Strength Behaviour of Cement Stabilised Marine Clay Cured Under Stress

Bushra, I.  
Research Scholar  
e-mail: bushrasmail@iitm.ac.in  

Robinson, R.G.  
Associate Professor  
e-mail: robinson@iitm.ac.in  

Department of Civil Engineering, IIT Madras, Chennai

ABSTRACT

Stabilisation of soft ground by deep cement mixing technique is a globally accepted ground improvement method for enhancing the bearing capacity and reducing settlement. At deeper depths the treated soil gets cured under stress due to the overburden. The role of curing stress on the strength behaviour of the cement treated soil under drained and undrained curing conditions has been studied in this paper. Unconfined compression tests were performed on cement treated samples with and without curing stress. Marine clay from Ennore, near Chennai, excavated at a depth of 1.5 m was selected for the study. The range of cement contents selected were 10 %, 15 % and 20 % with curing time of 28 days. The curing stresses adopted were 50, 100 and 200 kPa representing samples at an approximate depth of 5 m, 10 m and 20 m, respectively. The unconfined compressive strength values for both loaded drained and undrained curing conditions were discussed in this paper.

1. INTRODUCTION

Soft soil formations, especially when the in-situ water contents are high, have very low bearing capacity and high compressibility characteristics. The in-situ deep mixing method is an established technique for improving the strength and reducing settlement of soft soil deposits. In practice, upon completion of the treatment, the improved ground will be cured over a specific period of time, before commencement of construction activities. At deeper depths, curing takes place under stress due to the overburden. Limited studies are available in the literature, to study the influence of curing stress on the strength behaviour. 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 et al., (2004) established the fundamental parameters such as after-curing void ratio ($e_{ac}$) and cement content ($A_c$) 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) have established the existence of an optimum mixing water content in which the resulting cement-admixed clay is expected to give the highest strength.

Consoli et al., (2000 & 2006) 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. Chin (2006) performed tests on isotropic curing for cement treated Singapore marine clay for a short duration of 7 days. He concluded that the drained curing under confining stress improved both the compressibility and strength behaviour of cement treated clay, due to the densification of the soil skeleton.

This paper mainly aims in finding the strength behaviour of cement treated clay under loaded drained and undrained curing conditions using unconfined compressive strength (UCC) test. The stiffness, as well as the effect of after curing void ratio was also discussed.

2. EXPERIMENTAL INVESTIGATION

Soil Sample

Marine soil was collected from a site near Ennore, Chennai. As per the borehole charts available at the site, the soil stratification consists of 3m thick soft clay, 3-8m thick sand and 8-10 m stiff clay. The water table is at a depth of 0.7 m from the ground level. Sufficient quantity of the soil sample was collected from a depth of 1.5m. The soil was air dried, crushed and sieved through 4.75 mm sieve to remove shell pieces and other particles.
The soil contains 9% sand, 47% silt size and 44% clay sized particles. The liquid limit and plastic limit of the soil are 56% and 25%, respectively. The specific gravity is 2.62 and pH value is 7.2. The soil contains about 5.5% of organic matter. Ordinary Portland cement of 53 grade was packed in 1 kg to 2 kg polythene bags and placed in airtight containers to preserve the freshness.

The unconfined compressive strength of the soil in the field was below 20 kPa at a water content of 45% which is about 0.8 times the liquid limit. The coefficient of consolidation \( c_V \) obtained from consolidation test was 6.3 \( \times 10^{-5} \) cm/s and permeability was 6.4 \( \times 10^{-9} \) cm/s for an applied pressure of 400 kPa. X-ray diffraction (XRD) results of the base clay shows the presence of Quartz and Feldspar in the silt fraction and traces of illite and Kaolinite in the clay fraction.

**Methodology of Testing**

For given cement content, the shear strength of the cement treated soil depends on the clay water content. There exists an optimum clay water content at which the shear strength is maximum (Lorenzo et al., 2006). From the UCC tests performed on samples treated with cement contents of 10%, 15% and 20% the optimum clay water content was established as 1.25 times the liquid limit irrespective of the cement content. The remoulding water content \( w^* \) is defined as the water content prior to the addition of cement slurry. The base clay was mixed with the remoulding water content in the Hobart mixer for ten minutes with a planetary speed of 61 rpm for the first five minutes and a speed of 125 rpm for the last five minutes to obtain uniform mixing of samples based on trials. 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 until a homogeneous clay-water–cement paste was attained.

The unconfined compression tests constituted the main part of this paper as a quick assessment of strength can be made through unconfined compression test. The test is simple and also reliable. UCC tests have been used in most of the experimental programs reported in the literature in order to verify the effectiveness of the stabilization with cement or to access the importance of influencing factors on the strength of cemented soils (Uddin et al., 1997). The test was performed on 38 mm diameter and 80 mm length untreated and treated soil samples with a deformation rate of 0.625 mm/minute in accordance with IS: 2720 (Part 10) -1991. The specimens for unconfined compression tests were made by pushing the paste into the 38-mm diameter by 80-mm height PVC mould, by thumb kneading. Thumb kneading technique was done to eliminate air bubbles and the process was continued until the surface of the protruding specimen was uniform and smooth. The density of each specimen with the same mixing condition was monitored and kept constant. The specimens were demoulded the next day, wrapped in polythene covers and then placed in the mist room, having a maintained ambient temperature, for curing. All samples were cured for a period of 28 days. Two to three specimens were tested for every remoulding water content so as to check the reproducibility. The influence of curing time for a period of 1, 3, 7, 14, 28, 60, 90 and 365 days was studied. Also the effect of cement contents of 2.5%, 5%, 7.5%, 10%, 15% and 20% were studied for a curing period of 28 days.

