CONSOLIDATED DRAINED BEHAVIOUR OF CEMENTED SANDS

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Abstract Cementation plays an important role in the stress-strain and strength behaviour of frictional material. The study of cemented soil is of significant interest to geotechnical engineers. A number of parameters such as cement content, confining pressure and curing period can influence the stress-strain behavior of cemented sand. In the present study, a series of conventional drained triaxial compression tests were conducted on cemented poorly graded sand. Portland pozzolana cement used as the cementing agent was added to the sand 2.5% by dry weight of sand. Samples were prepared at 30% relative density and tested at confining pressures of 100kPa, 200kPa, and 300kPa. The tests were performed on cemented samples after 7, 14 and 28 days curing period. The deviatoric stress and axial strain increases with increasing the confining pressure and curing period. The cemented samples dilated after some contraction. The dilatancy increased with increase in the curing period and decreased with increase in the confining pressure. The shear strength parameters of cemented sands are greater than uncemented sands.

Keywords: Cementation, Drained behaviour, Curing period, Confining pressures, Portland Pozzolana cement

1 Introduction

Ground improvement increases the shear strength parameters and decreases the permeability and compressibility characteristics of the soil. Different methods are used to improve the geotechnical properties of soils and one of them is using additives. Additive stabilization is achieved by the addition of proper percentages of cement, lime, fly ash, bitumen, or combinations of these materials to the soil. Selection of the appropriate additive and determination of its percentage depends on the soil classification and the degree of improvement desired. The stabilization of soil with cement is an attractive and feasible technique. Cementation plays an important role in the stress-strain and strength behaviour of frictional materials. The study of cemented soil is of significant interest to geotechnical engineers. Soil cementation can be found naturally from precipitation of calcite, silica, alumina, iron oxides and possibly other inorganic or organic components. or induced artificially for the purpose of improving the bearing capacity of weak soil. Soil stabilization with cement is a good solution for pavement base layer, slope protection for earth dams, as base layer to shallow foundations and to prevent sand liquefaction. In recent works the soil-cement ratio has been assessed by numerous laboratory tests that aim to find the minimum amount of cement to achieve target properties in terms of stiffness, strength and durability. The strength and deformation behaviour of artificially cemented soils depends as soil type, stabilizing agent and stabilizer content as well as the method of compaction.

2 Background

In the past decades, many researchers started working on the performance and behavior of artificially cemented sand. Till date, there are many publications reported on the behavior of cemented soil using different cementing agent and also research has been carried out on various factors that enhances and decreases the strength of the cemented soil. The mechanical behviour of the cemented sands is influenced by the cement content, cement type, density, confining pressure, grain size, and stress strain history. Some of the significant works carried out on cemented sands using cement as a cementing agent and observations made on the stress strain characteristics and shear strength parameters are briefed below.

Previous researchers (Moore et al. 1970, Clough et al 1981,Consoli et al. 2010,2011) showed that the behvaiour of soil- cement mix is complex and affected by many factors such as physical-chemical properties of the soil, The amount of cement, and porosity and moisture content at the time of compaction. The cementation causes increase in brittleness and dilation in sands. Coop and Atkinson (1993) carried out a series of drained triaxial tests on artificially cemented carbonate sands. The authors showed that the stress–strain behaviour of cemented soils depends on the position of the initial state of the stress of the soil with respect to the yield locus of the bonding and it is possible to identify a yield curve outside the state boundary surface of the uncemented soil. A framework for the behaviour was defined depending on the relative magnitudes of the confining pressure and cement bond strength. Abdullah and Kiousiss (1997) studied the behaviour of poorly graded fine sands with cementation of 2%-6% at a density of 1.6g/cc and proved that cement content increases the cohesion in a non-linear way, while it does not change the friction angle with confining pressure. However increase in confinement caused a more ductile shear deformation, with larger initial volumetric compression and reduced ultimate dilation rate in their study. Dongliang et al. (2015) have conducted a detailed laboratory investigation on artificial cemented uniformly graded high-purity quartz sand prepared with ordinary Portland cement with different degrees of cementation such as 1%, 3%, 5% and 8%. In order to avoid adverse effects on the internal friction angle of the samples, spherical or elliptical sand grains were selected for this study. With the increase of cement content, the cohesion force c' and $\Delta\phi'$ gradually increased. The angle of shearing resistance of the artificial cemented sand was smaller than that of the uncemented sample when cement content was low; as cement content increased, it increases as well, but in a moderate manner. c' is much more sensitive than ϕ' to the change in the cement content.

