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Tensile Strength of Cement Treated Clay

TENSILE STRENGTH OF CEMENT TREATED CLAY

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Abstract

Tensile properties of geomaterials often play an important role in many geotechnical engineering problems. Compacted soil layers in dams, clay liners in landfills, reinforced earth-retaining wall systems, cement stabilized crushed rocks in pavements, etc. are constantly checked for tensile cracking. This type of cracking happens when the developed tensile stress exceeds the tensile strength of the material. Usually, the tensile strength of natural soil is assumed to be negligible. However, it is proven that cement treated soils possess some amount of tensile strength. The determination of tensile strength of cement treated clay, using a newly developed tensile testing apparatus, is focussed in this study. The existence of an optimum cement content for tensile strength is also discussed.

Keywords: Cement treated soil, direct tension, optimum cement content, tensile strength.

1. Introduction

Tensile properties of geomaterials play an important role in many geotechnical engineering problems. Compacted soil layers in dams, clay liners in landfills, cement stabilized crushed rocks in pavements, etc. are generally checked for tensile cracking. This type of cracking happens when the developed tensile stress exceeds the tensile strength of the material. Soil-cement columns or walls formed by deep cement mixing have been widely used for foundations, to mitigate liquefaction, as supports for excavations, etc. Research has shown that these improved columns are often susceptible to tensile cracking due to bending moments caused by external forces.

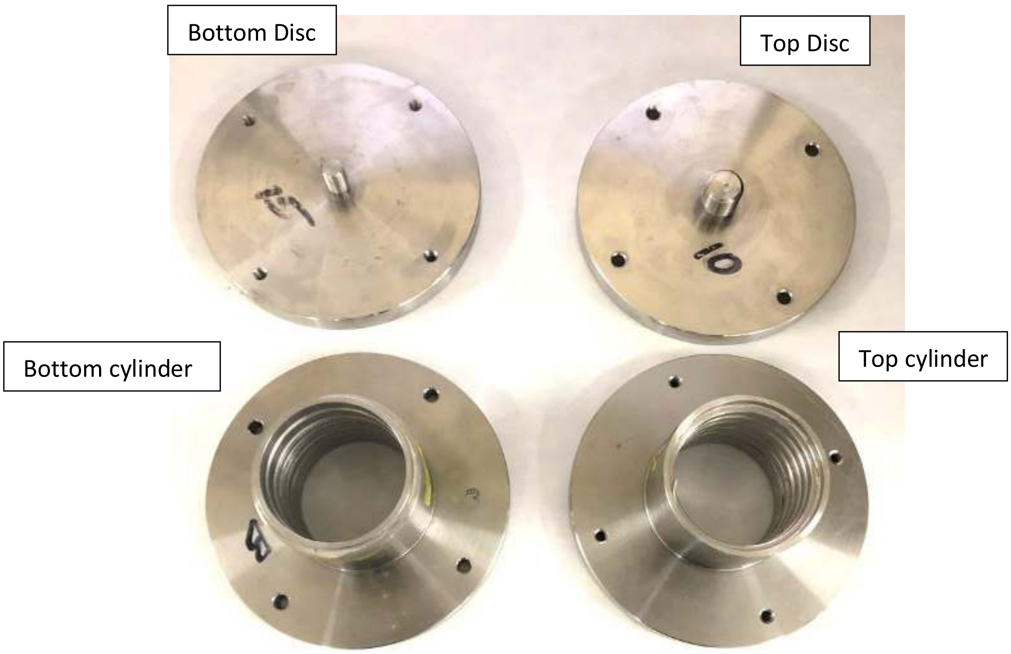
Tensile strength of cement treated soil is usually determined by two methods, tensile splitting strength test (also called Brazilian test) and direct tension test. Split tensile strength testing is the more popular of the two, owing to the ease with which it can be performed. This method has been included in most standards as a method to evaluate the tensile strength (ASTM C496). Owing to the difference in stress conditions, the tensile strength obtained vary with the type of test used. Namikawa and Koseki (2007) performed extensive numerical simulations to explain the differences in behaviour of cement treated soils subjected to different types of tensile strength tests. The Brazilian test was found to underestimate the tensile strength due to the shear failure that happens below the loading strip. Moreover, the stress condition is not well-defined at the boundaries in this type of testing and is hence not considered as an element test (Namikawa and Koseki, 2007). Direct tension test was found to be more appropriate and reliable for cement treated soils (Namikawa et al. 2017) and this method has been used in this study as well. Not many direct tension test data are reported in case of cement treated clays. An apparatus was developed in this study to estimate the tensile strength of cement treated clay.

