour of cement treated soil depends on the cement content. At very low cement contents (<5%), the stabilization effect is not significant. At higher cement content of more than 5%, very good improvement is observed. However, beyond a cement content of 15%, the effect is not very significant.
4. The effect of curing stress is to increase the yield stress due to densification and cementation effects. At higher stress level (200 kPa), the increase in yield stress is not significant possibly due to particle slippage that occur during curing and the squeezing out of water that is necessary for hydration.

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