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Sample Preparation Technique for Fiber Reinforced Cemented Soils

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Abstract:

Soil stabilization refers to the process of changing soil properties to improve strength and durability and the load carrying capacity of the soil. The analysis of reinforced soil for complete understanding of its mechanical behavior requires the preparation of the representative composite specimens. However, obtaining a homogenous and consistent composite specimen is a tedious task. In this paper, the sample preparation of artificially cemented and geosynthetic reinforced cemented soils with controlled initial relative density, void ratio and varying percent of fiber and cement content is described, and example results are presented for a range of soils. 100 mm height and 50 mm diameter samples were prepared for high pressure triaxial testing to determine the mechanical behaviour of artificially cemented and fiber reinforced cemented sands. Several difficulties in the preparation and testing of samples were identified and discussed.

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*Keywords:*sample preparation; cemented sand; isotropic compression; triaxial compression; fiber; cement.

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1. Introduction

The addition of cement, geosynthetics and natural fibers such as rice husk and wheat straw develops a composite material and therefore, changes the index properties of the base material. For a controlled specimen preparation to see the effect of the addition of the reinforcing agents; it is important to have the controlled parameters of the composite materials. Moreover, comparison with uncemented sands including the effects of fiber and cement, with spatial degree of variation can give a reasonable outline in understanding the fiber reinforced cemented materials behavior. However, to model a framework for reinforced materials, the microscopic changes due to macro mechanical forces are significant to incorporate. For this purpose Scanning Electron Microscopic (SEM) analysis is often used by many researchers (e.g. [1-4]). Thus coupling the macro and micro mechanics would definitely give a broader portrait of the micromechanical behavior of the materials. Therefore, the focus of this paper is to highlight the difficulties while preparing a composite material with ingredients having spatial degree of variation from each other.

2. Materials

Well-graded, medium quartz sand from Sheffield (England), so-called Portaway sand was used as the base material for the cemented specimens. The index properties of Portaway sand were determined by British Standard methods (BS 1377). The index properties of the Portaway sand are given in Marri et al. (2012)[5]. The sand grains were mainly sub angular and sub rounded in shape. Before the preparation of cemented specimens, the sand was passed through 2 mm sieve to remove gravel size particles and washed through 0.063 mm sieve under the running water to remove fines. Ordinary Portland cement was used as cementing material. Its initial setting time is 80 to 200 minutes and the specific gravity of 3.15. Method of undercompaction using moist soil was adopted for the preparation of both cemented and uncemented sand specimens to achieve varying degrees of initial relative densities, void ratios, and dry unit weights.

3. Experimental Setup

Bishop-Wesley Conventional pressure and GDS high-pressure triaxial apparatus were used for conventional and high pressure triaxial testing respectively. The experimental setup details may be seen in Marri et al. (2012)[5]

4. Testing Procedure

After curing, each specimen was placed on the base pedestal of the conventional or high pressure triaxial cell whichever, the test required. The surface of the specimens tested was covered with a thin film of a mixture of clay and fine sand to minimize membrane penetration effects. For saturation of cemented samples, the specimen was flushed with de-aired water from the bottom to the top for 60 minutes by applying a small positive effective stress and then raising simultaneously both the cell and backpressures. During saturation ramp the backpressure was increased typically to around 700 kPa, for uncemented sand and to around 2000 kPa for cemented sand, under an effective confining pressure of 50 kPa and 200 kPa respectively. The sample was allowed to saturate for at least 24 h or longer if required, until a B value of 95% was achieved. The consolidated drained shearing tests were then run the samples at a strain rate of 0.01%.

5. Calculation of Derived Parameters

5.1 Constant dry unit weight

For a constant dry unit weight with different cement contents, as the volume of the mould is same let suppose V; therefore, to get a constant dry unit weight (γ_d), the dry mass should also be constant for different percentages of cement. If M total is the total mass of sand + cement and C is the percent of cement by dry weight of sand then, the mass of sand M_{sand} and mass of cement M_{cement} can be calculated as follow:

$$M_{sand}=\left(\frac{100}{100+C}\right)M_{total} \tag{1}$$

$$M_{cement}=\left(\frac{C}{100+C}\right)M_{total} \tag{2}$$

Where, C is taken in percentage

5.2Void Ratio

The void ratio of each sample of dimensions was calculated from the initial dry unit weight. Following procedure was adopted for the determination of the void ratio of a cemented specimen and establishing a relationship between cement content and specific volume.

a) Specimen dimensions i.e., height, H and diameter, D
b) The specific gravity of sand G_{sand}
c) The specific gravity of cement G_{cement}
d) The dry mass of specimen, M_{dry} i.e., the mass of solid, M_{solid}