2. DEVELOPMENT OF TENSION TEST APPARATUS

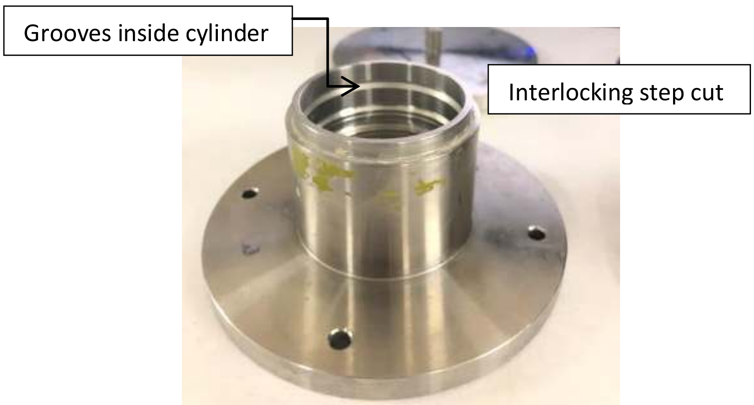
The tension testing apparatus was designed and fabricated at Indian Institute of Technology Madras, India. Figure 1 shows the components of the apparatus.

The apparatus was made of stainless steel and was designed to accommodate a cylindrical specimen of 50 mm diameter and 100 mm height. Since direct tension test involves pulling the specimen from top and bottom simultaneously in the vertical direction, the apparatus was designed as two coaxial hollow cylindrical parts of 50 mm diameter and 50 mm length each. This is to force the specimen to fail at half the length. This is justified because the cement treated clay specimen is usually prepared such that it is homogenous. The two individual parts of the apparatus were given an interlocking step cut at one end so that they could be easily connected to accommodate a full length specimen. Grooves were provided inside the cylinders to firmly grip the specimen. This technique was used by Indraratna et al. (2009). Moreover, cement treated soils may undergo minor shrinking in diameter after 28 days curing period. This may loosen the specimen against the walls of the cylinder and the specimen might just come out without taking any tensile load. Grooves are expected to take care of this too.

The direct tensile testing involves pulling the specimen longitudinally from one side, keeping the other side stationary. This apparatus was designed such that the top half can be fixed to the load cell and hence, would remain stationary during testing. The bottom half would be fixed to the pedestal of loading frame and will be pulled downwards at a specified deformation rate. To facilitate this, two discs were fabricated, each for top and bottom cylindrical portions (as shown in Figure 1). The bottom disc was attached to the bottom cylinder before sample preparation so as to serve as a base for the cylinder. This disc has a screw at the bottom and can be used to connect the setup to the pedestal of loading frame, at the time of testing. The top disc has a screw at the top which can be used to mount the setup to the load cell.



(a)



(b)

Figure 1 Tensile testing apparatus (a) Components (b) closer view of cylindrical part

3. MATERIAL TESTED

Marine clay was used in this study and was procured from National Institute of Ocean Technology (NIOT) campus, Chennai, India. All the basic properties of the soil were determined as per Indian Standard testing procedures (IS 2720) and are given in Table 1. The soil was classified as CH, as per IS 1498 (1970).

Table 1. Basic properties of soil

Soil Properties	Values
Liquid Limit (%)	59
Plastic Limit (%)	24
Plasticity Index (%)	35
Sand (%)	43
Silt size (%)	20
Clay size (%)	37
Specific Gravity (G)	2.71

4. SAMPLE PREPARATION

Cement can be introduced into the clay slurry in dry powder form or wet slurry form. Dry form may result in a non-homogenous mix and therefore might affect the strength development. Wet method ensures homogeneity and better workability, and hence higher strength (Tan et al., 2002). Wet method was used in this study. Water present in clay prior to addition of cement plays an instrumental role in strength development. This water content, called remoulding water content (Lorenzo and Bergado, 2004), was first optimized. Specimens prepared at various remoulding contents, ranging from 1 to 2 times the liquid limit of soil, were subjected to unconfined compression strength (UCS) test. The water content corresponding to maximum UCS value was selected as optimum remoulding water content. It was found out to be 1.2 times the liquid limit of soil. This procedure has been discussed in Azneb et al. (2019). This remoulding water content was used for the preparation of all the specimens. Water-cement ratio was maintained as 0.6, as has been adopted in the literature (Lorenzo and Bergado, 2004; Bushra and Robinson, 2012; Azneb et al. 2019).

