Strength characteristics developed in cement stabilized soil

K Raja*, E Elakkya2, A T Manikandan3, B Surya4, M Nekila2

1 Assistant Professor, Department of Civil Engineering, Kongu Engineering College, Perundurai, Tamil Nadu, India
2 UG Scholar, Department of Civil Engineering, Kongu Engineering College, Perundurai, Tamil Nadu, India
3 Geotechnical Engineer, Erode, Tamil Nadu, India
4 PG Scholar, Karur College of Engineering, Karur, Tamil Nadu, India
* Corresponding author : raja.civil@kongu.edu

Abstract. In the present study, unconfined compression tests (UCC) and directs shear tests (DST) were conducted on a sand gravel mixture stabilized with different proportions of cement. Ordinary Portland cement was used as the binding agent, added to the sand at 1%, 2%, and 3% with respect to its dry weight. Relative density of 70% is maintained throughout the study. In this study, unconfined compression tests and directs shear tests were conducted to assess the influence of the cement content on the engineering properties of the material. Numerical Analyses were performed illustrating rigid foundation on these stabilized soil which shows greater influence in the settlement of foundation. Centre, middle of the edges and corners of the rigid foundation are the point of interest in the study of settlement characteristics. The increase in the strength properties of soil shows decrease in settlement characteristics.

Keyword: sand, cement, engineering properties, settlement, numerical analyses

1. Introduction

The technological development in the construction industry, globalization of the economy, increased foreign direct investments; all has propelled the infrastructure development in the country. To promote a sustainable development in the construction industry, suitable techniques has to be adopted for a particular situation by considering the soil properties. Strength enhancement in sand is the ultimate requirement in the engineering properties of geotechnical materials; thus performance evaluation of its strength characteristics is essential, as most of the projects focused irrespective of the soil condition. One such soil condition, which doesn’t possess required shear strength parameters, is sand. Alternate stabilization is highly needed for such conditions. There have been many researches by scholars on cemented sand since 1990s. However, numerical analyses in the real time applications, incorporating the strength parameters through laboratory test is in deficient. The strength characteristics of cemented sand are influenced by various factors like properties of cement, particle size distribution of soil and stress-strain history.

In this study, UCC tests and DST are conducted to evaluate the influence of the cement admixture on the shear strength characteristics of material. Soil properties which have been determined using engineering methods are used as input parameters for analysing the settlement behaviour of the sandy soils. Though it takes place in rigid footing which would be less than when compared with the flexible
footing. The lesser the thickness of the footing more interaction would takes place which results in significant characteristics changes in the bending moment and shear forces on the footing. A previous study explains the addition of cement and aggregate increases shear strength and decreases temperature control. In order to meet the requirements for several applications in the infrastructural development, various strength criterions are proposed on a basis for the construction of a reasonable constitutive model suitable for various types of CSG materials [1]. In some cases, the addition of fiber also made an attempt to study the behavior characteristics of cemented soil [2]. Though several studies are made in this topic for the past years, the effect of principal stress rotation has not been clearly reported yet. Considering the natural properties of most sands, there is no clear statement whether the cement added shall show good response in the enhancement of strength and stiffness all directions [3]. Settlement parameters were analyzed in cemented sand are depended not only on the amounts of cement but also on some other factors, including the moulding water contents in case of pre-mixed cement-treated sands. The peak shear strength properties of cement treated sands were affected by the relative magnitudes of the intermediate principal stress. They were not affected by the preceding cyclic loading history [4]. Though there are several experimental studies to study the characteristics of cement stabilized soil, very few literatures has addressed its application in the real time. Hence a parametric numerical study has been carried out to understand the influence of strength characteristics developed in the settlement behavior of the rigid footing resting on the soil medium.

2. Materials and methods of experimental programme

2.1. Properties of materials used

2.1.1 Properties of sand
A typical sand is taken from Perundurai, Erode and tested for its physical properties – its specific gravity 2.621, unit weight 1.573 (kg/m³), angle of internal friction 35\(^\circ\) to 36\(^\circ\), relative density 52.89%. The particle size distribution curve for the sand shows the classification properties of the soil, which is a poorly graded sand.

