CONSOLIDATED UNDRAINED BEHAVIOUR OF CEMENTED SAND-SILT MIXTURES

Premalatha.K [1], Sabarishri K[2], Sureha.P[3]

Department of Civil Engineering,
College of Engineering, Guindy Anna University, Chennai-600025

kvpremalatha@yahoo.com[1];sabarikalyan@gmail.com[2]; sureha66@gmail.com

Abstract. Loose deposits of silty sand which are more prone to failure, on cementation show resistance against it. The presence of fines in sand changes the stress-strain-strength strength behaviour of sand and cemented sands. The sand has been replaced with non-plastic silt by varying percentage of 10%, 20%, 30% and 40% by dry weight of sand. Portland pozzolona cement of 2.5% by dry weight of sand was used as cementing agent with curing period of 7 days. The triaxial behaviour of cemented sand-silt mixture under consolidated undrained condition by varying silt content for confining pressures of 100kPa, 200kPa and 300kPa are studied. The Important observations made from laboratory investigations are given below. For a confining pressure of 100kPa, the sample with 20% silt shows higher failure deviatoric stress than 10% silt and the sample with 30% and 40% silt shows comparatively lesser failure deviatoric stress than the sample with 20% silt. The same pattern is followed for confining pressures of 200kPa and 300kPa. For confining pressure of 100kPa the failure axial strain is higher for samples with 30% silt content compared to 10% and 20% silt content . But the samples with 40% silt show comparatively lesser failure axial strain than 30% silt content. The same pattern is followed for confining pressure of 200kPa and 300kPa as discussed before. For silt content of 10%, increasing the confining pressure upto 200kPa increases failure axial strain and at confining pressure of 300kPa shows comparatively lesser failure axial strain than 200kPa. This variation in failure axial strain is observed in almost all the silt contents studied. Pore water pressure developed in all the silt content studied shows initial positive Pore water pressure and then changes to negative pore pressure but the magnitude of PWP developed decreases with increase in silt content.

Keywords: cement content, silt content, curing period, deviatoric stress, pore water pressure

1 Introduction

Ground improvement is a technique that improves the engineering properties of the soil mass. Usually, the properties that are modified are shear strength, stiffness and permeability. Sophisticated tools are being developed to employ different ground improvement technique for foundations of a wide variety of structures for construction of foundations in soils with poor bearing capacities, where the cost of deep foundation solution could be incompatible compared to the overall costs for low-budget building projects. The soil-cement technique has been used successfully in pavement base layers, slope protection for earth dams, as a base layer to shallow foundations and to prevent sand liquefaction. Addition of cement can significantly increase the strength and stiffness of layers with low bearing capacity, contributing to a reduction in their degradation and consequently to lower maintenance costs and higher serviceability. Artificially cemented soils are often used in the underlying layers of roads and railways as base or sub grade materials, especially when in situ soils do not have the required mechanical properties. Soil-cement ratio is affected by properties of the soil, the amount of cement, and the porosity and moisture content at the time of compaction. Presence of silt in natural deposits had always been a problem in geotechnical applications. When such deposits are improved by cement stabilization, the behaviour is found to be different from stabilized sand deposits.

2 Background

Some of the pioneering works on cemented silty sands are briefed in this section. Clough et al. (1981) studied the triaxial behavior of weakly cemented silty sands of California bay area and showed that density, grain size distribution, grain shape, grain arrangements have a significant effect on the behaviour of cemented sands. Cemented sands showed some residual cohesion though its residual strength was close to uncemented sands. Rotta et al. (2003) and Schnaid et al .(2001) studied the stress strain characteristics of Porto silty sand with 31.7% non plastic silt content. Portland pozzolona cement was used as a cementing agent with 7 days curing period. The former researchers proved that the cementation influences the primary yield stress in isotropic compression which decreased with reduction in void ratio during curing. The latter researchers showed that the stress-strain behaviour of the cemented soil was apparently linear to a well-defined yield point, beyond which it suffered increasingly plastic deformations until failure. Lo and Wardani (2002) studied the strength and dilatancy of a silt stabilized by 2% cement and 4% fly ash mixture. Natural estuary sandy silt deposits with 64% silt content was used in their study. The cemented soil showed higher dilatancy failure though the rate of dilation was smaller than the parent soil. At higher confining pressures the complete failure curve of thecemented soil merged back to the parent soil.