Before the start of sample preparation, the top and bottom cylinders (with the bottom disc attached) of the apparatus were kept together and the joint was wrapped with an adhesive tape. This is to avoid leakage upon pouring the sample. The clay was mixed with optimum remoulding water content and was thoroughly mixed in a Hobart mixer for 20 minutes. The cement slurry was then poured and mixed again for another 10 minutes. This sample was poured in layers into the apparatus, with proper tamping at each layer to get rid of entrapped air. Once the sample is filled up to the brim, the top disc was attached using allen screws, and was allowed to cure for 28 days. Cement contents of 10%, 15% and 20% were considered in this study and was calculated based on the dry weight of soil.

5. TESTING METHODOLOGY

Once the specimens were ready for testing, the adhesive tape was removed and the entire apparatus was carefully mounted to the load cell on the loading frame. The bottom disc was screwed to the pedestal of loading frame. Figure 2(a) shows the apparatus ready for testing.

(a)

(b)

Figure 2 Tensile testing apparatus (a) Ready for testing and (b) After testing is complete

The top part of the apparatus being stationary, the frame was now moved downwards at a specified deformation rate to induce tensile stresses inside the specimen. Strain controlled tensile tests were conducted at a deformation rate of 0.05 mm/min for all the specimens. As shown in Figure 2(b), the completion of test was marked by breakage of the sample at half the length of sample. At this stage, load cell recorded a residual value which includes the weights of top disc, top cylinder and half the specimen under suspension. This residual value was deducted from all the load readings to obtain the true tensile load taken by the specimen. The peak tensile load divided by the cross-sectional area was evaluated as the final tensile strength of the specimen. Axial strain was calculated by noting the time corresponding to each load reading and multiplying by the deformation rate.

6. RESULTS AND DISCUSSION

The variation of tensile stresses with the axial strain for various cement contents are shown in Figure 3. Compared to 10% cement content, 15% and 20% showed abrupt breakage after reaching the peak tensile stress. The drop in strength was higher for 20% cement content, after failure. This points towards the increase in brittle nature of cement treated clay with increase in cement content. The tensile strengths corresponding to different cement contents are shown in Table 2. tensile strength for 10% cement content is much less compared to other cement contents. However, 15% cement content showed an increase in tensile strength by about 397% compared to 10% cement content. However, a further increase in cement content by 5% (i.e. 20% cement content) resulted in a strength gain of merely 10%. Hence, 15% cement content can be considered to be optimum cement content for design, in terms of performance and economy. Similar results were discussed in Azneb et al. (2019). From micro-structural considerations, Horpibulsuk et al. (2010) explained that strength development upon increase in cement content happens in three zones- active, inert and deterioration zone. Strength keeps on increasing with increase in cement content in the active zone, whereas, the increase in strength is minimal in the inert zone. Post inert zone, the increase in cement content leads to reduction in strength. This reflects the deterioration zone. In the active zone, hydration products occupy the pores and cementitious products improve the inter-cluster bonding strength. Overall, the pore volume is significantly reduced during this zone and hence, strength increases with increase in cement content. Moreover, cement per grain contact increases and imparts a commensurate amount of bonding at the contact points. The increase in hydration products and cementitious products are relatively the same during inert zone and hence, the increase in strength is minimal. During deterioration zone, cement content is so high that water content of soil is significantly reduced. This leads to reduction in hydration products and hence, cementitious products. This literature confirms the existence of an optimum cement content.