The present work is mainly focuses on consolidated drained behavior of artificially cemented coarse sand using Portland pozzolona cement as a cementing agent. The strength characteristic of sand is determined by varying cement percentage and curing period. The results obtained from this study can be used to predict the drained stress-strain strength behavior of cemented sands with varying cement content under different confining pressure. It can be used to predict the optimum degree of cementation that would be contributing to the strength gain in cement stabilization of sands. Only a part of the work, which discusses the consolidated drained behaviour of cemented sands with 2.5% cementation and 7, 14 and 28 days curing period is presented in this paper.

3 Laboratory Investigations

The sand used for this study was collected from Palar river bed, Tamil Nadu, India. The cementing agent used for the study is Portland pozzlana cement. The specific gravity of sand and cement are 2.62, and 3.15 respectively. The sand consists of dominantly coarse sand fraction with D10 of 0.55 mm. The sand is classified as poorly graded sand (SP) with uniformity co-efficient of 3.81. The maximum and minimum dry densities are1.77 g/cc and 1.6 g/cc respectively and their respective void ratio are 0.60 and 0.44 respectively.

Consolidated 2.5% percentage of cemented sand samples. The samples were prepared at a moisture content of 10%. The sample was prepared for the dry density of 1.67g/cc for sand, 1.69g/cc for 2.5% cemented sand. Cement was taken by dry unit weight of sand and mixed well with the sand. 10% of water was added to moist the drained triaxial tests were carried out on cemented sands with 2.5% cementation and for 7, 14 and 28 days curing period. at 100kPa, 200kPa and 300 kPa. The samples were prepared by under compaction method. In order to prepare the soil sample at a relatively loose state, relative density of the cemented sand for sample preparation has been adopted as 30% and the void ratio of the sample is 0.55. The combined specific gravity of cemented sand was determined sample for easy saturation. The samples were cured at a temperature of 23-24°c at a relative humidity of 90%. The cemented sands were fully saturated in two stages prior to shearing through back saturation technique. As it is difficult to saturate cemented sands, all the samples were soaked in water for 24 hours before saturation at the first stage. After that the cell pressure and back pressure were ramped simultaneously to maintain a pressure difference of 15kPa, for complete saturation in the second stage. Saturation was complete for the Skempton's B parameter 0.9.

The cemented sands were consolidated up to desired confining pressures and sheared at a strain rate applied was 0.0162 mm/min for the consolidated drained tests.

4 Results and Discussion

The stress strain characteristics of sand and cemented sands with 2.5% cementation for 7,14 and 28 days curing period are shown in figures 1a to 1b, 2a to 2b, 3a to 3c and 4a to 4b respectively and discussed in this section. The failure deviatoric stress and axial strain are listed in table 1.