The average specific gravity of the specimen G (taking cement content = C %), void ratio during consolidation, void ratio during shear, and volume of voids at the end of consolidation were calculated using Eq. (3), Eq. (4), Eq. (5). and Eq. (6) respectively. Where, $(V_{Bvol})_{ci}$ is the back volume during consolidation, $(V_{Bvol})_{si}$is the back volume during shear, $(V_{Bvol})_{cf}$ is the back volume at the end of consolidation,Vc is the volume of voids at the end of consolidation, and V_{solids} is the volume of solid.

$$G=\frac{100-C}{100}\times G_{sand}+\frac{C}{100}\times G_{cement} \tag{3}$$

$$e_{ci}=\frac{V_{voids}-(V_{Bvol})_{ci}}{V_{solids}} \tag{4}$$

$$e_{si}=\frac{V_c-(V_{Bvol})_{si}}{V_{solids}} \tag{5}$$

$$V_c=V_{voids}-(V_{Bvol})_{cf} \tag{6}$$

6. Results and Discussion

An exploratory series of tests were run to identify and fix the problems before the commencement of investigatory testing. Specimen stratification and membrane punctures were noticed at high pressures. Suitable arrangements were made to avoid these errors. The effect of cement type having different specific unit weights was examined. For example, by the increase in gypsum content having specific unit weight less than the Portaway sand resulted to decrease in the specific volume of the composite; on the other hand the addition of Portland cement resulted to increase in the specific volume of the composite. Microscopic study of uncemented and cemented specimens of Portaway sand was carried out with the help of scanning electron microscopy (SEM). Particle shape, structure, sand-cement bond interaction (for cemented sand), and mineralogy of sand and sand-cement composition and homogeneity of the sand-cement mix were examined. Moreover, the specimens were investigated for subsequent deformations, change in the structure due to compression, and shear.

6.1 Homogeneity of Specimen

To characterize the nature of cementation and cement-particle interaction microscopic analysis was undertaken before subsequent triaxial testing in this study. SEM was used to analyze selected specimens before and after triaxial testing. Typical micrographs obtained from cut up sections of cemented specimens with cement content of 5%, 10% and 15% and fiber reinforced cemented sand with 5% cement and 0.5% fiber are shown in Fig.1(a), (b) (c) and (d) respectively.

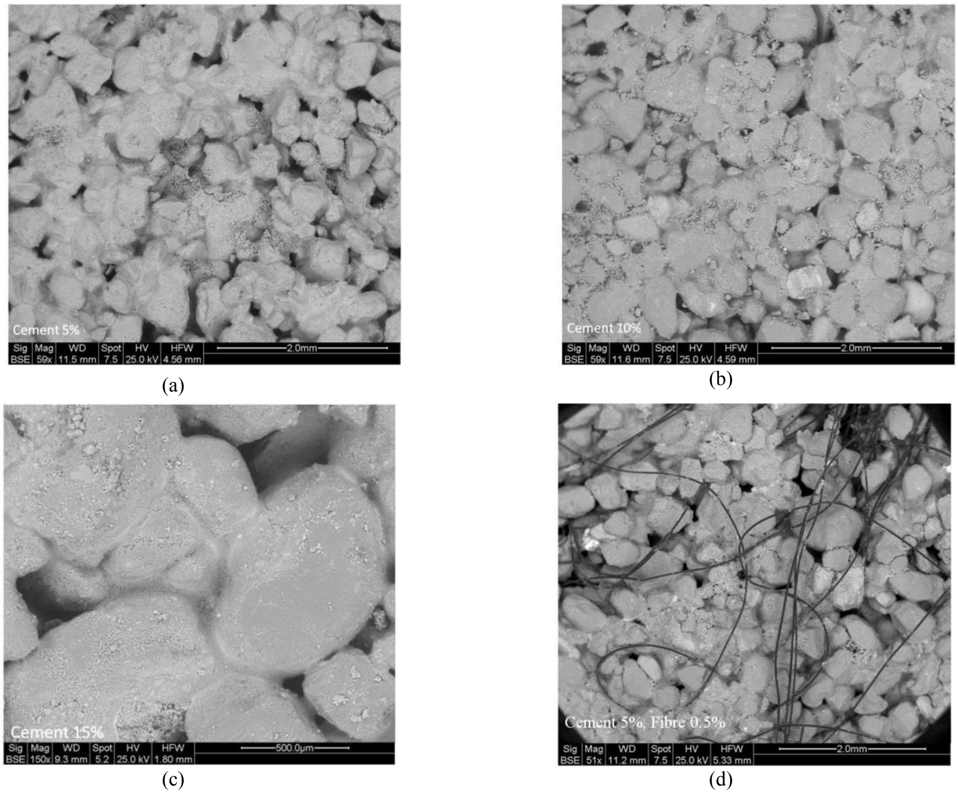


Fig.1. SEM photomicrographs of cemented specimens before testing: (a) 5% cement; (b) 10% cement; (c) 15% cement; (d) 5% cement and 0.5% fiber.

