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Triaxial Test Behavior of CSA-treated Sand with High Confining Pressure

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ABSTRACT

Over the years, cementitious materials such as ordinary Portland cement (OPC), fly ash, lime, and bitumen have been used for soil improvement. However, due to the environmental concerns associated with using OPC, replacing OPC with calcium sulfoaluminate (CSA) cement in ground improvement has excellent potential as it is more eco-friendly. Although previous studies have investigated the stabilizing effects of CSA cement-treated sands, no attempt has been made to examine the shear behavior under various confining pressure conditions. Therefore, this study aimed to investigate the CSA cement-treated sand's shear strength and deformation properties through a consolidated drained triaxial test with high confining pressure. In this study, quartz sand was used with 3%, 5%, and 7% cement contents and confining pressures of 0.5, 1.0, and 1.5 MPa. The test results suggested that the level of CSA cement content and confining pressures affect the stress-strain behavior of CSA cement-treated sands at high confining pressures.

1. INTRODUCTION

Soil stabilization has been utilized to improve soil's engineering behavior, enhancing its stability, compressibility, and load-bearing capacity. For instance, many researchers have studied cementitious materials like lime, fly ash, and ordinary Portland cement (OPC) to develop a more effective soil-stabilizing material (Chang et al., 2016; Mahedi et al., 2020; Singh et al., 2018). However, despite its durability and strength, OPC is gradually becoming less appealing for construction and geotechnical applications due to its high carbon emissions. As a result, an alternative soil stabilizing material is of the

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essence. Nevertheless, calcium sulfoaluminate cement (CSA), an environmentally friendly binder, has been recently introduced as an option for OPC because it has a lower carbon footprint (Jumassultan et al., 2021). Although a few studies on cemented soils have focused on the behavior of soils under low to moderate confining pressures, just a little has examined the impacts of high confining pressures (Clough et al., 1981; Lee1a et al., 2019; Marri et al., 2012; Schnaid et al., 2001; Ud-din et al., 2011). Although most engineering challenges occur at low confining pressures, soil behavior under high pressure should be investigated to comprehend better conditions like offshore piling, deep pile foundations, tunnels, and high earth dams (Marri et al., 2012). The study aims to investigate the CSA cement-treated sand's shear strength and deformation properties through a consolidated drained triaxial test with high confining pressure.

2. MATERIALS AND METHOD

2.1 Materials

Quartz sand, CSA cement, and gypsum were used for the preparation of test samples. The index properties of quartz sand determined by the Unified Soil Classification System (USCS) are given in Table 2. Figure 2 shows the quartz sand particle size distribution curve. The USCS classifies the quartz sand as "SP" (poorly graded sand). Subramanian, Moon, et al. (2019) suggested a significant initial strength gain and continued strength improvement when 30% of CSA cement content was replaced by gypsum. Hence, the optimum gypsum content of 30% was used to replace a portion of the CSA contents in the experiment.

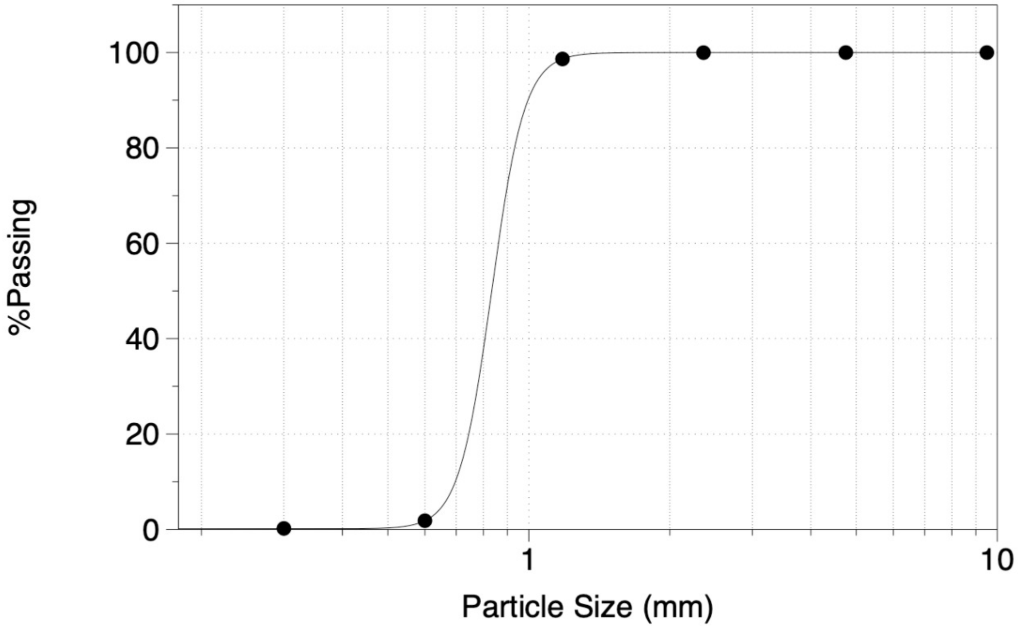


Figure 1: The quartz sand particle distribution curve used for this research.