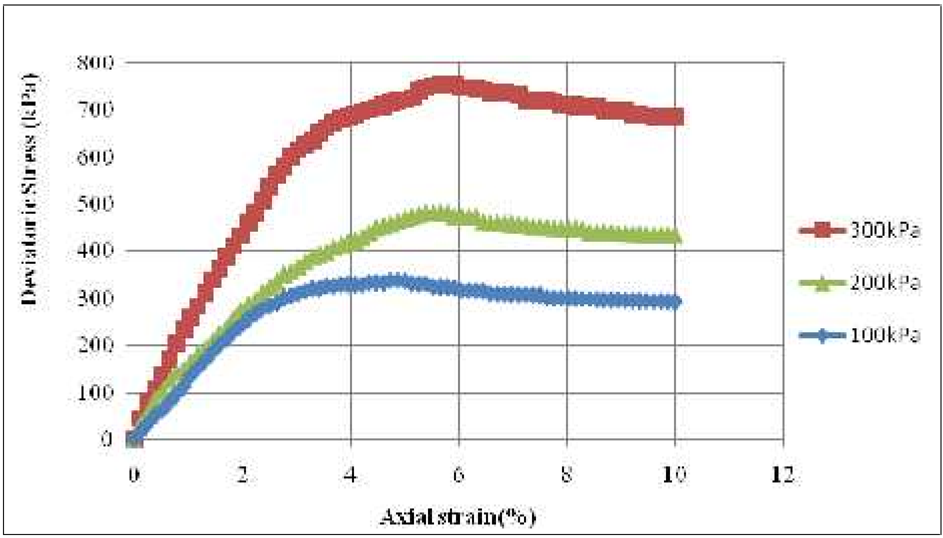

Figure 1a Stress strain curve of sand at different confining pressures

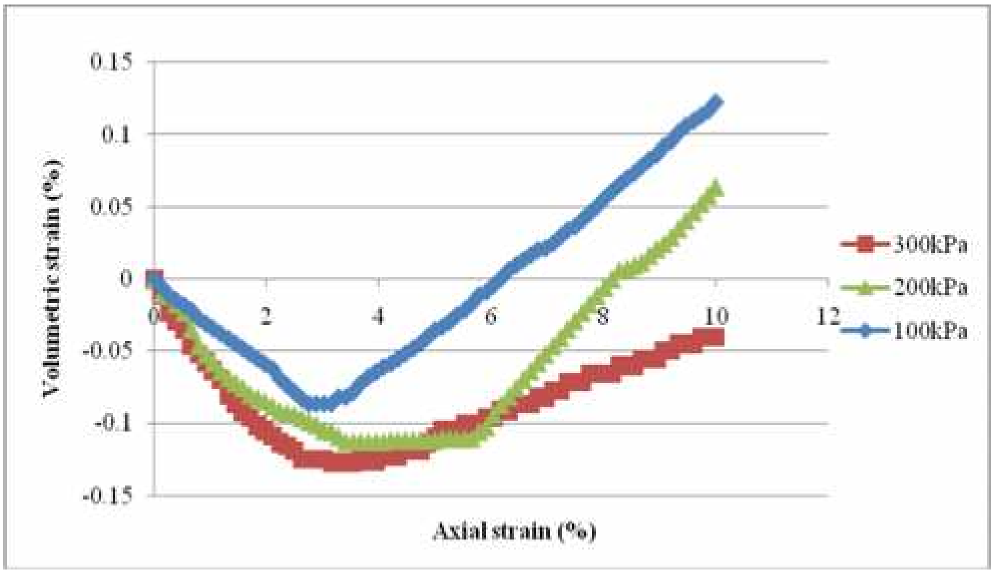

Figure 1b Volumetric strain Vs Axial strain curve of sand at different confining pressures