Sharma et al. (2011) studied the multistage drained triaxial behaviour of cemented silty sand with 35% silt content. Portland cement of 1% and 2.5% was used with 14 days curing. The values of cohesion were consistently larger in the multistage tests as the initial volumetric contraction of 0.5–1.5% caused a slight increase in density of the cemented silty sands. Marques et al (2014) studied the influence of cement percentage, porosity and water content in cement improved residual sandy silt red clay layer with silt content of 26% with 7 days curing. The addition of cement or reduction in porosity improved the strength of the cemented sandy silt red clay.

The literatures discussed shows that almost all the studies on silty sands were conducted in triaxial drained conditions and undrained condition is almost scarce. The main aim of the present research is to study the stress strain behaviour of cemented sand by varying silt content and cement percentage for different curing periods. Only a part of the research work of the cemented sands studied with 10%, 20% and 40% silt content and 2.5% cement and 7 days curing period is presented in this paper.

3 Laboratory Investigations

The sand was collected from the Palar river bed and the silt was collected from M-sand quarry in cheyyar, Chennai. A wet analysis was carried to know the percentage of particles passing 75µ sieves on the collected soil samples. The material which passes through 75µ sieve was collected in a container and allowed to settle. Then the passing material was dried in the atmospheric exposure. This non-plastic fines which passed through IS 75µ sieve were used. The cementing agent used for the study is Portland pozzolana cement. The specific gravity of sand, silt and cement are 2.62, 2.67 and 3.15 respectively. Palar sand consists of dominantly coarse sand 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 the maximum and minimum void ratios are 0.60 and 0.44 respective-ly. The silt consists 75% of coarse silt, 13% of medium silt and 12% of clay size frac-tion. The grain size distribution curve of the sand and silt are shown in figures 1 and 2 respectively.