Table 2: Quartz Sand Physical Properties

(D_{10}) (mm)	(D_{60}) (mm)	Cu	Cc	USCS
0.65	0.95	1.46	0.96	SP

2.2 Sample preparation

All the samples in this research were produced by mixing quartz sand with 3%, 5%, and 7% of CSA cement and gypsum, respectively, by the total mass of the dry quartz sand. The CSA cement-sand mixture was continuously mixed until a homogeneous appearance was reached. After that, water was then added to the mixture according to the OMC estimated by the Standard Proctor Test (ASTM/D698, 2012). Table 3 presents the OMC test results for quartz sand samples containing 0%, 3%, 5%, and 7%, CSA cement, which were 19%, 17.25%, 16.75%, and 15.75%, respectively.

After mixing, the samples were compacted in 3 layers in a 38 mm diameter and 76 mm high cylindrical mold. Oil was used to lubricate the inner walls of the cylindrical steel molds, allowing for easy specimen extrusion. Each of the three layers was compacted 25 times using a hand rammer. The tops of the first and second compaction layers were scarified to eliminate any issues with smooth compaction planes. The samples were then allowed to cure for 7 days before testing.

Table 3: Compaction Tests results on CSA-treated quartz sand

CSA content (%)	Optimum Moisture Content (OMC) (%)	Maximum Dry Density (MDD) (kN/m3)
0	19.00	1.56
3	17.25	1.59
5	16.75	1.61
7	15.75	1.65

2.3 Testing system

A Triaxial Automated System was used for this experiment. The University of Nottingham, in collaboration with GDS Instruments Ltd, built the system. Triaxial cell, pedestal, top cap, Pressure/Volume controllers, Velocity controlled load frames, PWP/Axial displacement transducer, GDSlab control software, and Datalogger are vital components of the system. The two digital pressure/volume controllers were used during the experiment to apply and control the cell and back pressure (DPVC). A digital hydraulic force actuator was also used to apply the load in the system from the bottom of a loading frame. The pore water pressure transducer measured the PWP at the bottom of the sample. The capacity of the DPVCs employed in this study is 4MPa, while the triaxial cell and the working axial load capacity are 4MPa and 50kN, respectively.