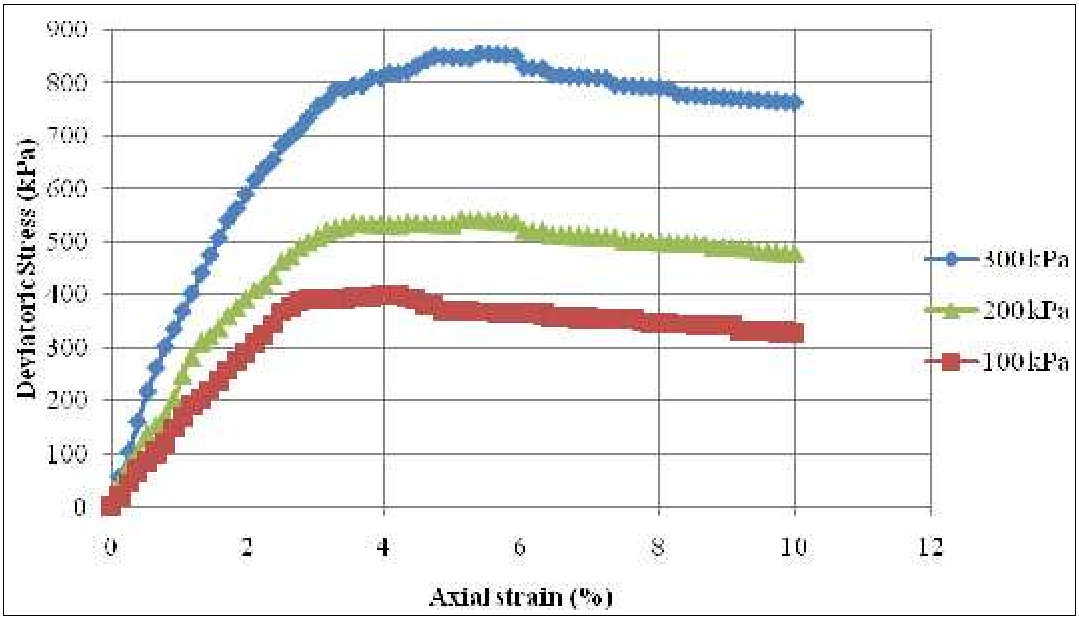

Figure 2a Stress strain curve of cemented sand for 7 days curing period at different confining pressures

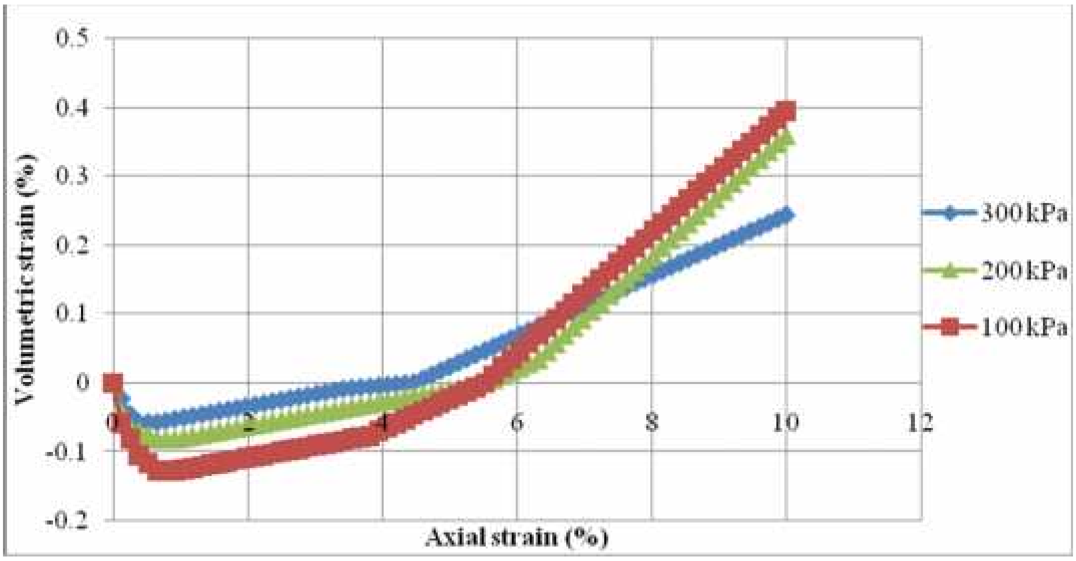

Figure 2b Volumetric strain Vs axial strain curve of cemented sand for 7 days curing period at different confining pressures