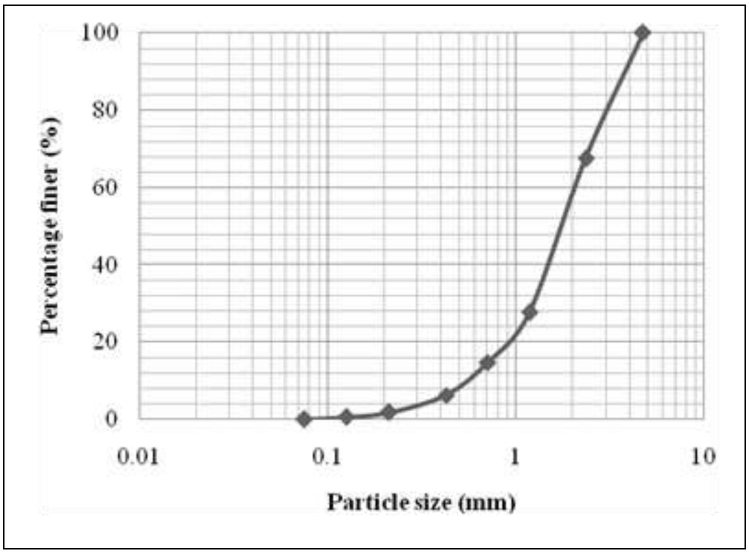

Fig. 1. Grain size distribution curve of sand

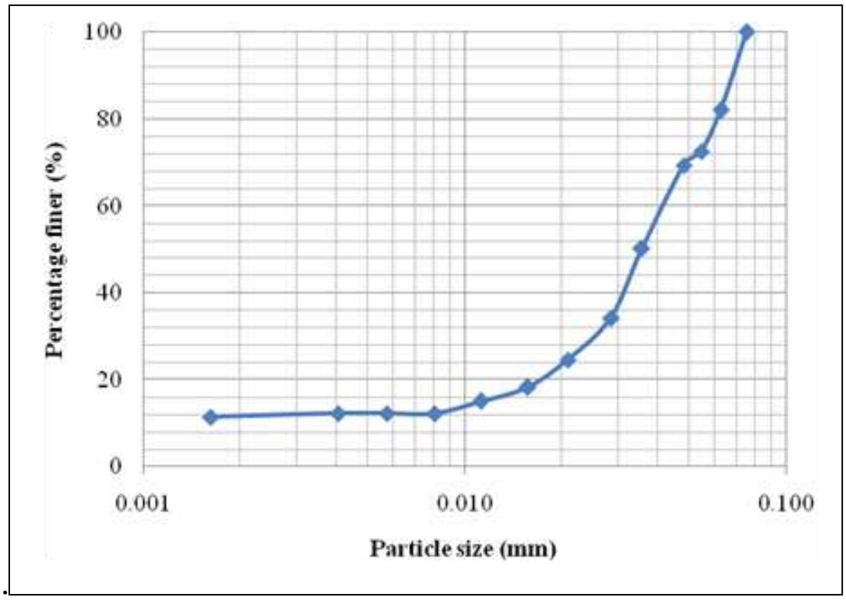

Fig. 2. Grain size distribution curve of silt

Consolidated undrained triaxial tests were carried out on cemented sands with 2.5% cementation and 10%, 20%,30% and 40% silt content for 7 days curing at 100kPa, 200kPa and 300 kPa. The dry density at which the static triaxial tests for cement of 2.5% sand-silt mixtures is 1.7 g/cc. The samples were prepared by under compaction method. The displacement rate applied was 0.08 mm/min. Cement and silt was taken by dry unit weight of sand and mixed well with the sand. 10% of water to moist the samples for easy saturation. The samples were cured in gunny bags. It is difficult to saturate the cemented sand specimens. Skepmton's pore pressure parameter value B = 0.85 was achieved by back saturation technique .This is equivalent to the B value that can be achieved for fully saturated very stiff clays.

4 Results and Discussion

The stress strain characteristics of sand and sandy silt mixtures with 10%, 20%,30% and 40% silt content and 2.5% cementation for 7days curing period is shown in figures 3, 4a to 4d respectively and discussed in this section. The failure deviatoric stress and axial strain of the cemented sand-silt mixtures are listed in Table 1 and Table 2.

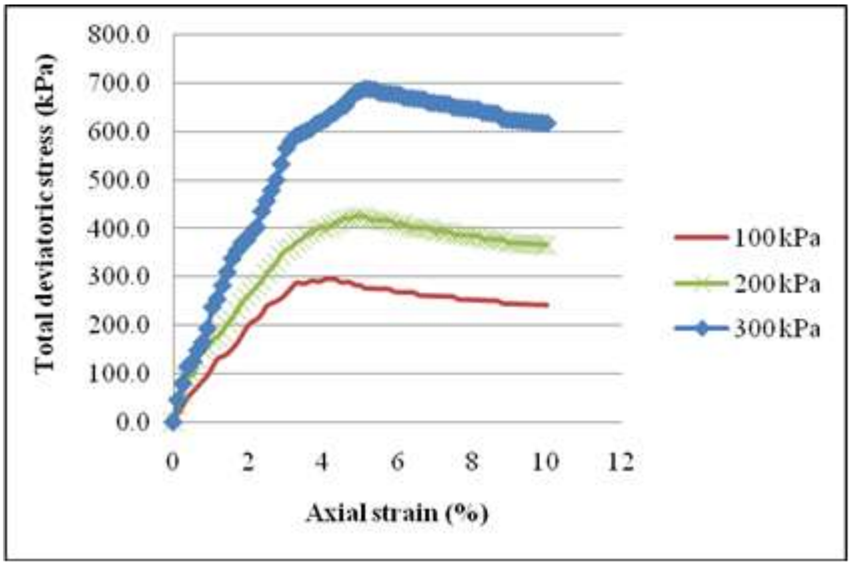

Fig. 3. Stress strain curve of sand under consolidated undrained condition for different confining pressures

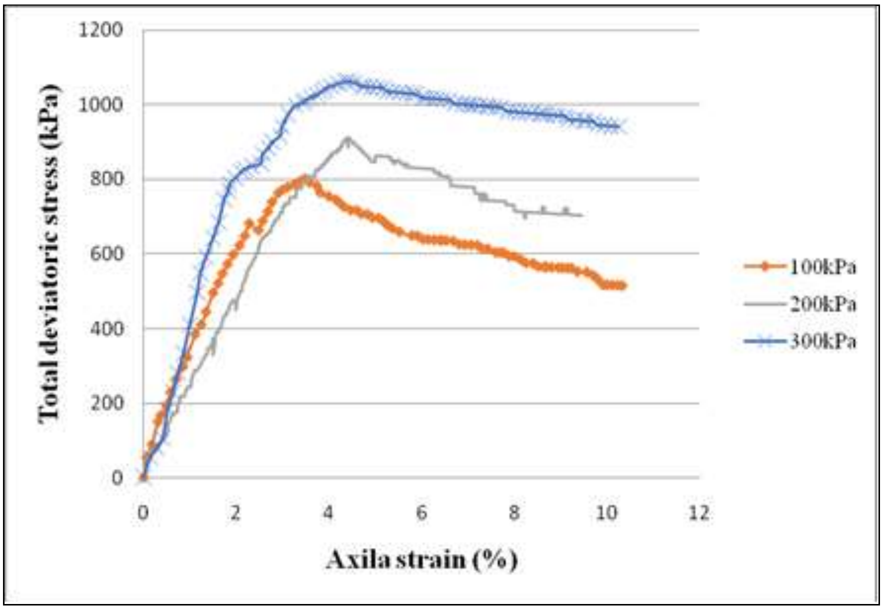

Fig. 3a Stress strain curves of cemented silty sand with 2.5% cement and 10% silt content at different confining pressures for curing period of 7 days