2.1.2 Cement
An ordinary Portland cement 53 grade, obtained from the cement manufacturing company was used in this study. The cement is examined for various properties as per the IS: 4031-1988 is given in Table 1.

| Description                  | Properties |
|------------------------------|------------|
| Type                         | OPC        |
| Grade of cement used         | 53 Grade   |
| Standard consistency         | 32.5 %     |
| Specific gravity g/cm³       | 3.15       |
| Initial setting time in minutes | 30        |
| Final setting time in minutes | 600       |

2.2 Methodology
After conducting series of test on materials, the mixes are planned for experimental investigation. In this study, the cement percentage varies from 1 to 3% were taken in addition to poorly graded sand. Investigating the samples with tests like unconfined compression test and direct shear test was undertaken. Settlement analysis for isolated footing were analyzed using PLAXIS 3D, by considering the loading pattern in three stages i.e., center, middle of the corners, and edges. For the rapid analysis, the footing is divided into four quadrants in which one will be consider for the analysis. Finally, results were compared with the minimum settlements of footing.
2.3 Laboratory test

The characteristics strength of the cemented sands are a function of density, amount of cementing agent, grain shape and grain arrangement [5]. In order to study the strength characteristics of cement-sand following tests were conducted.

2.3.1 Unconfined compression test

The UCC test is a special form of tri-axial test in which the cell pressure is zero. The test can be conducted only for clayey soil without any confinement [6, 7], so a special attention was given to mould and sample preparation. The critical factors that influence the compressive strength of cement-sand are in-situ density, initial void ratio, water content, water-cement ratio (w/c), and cement content [8].

Before conducting the test, samples were prepared for the UCC test. Sand, cement and water can be mixed in the desired proportions to produce a uniform paste and that can be poured into plastic molds of the desired dimensions. The inner surface of the molds are to be lubricated to reduce adhesion [9].

Relative density is determined, from the mass of the sand. UCC customized mould was prepared as shown in figure 1.a. Samples are prepared by mixing the sand with 1%, 2%, 3% cement content with 7% distilled water. It is noted that the height of the sample used for the UCC at least equal to the twice the diameter of the sample.

![Figure 1.a UCC Mould](image1a.png)  
![Figure 1.b UCC Sample](image1b.png)

The sample prepared as shown in figure 1.b are placed on the fixed bottom plate in the UCC apparatus. The strain was measured in dial gauge and the upper plate rotates in such a way that strain in the specimen should not exceed 2% per minute. The shearing of samples was allowed to continue till the specimen fails or till 20% of the axial strain occurs, whichever is earlier.

2.3.2 Direct shear test

DST mould was prepared as shown in figure 2. Samples are prepared by mixing the sand with varying cement content (1% - 3%) using 7%. Tests are conducted as per Indian Standard while measuring volume change till failure [10].
2.3.3 Numerical analysis
Settlement analyses are done by using PLAXIS 3D software. The following conditions were taken into account for modelling the footing to find the settlement of footing. The volume elements were chosen for simulation of basement and linear elastic for material type. The foundation having relatively higher stiffness in comparison with soil can be modeled using linear elastic model and the soil can be modeled using Mohr-Coulomb model [11]. The total weight of the basement corresponds to the total permanent and variable load of the building.

![Building and Sand Model](image)

**Figure 3.** Modelling of Building on Sand

The material properties were defined for generating mesh. As, stated above, the loading pattern are given to the model in three stages like center, middle of the corners, and edges. The building is modeled as shown in figure 3 for Linear Elastic material with Non-porous drainage type. The values of unsaturated unit weight and Young’s modulus for the untreated material or virgin sand are 50 kN/m³ and 3.0E+07 kN/m² respectively. The poisons ratio value kept as 0.15 while Lateral Earth pressure coefficient as 1.0. The following Table 2 shows the material properties for the cemented sand cured at 7 and 21 days.
Table 2 Material Properties at 7 & 21 days of curing

| Parameter                          | Cemented sand at 7 Days Curing | Cemented sand at 21 Days Curing |
|-----------------------------------|---------------------------------|---------------------------------|
| Cement Content                    | 1% 2% 3%                        | 1% 2% 3%                        |
| Material Model                    | Mohr-Coulomb                    | Mohr-Coulomb                    |
| Drainage type                     | Drained                         | Drained                         |
| Unsaturated Unit weight, $Y_{\text{unsat}}$, kN/m$^3$ | 17                              | 17                              |
| Saturated Unit weight, $Y_{\text{sat}}$, kN/m$^3$ | 18                              | 18                              |
| Youngs Modulus, E, kN/m$^2$       | 30 E+03 45 E+03 60 E+03         | 45 E+03 60 E+03 75 E+03         |
| Poisson’s Ratio, $\nu$            | 0.3 0.35 0.4                    | 0.3 0.35 0.4                    |
| Cohesion, C, kN/m$^2$             | 1.2 10.5 20                     | 10.3 21 39                      |
| Friction angle, $\phi$            | 35 38 42                        | 36 39 43                        |
| Dilatancy, $\Psi$                 | 5 8 12                          | 6 9 13                          |
| Lateral Earth pressure coefficient, $k_0$ | 0.42 0.38 0.33 | 0.41 0.37 0.32 |

After the completion of modelling, mesh is generated. The exact position of layers, loads and structures is accounted in the finite element meshing. In the geometry model, mesh generation takes full account of the position of the geometry entities [12]. Mesh is refined around the building volume for obtaining clear structural responses.