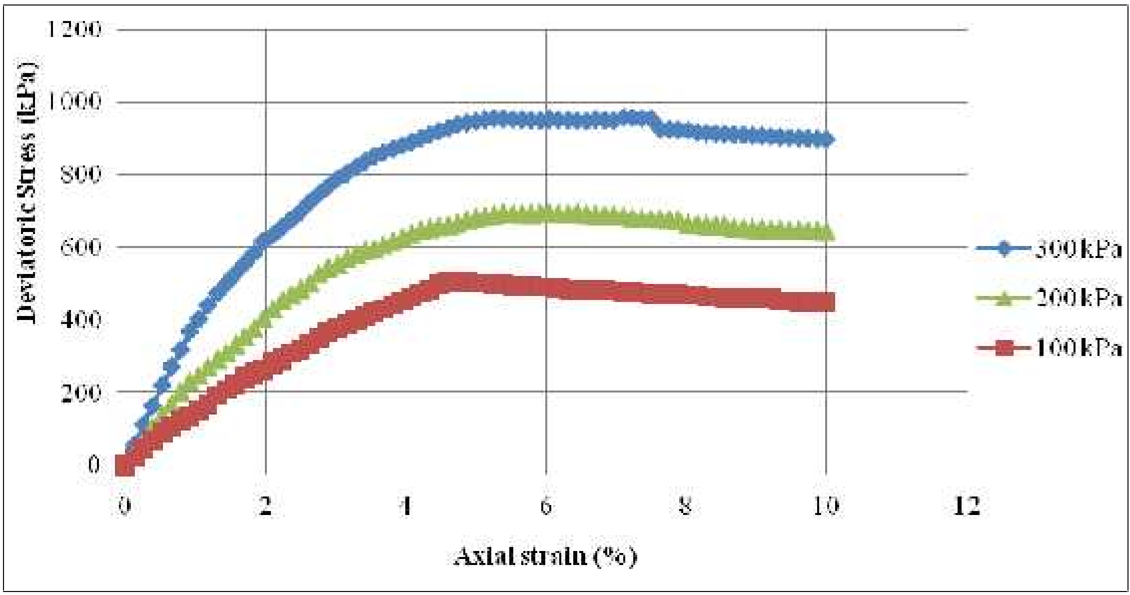

Figure 3a Stress strain curve of cemented sand for 14 days curing period at different confining pressures

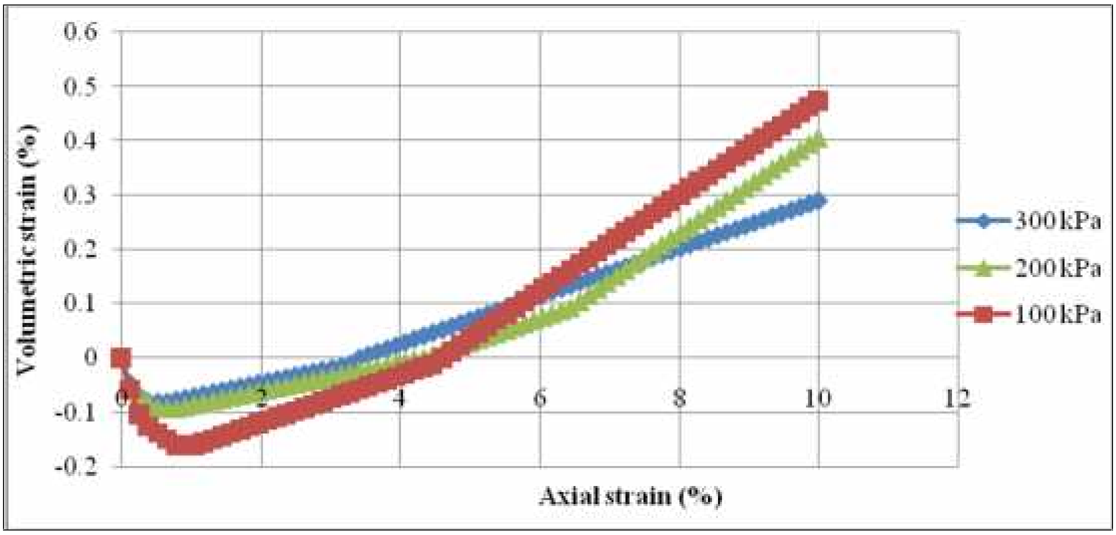

Figure 3b Volumetric strain Vs axial strain curve of cemented sand for 14 days curing period at different confining pressures