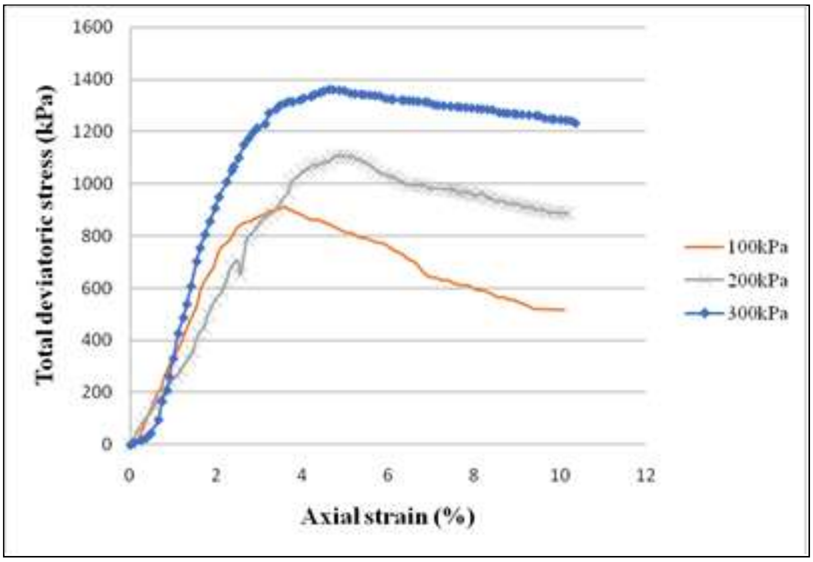

Fig. 3b Stress strain curves of cemented silty sand with 2.5% cement and 20% silt content at different confining pressures for curing period of 7 days

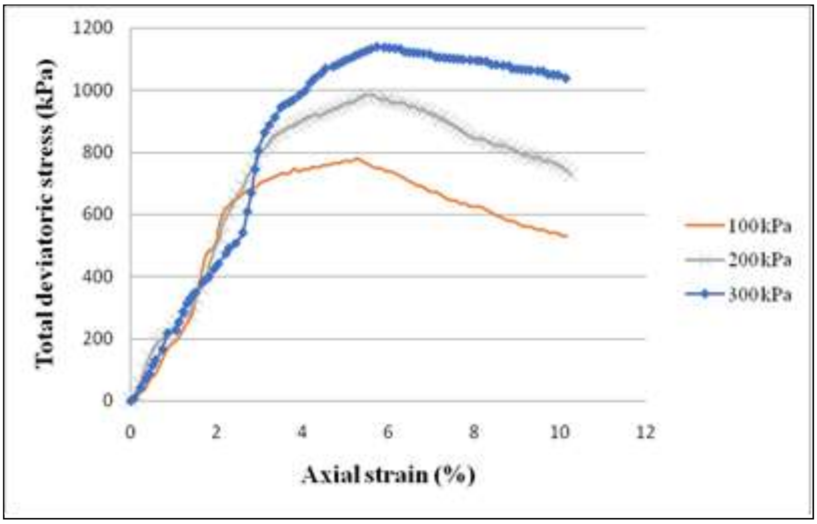

Fig. 3c Stress strain curves of cemented silty sand with 2.5% cement and 30% silt content at different confining pressures for curing period of 7 days