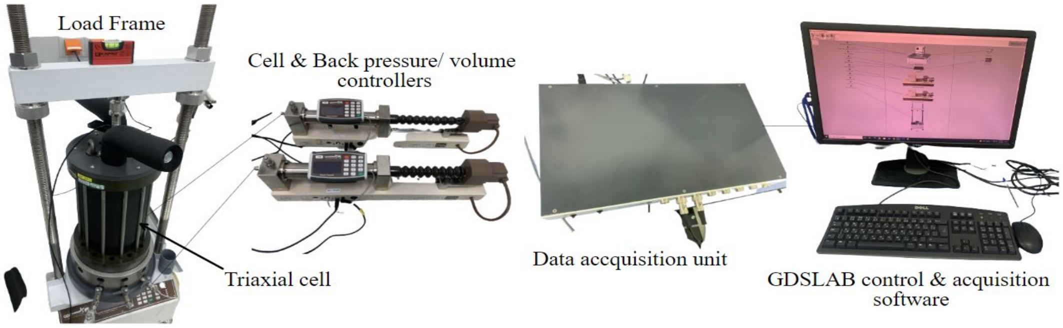


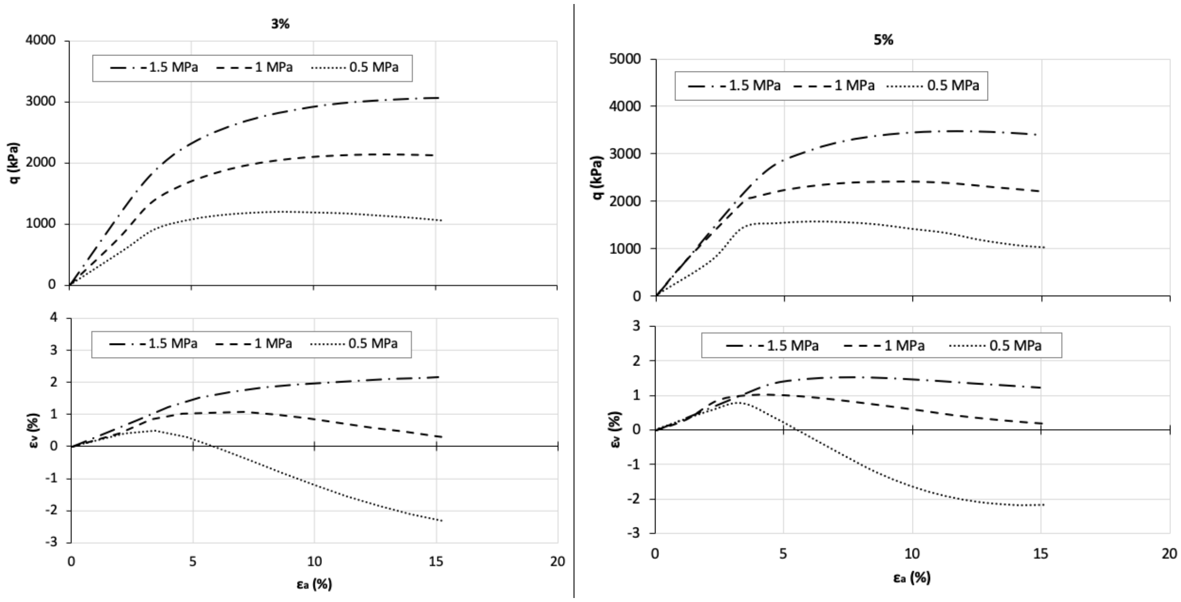
Figure 2: The Environmental Triaxial Automated System (ETAS) components.

2.4 Test procedure

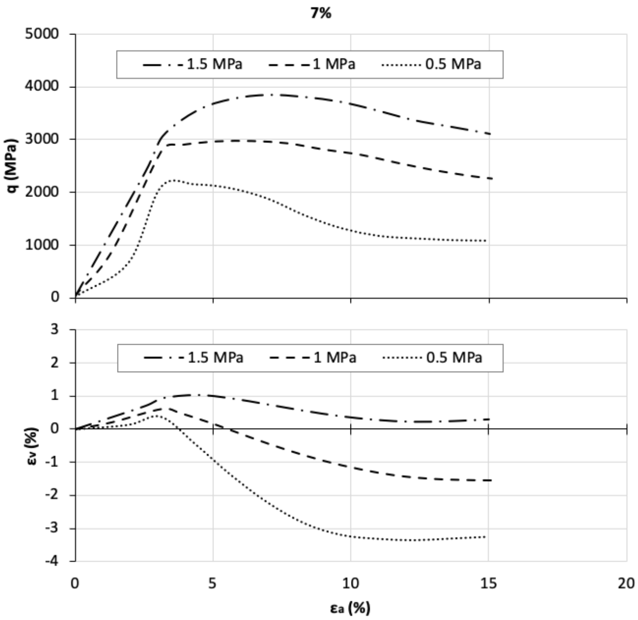
For this study, a porous stone of 38mm diameter and a circular filter paper was positioned on the pedestal after the samples were cured. The CSA cement-treated sample was then set on the filter paper, then covered with a latex membrane, with another filter paper and saturated porous stone placed on it. Then, O-rings were positioned at the base and top of the platens of the samples to keep the cell oil out. After which, the cell was fitted together and filled with distilled oil. The sample was then saturated by flushing it with water without dissolved air from top to bottom for roughly two hours, with the back pressure 10kPa lower than the cell pressure. The back and cell pressure were raised simultaneously until Skempton's value was greater than or equal to 0.90 (Lee1a et al., 2019; Schnaid et al., 2001). Then, the sample was consolidated to the appropriate confining pressure and sheared under draining conditions with 0.1 mm/min.

3. RESULTS AND DISCUSSIONS

This study conducted a consolidated drained triaxial test to investigate CSA-treated quartz sand samples' strength and mechanical behavior with 3%, 5%, and 7% cementation. The test results for the different percentages of cement at several confining pressures are represented as stress-strain and volumetric strain curves in Figure 3.



(a) (b)



(c)

Figure 3: Stress-strain relationship and volume change behavior of the CSA-treated quartz sand sample: (a) 3% (b) 5% (c) 7%

Figure 3 clearly illustrates that the quartz sand sample behavior strongly depends on the degree of CSA cement content and confining pressure. Furthermore, it shows that the increase in the CSA cement content and confining pressures increases the initial stiffness and peak deviator stress of the treated quartz sand samples. For instance, for 5% CSA - treated samples at the confining pressure (σ'_3) of 0.5 MPa, 1 MPa, and 1.5 MPa, the deviatoric stress peaks were 1579 kPa, 2422 kPa, and 3477 kPa, respectively. Also, the q-ε curves show a tendency for the deviator stress to reach its peak value at lower confining pressures, followed by a strain-softening. However, for the confining pressure of 1.5 MPa in the case of Figures 3(a) and 3(b), the strain softening transforms into a strain hardening kind of failure behavior without any prominent peak in the q-ε curves. This is because of the degree of cementation and higher confining pressure.