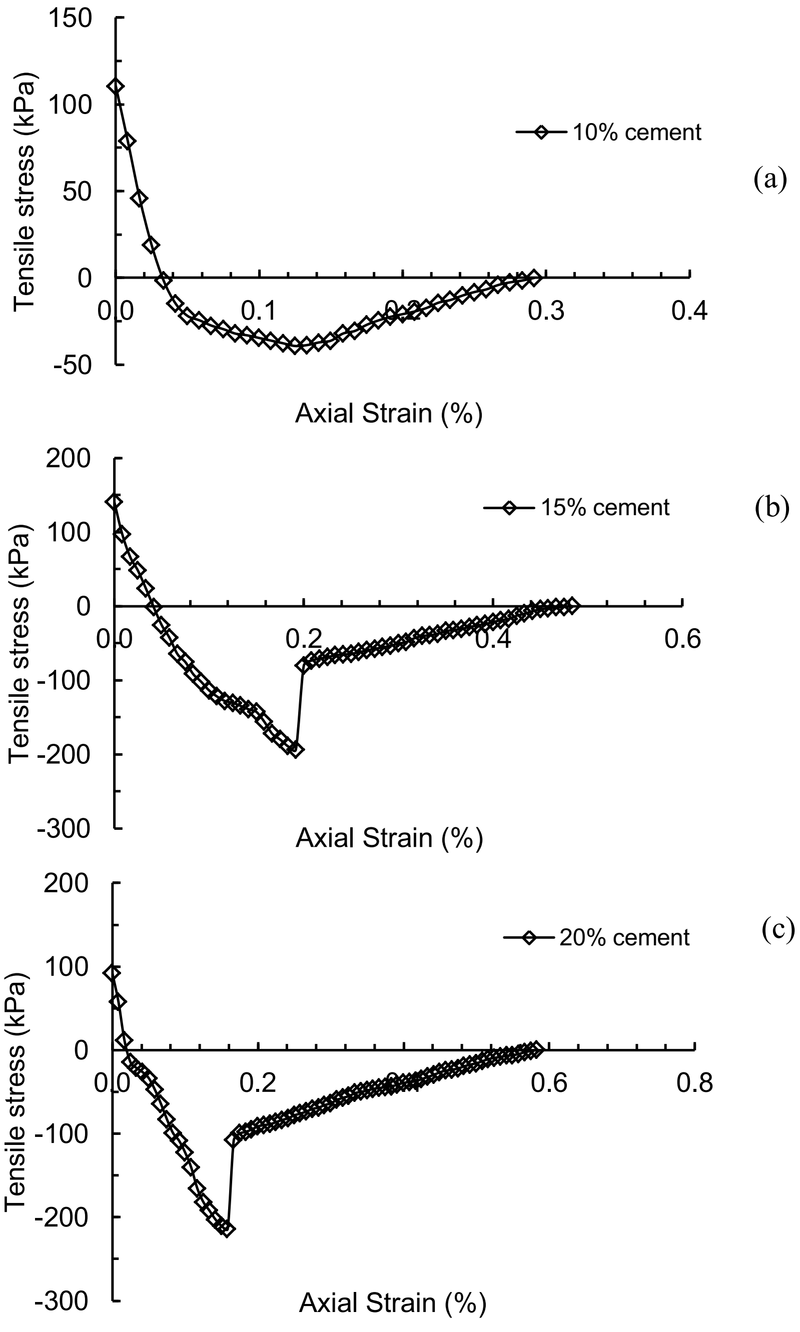


Figure 3 Variation of tensile stresses versus axial strain for (a) 10% cement content (b) 15% cement content (c) 20% cement content

Table 2. Tensile strength values for different cement contents

Cement content (%)	Tensile strength, σ_t (kPa)
10	39
15	194
20	214

To summarise, the bonding strength in 10% cement content was found to be less to generate reasonable tensile strength. However, further increase of 5% cement content yielded much higher tensile strength by 397%. Cement content beyond 15% cement content did not result in significant increase in tensile strength Hence, the optimum cement content which yields reasonable tensile strength needs to be found out for problems involving tensile stresses.

7. CONCLUSIONS

The tensile strength of cement treated clay is an important parameter in various ground improvement applications. Literature suggests that direct tension test is the most reliable test to determine the tensile strength of cement treated soils compared to the commonly used Brazilian test. A direct tension test apparatus was developed at Indian Institute of Technology Madras, India. Tests results showed that the tensile strength is considerably less for 10% cement content, compared to higher cement contents. 15% cement content was identified as optimum cement content, beyond which addition of cement did not result in significant increase in tensile strength. For field problems involving tensile stresses, determination of cement content, which generates maximum tensile strength, would be helpful in terms of strength and economy.

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