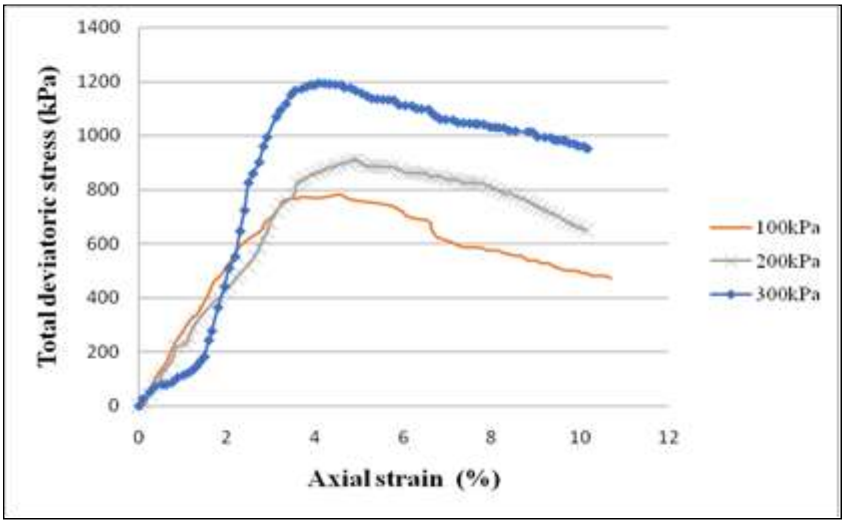

Fig. 3d Stress strain curves of cemented silty sand with 2.5% cement and 40% silt content at different confining pressures for curing period of 7 days

Table 1. Failure Deviatoric Stress of cemented sand-silt mixtures for 2.5% cement content and 7 days curing period.

Sand silt mixtures	Failure deviatoric stress kPa		
	100 kPa	**200 kPa**	**300 kPa**
Sand + 10% silt	801	911	1063
Sand + 20% silt	910	1108	1363
Sand + 30% silt	773	983	1150
Sand + 40% silt	783	907	1193

Table 2. Failure axial strain (%) of cemented sand-silt mixtures for 2.5% cement content and 7 days Curing period

Sand silt mixtures	100 kPa	200 kPa	300 kPa
Sand + 10% silt	3.48	4.37	4.35
Sand + 20% silt	3.58	4.81	4.62
Sand + 30% silt	5.23	5.48	5.74
Sand + 40% silt	4.57	4.83	4.07

4.1 Influence of confining pressure, curing period, cement percentage and silt content in stress-strain behaviour of cemented sand-silt mixtures

The stress strain curves in figures 4a to 4 b and shows that, for 2.5% of cement, the stress-strain behaviour is almost ductile for all silt contents from 10% to 40% at different confining pressures. From figure 3, the failure deviatoric stress for sand is in the range of 297 kPa to 690 kPa.

With addition of small percentage of cement, the failure deviatoric stress of the cemented sand-silt mixtures increased with increase in confining pressure. In a broader sense, it can be concluded that addition of cement for the sand-silt mixtures increases the failure deviatoric stress for all the confining pressures.

The failure axial strain for sand is in the range of 4.1% to 5.13%. Addition of silt from 10% to 40% in sand increases the axial strain as reported by Arivazhagan.R (2018). Addition of cement percentage in sand-silt mixtures, the failure axial strain increases with increase in confining pressure and this increment is relatively more for 100 kPa to 200 kPa, when compared to 300 kPa, for all the silt content.

The failure deviatoric stress for 7 days curing period for 2.5% cement percentage and all silt contents are in the range of 773 kPa to 1363 kPa. For 2.5% cement, the silt content of 10% shows an increase in failure axial strain for 7days curing period.

The failure deviatoric stress for 10% silt content for all cement percentage and curing periods are in the range of 801kPa to1063 kPa. The failure deviatoric stress for 20% silt content is in the range of 910 kPa to 1363 kPa. The failure deviatoric stress for 30% silt content is in the range of 773 kPa to 1150 kPa. Generally, increase in confining pressure increases failure axial strain. The lesser deviatoric stress up to 3.5 % strain under 300kPa cell pressure as compared to 200kPa may be due to slight variation in density or the fabric of the cemented sand specimen during triaxial specimen preparation. The failure deviatoric stress for 40% is in the range of 783 kPa to 1153 kPa. Addition of silt in sand decreases the failure deviatoric stress. But addition of cement increases the failure deviatoric stress for all silt contents. For 2.5% of cement with 7 days curing period, the failure axial strain increases from silt content 10% to 40%.