The micrographs were taken after curing but before triaxial testing. It can be seen that in the specimens the sand grains are well coated by the cement. However, the thickness and size of the bonds increases with increasing cement content. Furthermore, it was observed from several micrographs at various magnifications that the number and size of inter-particle voids reduced with higher cement contents. However, at microscale non uniformity in the specimens could be noticed. This is because when the cement content increases; the cement not only bonds particles together (with some sand particles completely surrounded by the cement) but also fills some of the pores as inclusions. Similar is the case of micro scale non uniformity for fiber reinforced specimens. Although prior to the specimens preparation, the mixing was continued until achieving an excellent homogeneous mixture of the composite; however, the micrographs reveal that at microscale the homogeneity is not as good as observed in the visual inspection.

6.2 Strength control

Dry density of the compacted soil is one of the main factors that influence the strength of the cement-sand. In addition, water is essential to achieve maximum density and to aid in hydration of the cement. Cement-sand samples prepared using the standard Proctor compaction tests with cement contents of 0%, 5%, 10%, and 15%. The average optimum moisture content of 10% was observed to be giving the maximum dry density for the Portaway sand. Samples with aforementioned cement contents were prepared at the constant maximum dry unit weight of 17.4 kN/m^3 (approx :), and were cured for 14 days in moisture control room. Unconfined compressive strength (UCS) tests were conducted on these samples. The average results are presented in Fig.2. The UCS is observed to be increasing exponentially with the increase in cement content.

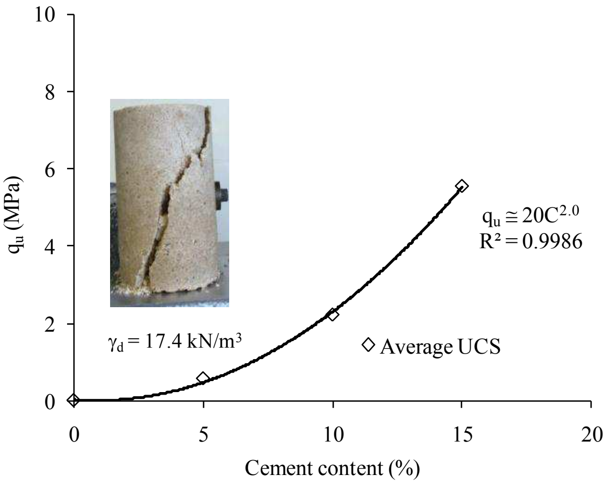


Fig.2: Effect of cement content on unconfined compressive strength of Portaway sand.

6.3 Effect of cement content on specific volume

According to theCoop and Atkinson (1993)[6] the addition of gypsum fines, result in samples of considerably smaller specific volume. However, it is in contrary for Portland cement. This is due to the specific weight of the cementing materials as compared to the base material. For example, the specific weight of Portaway sand is 2.65 and that of an average value of the specific weight of the gypsum is approximately 2.3. On the other hand, the specific weight of Portland cement is 3.15. Therefore, increase in gypsum content results of decreasing the specific volume and increase in cement content results an increase in specific volume of the composite (Fig.3). Differences in the specific gravities of the gypsum/cement and the sand also affect the density and thus even if the void ratios are identical, the densities will be different, possibly leading to differences in the mechanical behaviour of the composite material.

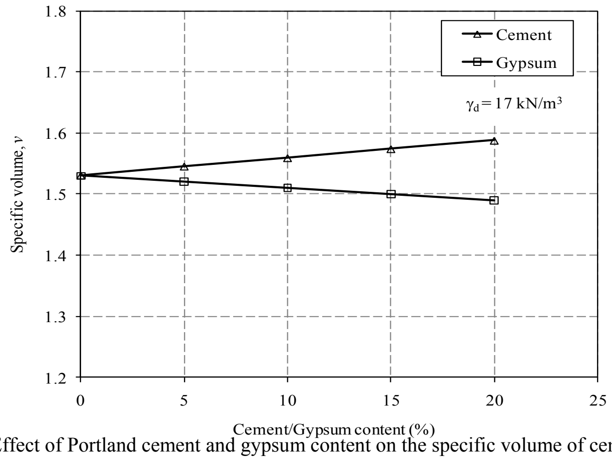


Fig.3: Effect of Portland cement and gypsum content on the specific volume of cemented sand

6.4 Problems involved with triaxial testing of cemented specimen

An exploratory series of test were run to identify and fix the problems before the commencement of investigatory testing. Stratification of the samples due to compaction in layers and membrane punctures due to high pressure were the prominently noticed.