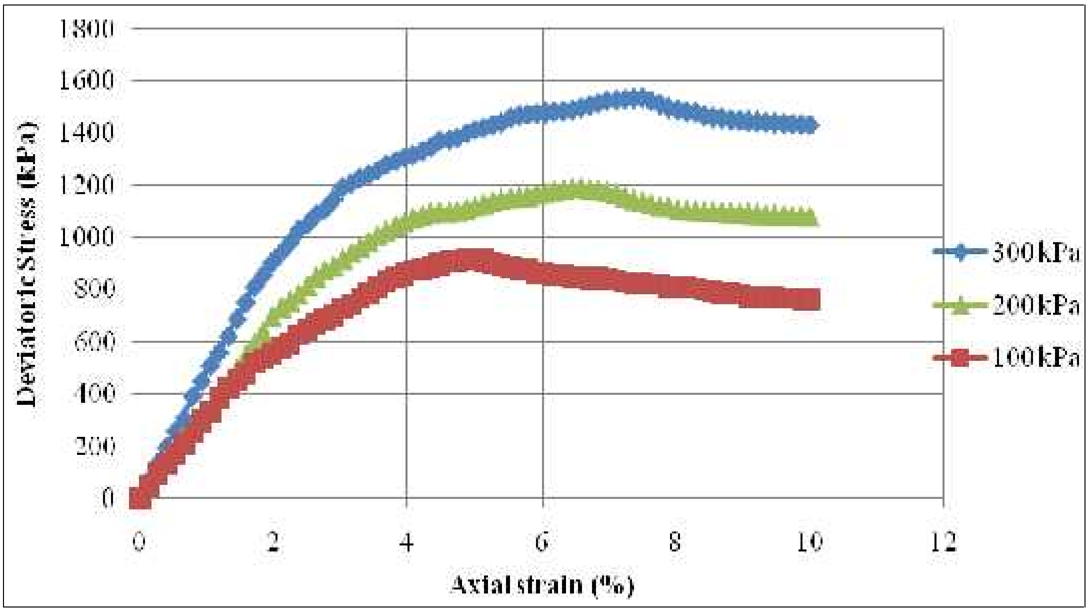

Figure 4a Stress strain curve of cemented sand for 28 days curing period at different confining pressures

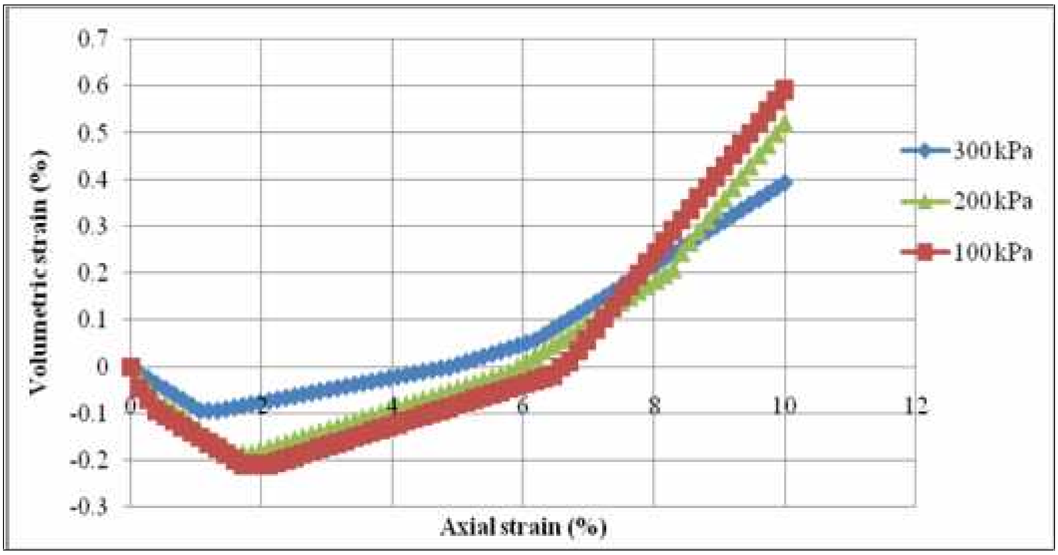

Figure 4b Volumetric strain Vs axial strain curve of cemented sand for 28 days curing period at different confining pressures

To understand the influence of confining pressures, curing periods and cement percentages the volumetric strain at failure and axial strain where the dilation starts for cemented sands are observed from fig 2b,3b,4b and 5b and listed in table 2. From the test results in figures 2 to 4 and tables 1 and 2 the following observations were made.