4.2 Influence of confining pressure, curing period, cement percentage and silt content in pore water pressure of cemented sand-silt mixtures

The maximum positive and negative pore water pressure for different cement percentage, curing period and silt content at different confining pressure are presented in Table 3

Table 3. Maximum positive and negative pore water pressure for cemented sand-silt mixtures at different confining pressure for 2.5% cement content

Confining Pressure kPa	**100**		**200**		**300**	
Pore Pressure kPa	**+ve**	**-ve**	**+ve**	**-ve**	**+ve**	**-ve**
Sand+10% silt	4	-10	3	-10	109	-
Sand+20% silt	4	-12	7	-10	10	-12
Sand+30% silt	3	-11	9	-2	9	-
Sand+40% silt	6	-2	7	-2	6	-

Arivazhagan (2018) reported that addition of silt content increases the pore water pressure with increase in confining pressure and the increment is in the order of 10 kPa to 50 kPa. For sand and different sand-silt mixtures, for the tested relative density, the nature of pore water pressure is positive which indicates the compressive nature of sand and sand-silt mixtures.

From Table 3, it is observed that the positive and negative pore water pressure for 100 kPa confining pressure is in the range of 4 to 6 kPa and -2 to -10 kPa respectively. Similarly the positive and negative pore water pressure for 200 kPa confining pressure is in the range of 3 to 9 kPa and -2 to -10 kPa respectively. For 300 kPa of confining pressure with 2.5% of cement with 7 days curing, the compressive pore water pressure is highest of all the combination of cemented sand-silt mixtures and the value is 109 kPa. The development of positive pore water pressure indicates the compressive nature of the cemented sand-silt mixtures and the negative pore water pressure indicates the dilative nature of the cemented sand-silt mixtures.

In general, it is observed that irrespective of curing period and silt content, initially the pore water pressure is compressive and on shearing the pore water pressure becomes negative for confining pressures of 100 kPa and 200 kPa. For 300 kPa of confining pressure, the pore pressure variation for all the combinations of cemented sand-silt mixtures at both the curing periods studied is found to be complex. The complex behaviour of pore water pressure may be attributed to the difficulty in ensuring the saturation of cemented sand-silt mixtures with cement content and increase in curing period. There is a development of positive pore water pressure followed by negative pore water pressure and vice-versa. The development of initial negative pore water pressure followed by positive pore water pressure is dominantly observed for cemented sand-silt mixtures of high silt content for the cement percentage studied and curing period

4.3 Shear strength parameters of cemented sand-silt mixtures

Angle of internal friction and cohesion for cemented sand-silt mixtures are shown in Table 4.

Table 4. Angle of internal friction and cohesion for cemented silty sand for 2.5% cement content

Sand Silt mixtures	Angle of internal friction, φ	Cohesion Cu(kPa)
Sand + 10% silt	25.8°	190
Sand + 20% silt	33.3°	172
Sand + 30% silt	30°	164
Sand + 40% silt	30°	160

Generally addition of silt decreases the angle of internal friction of sand and for higher percentage of silt content adds minimum value of cohesion to the sand-silt mixtures. The angle of internal friction for sand is 30.7°. From Table 4, for cement ed silty sands of of 2.5% cement content , the φ is in the range of 25 ° - 30°.Due to addition of cement the cemented samples shows cohesion. In General, addition of silt decreases the angle of internal friction and when cement is added, during shearing, bond breakage occurs between cement to cement particles for the cemented sand. Because of additional friction, the angle of internal friction increases with addition of cement content. The decrease in cohesion value with increase in silt content, though silt is finer may be due to the nature of bonding and fabric of the cemented sand-silt mixture which needs further investigation. The developed pore pressure at failure is comparatively less than the failure deviatoric stress and as a result of this; the effective angle of internal friction (φ') is approximately equal to the angle of internal friction (φ).

5 Conclusions

The following conclusions were drawn for addition of 2.5% of cement to 10%, 20% 30% and 40% silt content of cemented sandy silts for 7 days curing period under consolidated undrained conditions.

1. The failure deviatoric stress of the cemented sand-silt mixtures increases with increase in confining pressure and the corresponding axial strain increases with increase in confining pressure with addition of cement and silt content.
2. At low confining pressure, initially the pore water pressure is compressive and on shearing the pore water pressure becomes negative for the cement

percentage, curing period and silt content studied.

3. At high confining pressure the variation of pore water pressure depends on the percentage of silt content in the cemented sand-silt mixtures.
4. The failure axial strain decreases with increase in silt content for the cement percentage, curing period and confining pressures studied. The development of initial negative pore water pressure followed by positive pore water pressure is dominantly observed for higher silt content at high confining pressure for the cement percentage and curing period studied.
5. The shear strength parameters of the sand-silt mixtures increase on addition of cement. Increase in silt content decreases the angle of internal friction for the cement percentage and curing period studied. As the developed pore water pressure at failure is comparatively less than the failure deviatoric stress, there is no much variation in the effective angle of internal friction (φ') and angle of internal friction (φ).

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