6.4.1 Stratification of the samples

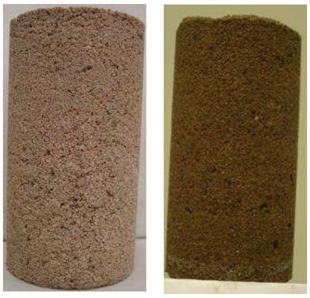
The method of undercompaction is theoretically quite reasonable as compared to normal compaction methods of compacting, each layer with equal number of blows for the preparation of the samples. However, controlling height and uniformity of the blows have always been bit tricky. A suitable height adjustment setup and base rotation controlled device would improve the consistency of the sample. Secondly, the more objectionable point is to avoid layering. Even carefully scarifying the surface of each layer prior to the placement of subsequent layers, the layering effect could not be avoided. Although at conventional pressure it is not noticeable; however, at high confining pressures the layering effect can be seen clearly (Fig.4). On the other hand, by 'density controlled vibratory tamping', it can be seen that there is no layering effect even compressed at high confining pressures (Fig.5). However, it further needs to be investigated for any other effects, such as bleeding and segregation and uniformity of cement bonding (in particular for loose cemented specimens) etc.

6.4.2Membrane Puncture

During experimentations, it was noticed that the membranes were more prone to damage and puncture at high pressures. In particular, the maximum likelihood of the membranes to be damaged and punctured was noticed at contact points of porous stone with the specimen edges (see Fig.6a). The top and bottom edges were covered with thin strips of membrane to avoid membrane damage (see Fig.6b) The loose and porous cemented specimens resulted to the membrane puncture due to penetration (Fig.7)which was avoided by providing a thin layer of sand-clay mixture on the specimen surface as shown in Fig.8. The sharp edges of the grains pointing outward on the surface of the specimen and deformation along the shear plane (see Fig.9) also resulted to the membrane puncture ultimately to the test failure. In order to avoid testing failures due to membrane damage and puncture at high pressures, double membranes were provided to the specimens. The mentioned remedial measures were resulted to a successful completion of testing. The corrections due to membrane effects were incorporated while finding the stress-strain behaviour.

(a) (b)

Fig.4 Stratification of cemented materials prepared by the method of undercompaction compressed at high confining pressures: (a) before isotropic compression; (b) after isotropic compression.



(a) (b)

Fig.5 Homogeneity check of cemented materials prepared by density controlled vibratory tamping method compressed at high confining pressures (a) before isotropic compression; (b) after isotropic compression.

(a) (b)

Fig.6 Avoiding membrane puncture: (a) the top and bottom edges of the specimen; (b) Membrane strip provided to avoid penetration and puncture at sharp edges.

(a) (b)

Fig.7 Membrane puncture: (a) Loose and porous cemented specimen; (b) the membrane punctures due to penetration.

(a) (b)

Fig.8 Avoiding membrane puncture: (a) Pores on the surface of the sample (b) Pores are filled with clay sand mixture to avoid membrane punctures.

(a) (b)

Fig.9 Membrane damage and puncture: (a) due to sharp edges of particles; (b) along shear plane.

7. Conclusion

From the experimental work the following conclusions were drawn:

1. It is difficult to achieve an excellent homogeneity at microscopic level even though a composite material may look perfectly homogeneous at macro scale.
2. While analyzing the effect of reinforced materials, the targeted density (reference density)value may be fixed below the maximum dry density; otherwise it would be difficult to achieve the reference density value while adding reinforcing agents into the base materials.
3. Compaction of a sample in layers (even scratching the surface of each layer before placing the subsequent layers) may not give a perfect homogeneity; ultimately would result to layering effect. This may be avoided through 'density controlled vibratory tamping'.
4. In density controlled vibratory tamping, a known weight of soil is compacted into a known volume of a mould through continuously vibrating and tamping the soil in the mould till entire mass of soil is accommodated into it.

5. Membrane puncture due to the pores on the surface of the specimen may be avoided by coating a thin layer of sand clay mixture on the specimen surface. And the punctures due to sharp edges of cemented specimen may be avoided by providing a membrane strip on it.

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