The curing stresses used were 0 (atmospheric curing), 50, 100 and 200 kPa representing samples to a depth of 0, 5 m, 10 m and 20 m, respectively. For loaded drained and undrained curing conditions, the samples were prepared in stainless steel moulds. The loads corresponding to stresses of 50, 100 and 200 kPa were applied for a curing period of 28 days. The cement contents selected were 10%, 15% and 20% i.e in the range of deep mixing application.

**3. RESULTS AND DISCUSSIONS**

**Influence of Curing Time**

The effect of curing time on cement contents of 10%, 15% and 20% for various curing periods of 1, 3, 7, 14, 28, 60, 90 and 365 days was studied. Figure 1. shows the influence of curing time for the above cement contents. For 10% cement content, beyond 60 days noticeable improvement was not observed. It can be also observed that tremendous improvement in strength was observed for 15% cement content. The strength of the cement treated soil for the 15% cement content and 20% cement content are nearly the same at longer curing periods. Curing time increases the strength with cement content and may be due to the formation of secondary cementitious products due to pozzolanic reactions in addition to earlier hydration reaction which imparts further strength to the cement treated soil. Depending upon the target strength and the time required for completion of the project, the curing period can be prolonged so that savings in cement can be obtained.

![Fig. 1: Influence of Curing Time on Compressive Strength](image)

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Influence of Cement Content

The stress-strain curves for different cement contents are shown in Figure 2. At lower cement contents, strain softening behaviour was noticed. As the cement content is increased, brittle failure was observed. Figure 3 shows the variation of UCC values with cement content. Cement content of 2.5% is found to be not effective, probably due to the lack of formation of pozzolanic compounds. Cement contents of 5% and 7.5% can be effectively used for lighter loads. Substantial improvement in strength can be attained with cement contents beyond 10%. This is due to the formation of cementitious compounds with increase in cement content.

![Fig. 2: Stress-Strain Curves for Cement Content of 2.5%, 5%, 7.5%, 10%, 15% and 20%](image)

![Fig. 3: Variations of UCC Values with Cement Content](image)

Influence of Curing Stresses

Tests were conducted for both loaded drained and loaded undrained curing condition for cement contents of 10%, 15% and 20% with curing stresses of 50, 100 and 200 kPa.

**Cured Under Drained Condition**

Typical stress-strain plots showing the effect of curing under drained condition with curing stress of 50 kPa for different cement contents are shown in Figure 4. The plot also shows samples cured without curing stress. It was found that curing stress increased the strength of treated samples when compared to the samples cured without stress. The increase in strength due to the influence of curing stress of 50 kPa was found to be 17.5% for 10% cement content. An increase of 41% was noted for 15% cement content. But for 20% cement content, it was found only 7% when compared to the condition of without curing stress. Hence it can be concluded that 15% cement content was found to be more effective.

![Fig. 4: Stress-Strain Curves with Loaded Drained Curing Stress of 50 kPa](image)

**Cured Under Undrained Condition**

Typical stress-strain plots showing the effect of curing under undrained condition with curing stress of 50 kPa for different cement contents are shown in Figure 5 and compared with the samples of without curing stress.

![Fig. 5: Stress-Strain Curves with Loaded Undrained Curing Stress of 50 kPa](image)

It was found that the influence of curing stress under undrained curing condition also increased the strength of the treated samples when compared to the samples cured without stress. Since no drainage was permitted during curing period, the water content after curing period was slightly higher than drained curing condition. The strength when compared to drained curing was less for undrained curing condition. Variation of compressive strength with curing stress is shown in Figure 6. The coupled effect of densification and cementation takes place during curing period. As can be seen from Figure 6, the general trend is that the strength increases up to a curing stress of 100 kPa and thereafter it decreases. Due to the immediate application of load, the cementation effect may not take place properly due to the slippage of particles at higher curing stresses.
The stiffness in terms of initial tangent modulus for samples cured under drained condition increased to 34% for 10% cement, 61% for 15% cement and 44% for 20% cement, for a curing stress of 200 kPa when compared with the condition without curing stress. Figure 7 shows the variation of after curing void ratio with curing stress. The post curing void ratio also decreased with the influence of curing stress.

Fig. 6: Variations of Compressive Strength with Curing Stress

Fig. 7: Variations of Void Ratio with Curing Stress

4. CONCLUSIONS

1. Curing time increases the strength with cement content and may be due to the formation of secondary cementitious products. 15% cement content was found to be more effective.

2. Substantial improvement in strength can be attained with cement contents beyond 10%.

3. The influence of curing stress under drained and undrained curing condition increased the strength of the cement treated samples due to coupled effect of densification and cementation process during curing period.

4. The strength due to influence of curing stress under drained condition is more when compared with undrained condition. This may be due to the increase in water content at the end of curing period for the samples cured under undrained condition.

5. The general trend observed was that the strength increased up to a curing stress of 100 kPa and thereafter the strength decreased or almost found to be constant. Due to the immediate application of load, the cementation effect may not take place properly due to the slippage of particles at higher curing stresses.

6. The influence of reduction of post-curing void ratio along with the cementation effect contributes to the strength of the treated sample.

REFERENCES