3. Results and discussion

UCC, DST tests were conducted with various percentages of cement (as mentioned above) as admixtures in sand. All the above test are conducted at different curing periods like 7 and 21 days for better understanding of strength development and settlement analysis.

3.1 Unconfined compression test

The test result of UCC strength is shown in figure 4a & figure 4b. This illustrates the value of UCC with varying percentage of cement with sand. The UCS value found to be increasing with increasing percentage of sand. The specimens prepared with sand and 1, 2, 3% cement shows failure of the specimen from the failure plane of specimens.

Increasing in the percentage of cement, the sample tends to fail brittle, since the samples are becoming hardened from its original ductile nature [13].

3.2 Direct shear test

The results of direct shear test are shown in figure 5a & figure 5b. This shows the value of DST with varying percentage of cement with sand. The DST value found to be increasing with increasing percentage of sand. The specimen prepared with sand and 1, 2, 3% cement. The volume change also measured and found to be in decreased in nature as percentage of cement increases. The factors responsible for higher angle of internal are mainly on cement content and secondly on moisture content of intact soil [14].
Figure 4a. UCC test on cemented sand cured at 21 days

Figure 4b. UCC test on cemented sand cured at 7 days
3.3 Numerical analysis for cemented sand

The numerical analyses for cemented sand at different curing periods were found. The material properties and loading pattern as discussed in clause 2.3.3. Rigid raft footing was analyzed for settlement of cemented sand at different curing periods at 7 and 21 days. Artificially cemented soils increase bearing capacity and decrease settlement of the foundations, which are the two major design considerations [15]. The settlement is analyzed at center, middle edge and center of the footing. The loading were given to the one of the quadrant and displacement was found which are listed below in Table 3. The displacement of soil beneath the rigid footing founded on cement stabilized soils of various proportions and properties of different curing days are shown from figure 6a to figure 6f.
This behavior is validated with experimental study on increasing the compactness of sand inside the chamber with increasing cement content [15]. It is observed that the increase in cement content increases the bearing capacity and reduces the settlement.

### Table 3 Settlement of rigid raft footing on Cemented sand

| Days of Curing | Cement % | Settlement of footing, mm |
|---------------|----------|--------------------------|
|               |          | Centre | Middle Edges | Corner |
| 7 days        | 1        | 39.7   | 32.9         | 26.3   |
|               | 2        | 26.2   | 19.9         | 13.9   |
|               | 3        | 20.2   | 14.4         | 10.1   |
| 21 days       | 1        | 27.4   | 20.9         | 15.4   |
|               | 2        | 20.2   | 14.8         | 9.9    |
|               | 3        | 15.5   | 10.7         | 6.7    |

![Figure 6a. Settlement of footing on 1% cemented sand cured at 7 days](image)

![Figure 6b. Settlement of footing on 2% cemented sand cured at 7 days](image)

![Figure 6c. Settlement of footing on 3% cemented sand cured at 7 days](image)

![Figure 6d. Settlement of footing on 1% cemented sand cured at 21 days](image)
4. Conclusion

Thus the present study reveals the characteristics change in the engineering properties of cemented poorly graded sand mixtures. The following conclusions drawn based on the test results are:

- The significant improvement was found in the sand strength for even a small increment in cement content. An approximate linear increment of unconfined compression strength is observed with an increase in the cement dosage.
- Longer the curing time increases the UCC; however the influence of curing time on maximum UCC is more for higher amounts of cement.
- The cement stabilized behaves brittle in nature during the UCC test. The increase in cement content shows significant decrement in the strain at failure.
- The numerical analyses results shows that settlement of rigid footing decreases by increasing the percentage of cement content and curing days, but this investigation has restricted up to 3% of cement content. Further studies may be carried out to study the effect of brittle nature in increasing percentage of cement and also optimum percentage can be found in respect of maximum internal friction and cohesion values.

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