Table 1 Failure deviatoric stress and failure axial strain for different Curing periods and Confining pressures of cemented sands

Curing period	Confining pressure	σ kPa	%
7 days	100	402	3.95
	200	543	5.13
	300	856	5.39
14 days	100	502	4.61
	200	696	6.45
	300	958	7.11
28 days	100	920	5
	200	1193	6.58
	300	1536	7.5
	100	338	4.74
sand	200	482	5.39
	300	756	5.66

Table 2 Volumetric strain at failure and axial strain at start of dilation for 2.5% cemented sand

Curing period	Confining pressure kPa	Volume change	Axial strain %
7 days	100	-0.0696	0.92
	200	-0.0069	0.92
	300	0.0406	0.66
14 days	100	0	1.05
	200	0.0696	0.79

	300	0.1450	0.66
28 days	100	-0.0812	2.11
	200	0.0580	1.84
	300	0.1740	1.32
	100	-0.0452	3.16
Sand	200	-0.1102	4.08
	300	-0.1009	3.55

4.1 Influence of confining pressure on stress-strain and volumetric response of cemented sands

Increase in confining pressure increases the deviatoric stress at failure for cemented and uncemented sands. The failure axial strain increases with increase in confinement. There is a steady degradation in the stress-strain curve after peak. The ductility of cemented sample increases with increase in confining pressure for the cement content studied.

4.2 Influence of curing period on stress-strain and volumetric response of cemented sands

The deviatoric stress, axial strain and initial compression increases with increase in the curing period. The axial strain at dilation point increases with increase in curing period. Increment in deviatoric stress from 7 days to 14 days curing is less when compared to the increment from 14 days to 28 days curing period. This is a direct reflection of the strength of Portland pozzolana cement which is used as cementing agent in this study. PPC has low initial setting strength but hardens over a period of time with proper cuing which has contributed to this behavior. Proper curing of all the cemented sands has shown higher deviatoric stress for 28 days curing.

4.3 Shear strength parameters of cemented sands

To determine the shear strength parameters of sand and cemented sands the Mohr circle were drawn for 2.5% cement content and curing period of 7,14 and 28 days. Mohr circles are shown in figures 5a to 5c for respective curing periods and the shear strength parameters are listed in table 3.