Meanwhile, the test results indicate that CSA cement is very effective for soil improvement under specific confining pressures. There was a noticeable improvement in soil strength with increased CSA cement content at high confining pressures. For example, the peak deviatoric stress at σ'_3 = 1.5 MPa increased from 3477 kPa to 3856 kPa (11% increase) when cementation was increased from 5% to 7%, respectively. However, at σ'_3 = 0.5 MPa, the peak stress increased from 1579 kPa to 2147 kPa (36 % increase), with the increase of cement content from 5% to 7%, respectively.

The volumetric strain curves of the CSA-treated quartz sand are also illustrated in figure 3. It can be observed from the εv-εa curves that all of the tested samples exhibited an initial compression for all confining pressures used for this study. For samples sheared by 0.5 MPa, and 1MPa, the initial contraction was followed by a slow volumetric dilation.

However, the dilation was reduced, and only volumetric compression was noted in samples sheared by confining pressures greater than 1MPa. It is because of the shearing of samples at higher confining pressure. The εv-εa curves also indicated that the volumetric strain curves were attaining a constant value towards the end of the experiment. Consequently, the ultimate state derived from stress-strain curves might similarly be close to the critical state of the CSA-treated quartz sand samples employed in this study.

3. CONCLUSIONS

This study investigated the influence of cementation and high confining pressure on CSA-treated quartz sand samples' strength and mechanical behavior by performing consolidated drained triaxial tests with high confining pressures. The following conclusions were drawn from the experimental results:

1. CSA cement content and confining pressure substantially affect the stress-strain and volume change behavior of the investigated samples, according to CD triaxial test results. The peak deviatoric stress rises as CSA cement content increases, although volumetric compression during shearing decreases (increase in dilation). However, when the confining pressure increases, there is also an increase in the peak deviator stress, which increases the amount of compression during shearing. Therefore, the q-ε- behavior is ductile at low confining pressures and brittle at high confining pressures.
2. The brittleness and ductility of the tested samples are highly dependent on the CSA cement content and confining pressure. In other words, the cement concentration and confining pressure substantially impact the failure properties of quartz sand.

REFERENCES

Chang, I., Im, J., & Cho, G.-C. (2016). Geotechnical engineering behaviors of gellan gum biopolymer treated sand. *Canadian Geotechnical Journal, 53*(10), 1658-1670.

Clough, G. W., Sitar, N., Bachus, R. C., & Rad, N. S. (1981). Cemented sands under static loading. *Journal of the Geotechnical Engineering Division, 107*(6), 799-817.

Jumassultan, A., Sagidullina, N., Kim, J., Ku, T., & Moon, S.-W. (2021). Performance of cement-stabilized sand subjected to freeze-thaw cycles. *Geomechanics and Engineering, 25*(1), 41-48.

Lee1a, S., Im, J., Cho, G., & Chang, I. (2019). Laboratory triaxial test behavior of xanthan gum biopolymer-treated sands. *Geomechanics and Engineering, 17*(5), 445-452.

Mahedi, M., Cetin, B., & White, D. J. (2020). Cement, lime, and fly ashes in stabilizing expansive soils: performance evaluation and comparison. *Journal of Materials in Civil Engineering, 32*(7), 04020177.

Marri, A., Wanatowski, D., & Yu, H. (2012). Drained behaviour of cemented sand in high pressure triaxial compression tests. *Geomechanics and Geoengineering, 7*(3), 159-174.

Schnaid, F., Prietto, P. D., & Consoli, N. C. (2001). Characterization of cemented sand in triaxial compression. *Journal of geotechnical and geoenvironmental engineering, 127*(10), 857-868.

Singh, R., Ray, D., Mehrotra, A., & Afaque Khan, M. (2018). A review paper on comparative study of soil stabilization with widely used admixtures like lime, cement, flyash and bitumen emulsion. *International Journal of Engineering Trends and Technology, 58*(2), 96-99.

Subramanian, S., Khan, Q., & Ku, T. (2019). Strength development and prediction of calcium sulfoaluminate treated sand with optimized gypsum for replacing OPC in ground improvement. *Construction and Building Materials, 202*, 308-318.

Subramanian, S., Moon, S.-W., & Ku, T. (2019). *Effect of Gypsum on the strength of CSA treated sand.* Paper presented at the 16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering.

Ud-din, S., Marri, A., & Wanatowski, D. (2011). Effect of high confining pressure on the behaviour of fibre reinforced sand. *Geotechnical engineering journal of the SEAGS & AGSSEA, 42*(4), 69-76.