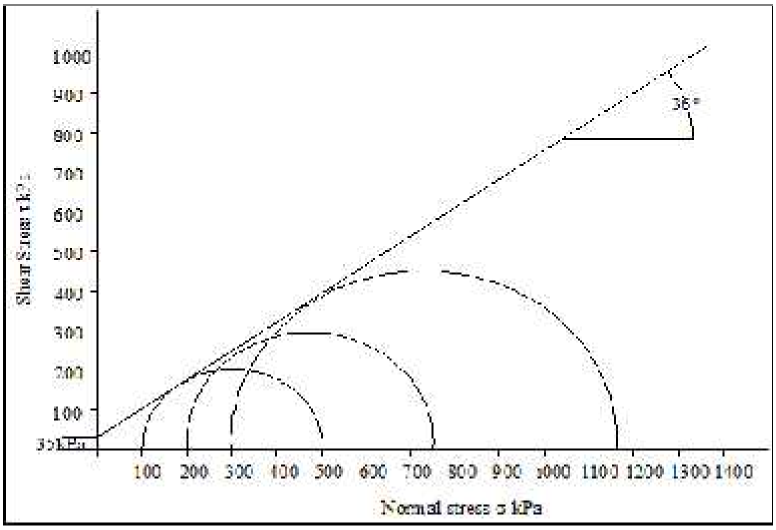

Figure 5a Mohr circle for 2.5% cemented sand of 7 days curing periods

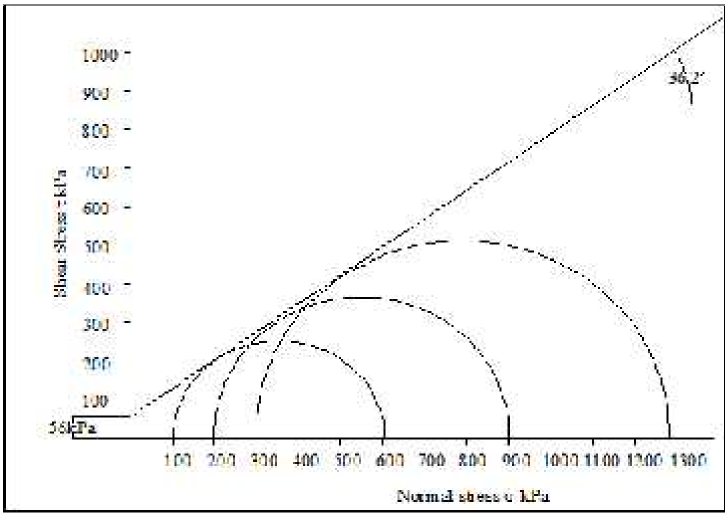

Figure 5b Mohr circle for 2.5% cemented sand of 14 days curing periods

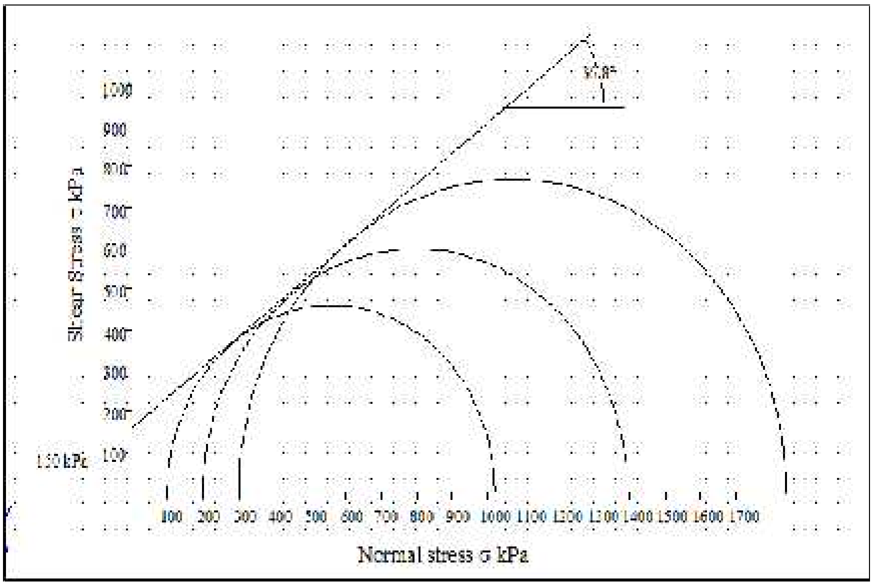

Figure 5c Mohr circle for 2.5% cemented sand of 28 days curing periods

Table 3 Shear strength parameters of sand and cemeneted sands

Curing Period	**7 days**		**14 days**		**28 days**	
	c (kPa)	**ϕ**	**c (kPa)**	**ϕ**	**c(kPa)**	**ϕ**
2.5% cemented sand	35	36^0	56	36.2^0	150	36.8^0
Sand			34.2^0			

The Mohr-coulomb failure envelope is a straight line for the cement percentage and curing periods studied and the shear strength parameters increases with increase in curing period. But Asghari (2003) reported the failure envelope was curved for cemented sand. He used six confining pressures from very low (25kPa) to High (1000kPa). In this work, the failure envelope obtained is linear for confining pressures in the range of 100kPa-300kPa. During shearing bond to bond breakage occurs in cemented sands which slightly increase the angle of internal friction. The Mohr circle shows some cohesion value for cemented sands. As observed by Dongliang et al. (2015), in the present study also the addition of cement has more effect on the cohesion than angle of internal friction for the studied percentage of cement. Cohesion happens between two similar materials. Adhesion happens between two dissimilar materials. But in the case of cemented sand the cement binds the sand and the heat of hydration of the cement gives the strength for the cemented sand. Hence it would be more appropriate to call this property as binding strength rather than cohesion.

5 Conclusions

The following observations were made on the consolidated drained behaviour of cemented sands under triaxial compression for different curing periods.

1. The maximum deviatoric stress and corresponding axial strain increases with increase in curing period for all the confining pressures. Increment in the deviatoric stress depends on the initial setting strength of cementing agent. Ultimate dilation increases with increase in curing period.

2. The maximum deviatoric stress and corresponding axial strain increases with increase in confining pressure for the cement percentage studied. The increase in confining pressure decreases the amount of dilation for the cement percentage and curing periods studied.

3. The Mohr-coulomb failure envelops of cemented sand is linear. It is more appropriate to call the cohesion of cemented sands as binding strength because the strength of the cemented sand is contributed mainly due to cement particles which binds the sand or coated sand.

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