Cementing Material on Mechanical Property of Calcareous Sand

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Abstract: It is difficult to obtain high quality samples of natural material covering a range of densities and degree of cementation, so study on the sample preparation techniques with similar mechanical properties of natural samples are very important. Experiments were carried out to study the effects of cementation of different materials on the mechanical properties of calcareous sand, e.g., the effects of contents and types of cementation materials on the strength and the characteristics of stress-strain. It is shown that Portland cement is a good cementation agent, compared to calcite and gypsum. The strength of calcareous sand increases with the increase of Portland cement content.

Keywords: Calcareous sand, mechanical properties, cementation, Portland cement.

INTRODUCTION

Since the late 1970s there has been increasing interest in understanding the behavior of cemented calcareous sand which is widespread in ocean floor [1-9]. In the zone distributed calcareous sand, the design of piles is different with that in traditional soil zone [10-13]. The difficulties to understand the response of cemented sand is in obtaining high quality samples of natural material covering a range of densities and degree of cementation, and is also the high spetial variability in the degree of cementation, so that closely spaced samples may have significantly differing properties. These difficulties lead researchers to study the responses of artificially cemented soils [14-16]. Accordingly, various sample preparation techniques and cementing agents have been reported in the literature. The mechanical properties of the soils determines the engineering characteristics such as bearing capacity, stability etc. Thus it is practical to preparing samples with similar or close mechanical properties with the natural calcareous sand at the engineering site.

The first attempt to prepare artificially cemented soils was made by Akili & Torrance [17] based on the deposition of calcite cement from calcite-enriched water by evaporation. However, the amount of calcite precipitated was negligible even over a long time. Later, a method to create calcite by chemical reaction was proved effective.

The main disfigurement of artificially cementing calcareous sand by using of early common methods is the addition of significant fractions of fines, with the cementing process nucleated from those fines. Recently, a cementing process, called CIPS (Calcite In Situ Precipitation System), has been developed [18-19]. CIPS needs a set of complex system, and the corresponding cementing process is long. Therefore, mixing-cementation-process is adopted in this paper. The cement agent liquor is mixed with calcareous sand in a given proportion first, then the sand is made into samples and deposited for some days.

The aim of this paper is to study the effects of cementation on the mechanical characteristics of calcareous sand so as to provide some references for the sample preparing of calcareous sand.

PHYSICAL PARAMETERS OF IN-SITU CALCAREOUS SAND

The calcareous sand used in the following experiments is obtained from the South China Sea near the Yongfu reef. The diameters of calcareous sand are generally larger than 0.1mm, thus the method of griddle analysis is adopted in grain series tests and the results are shown in Fig. (**1**). The main characteristic parameters are shown in Table **1**.

The diameters of calcareous sand used in experiments are all less than 5.0mm, thus the pyknometer method is adopted to measure the specific gravity. Pure water and kerosene are used as the liquid media, respectively. The experiments are repeated twice. The specific gravity is 2.75 when using pure water as liquid media while it is 2.73 when using kerosene as liquid media. On the surface of sand grain, there exist salts which are easy to dissolve into water, which leads to the increase of specific gravity. Therefore, we adopt the value 2.73 measured using kerosene as liquid media. The relative densities are shown in Table **2**.

RESULTS OF TRIAXIAL EXPERIMENTS OF IN-SITU CALCAREOUS SAND

Three types of samples are used to carry out the consolidated and drained (CD) shear experiments. The parameters of the three samples are shown in Table **3**.

Shown in Fig. (**2**) are the CD curves under different confined pressures which there are obvious dilatancy under low confined pressure, for example, 50kPa, taking sample B as example. With the increase of confined pressure, the failure strain increases and the volume becomes shrinkage from dilatancy. Fig. (**2b**) shows the curves of volume strain ~

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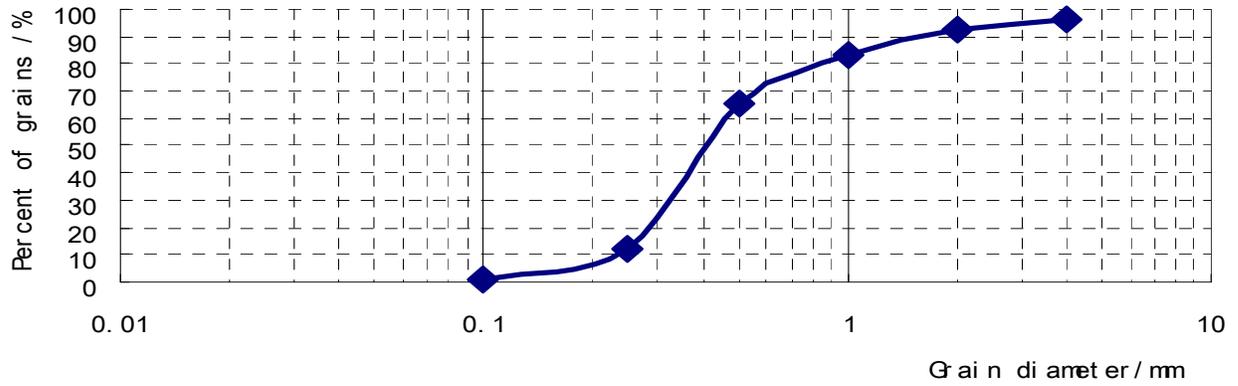
Fig. (1). Grain series of the calcareous sand used in experiments.

Table 1. The Grain Size Characteristics

d_{60}/mm	d_{50}/mm	d_{30}/mm	d_{10}/mm	C_u	C_c
0.46	0.41	0.33	0.24	2.83	0.819

(in which d_{60}, d_{50}, d_{30}, d_{10} are the maximum diameters corresponding to the 60%, 50%, 30% and 10% of the total quality, C_c is the non-uniform coefficient, C_c is the curvature coefficient)

Table 2. Specific Density and Porosity Ratio

ρ_{min}/g / cm^3	ρ_{max} / g / cm^3	e_{max}	e_{min}
1.131	1.421	1.4138	0.9204

Table 3. Basic Physical Index of Samples

	ρ_{min}/g / cm^3	ρ_{max} / g / cm^3	ρ_d / g / cm^3	d_{60}(mm)	d_{50}(mm)	d_{30}(mm)	d_{10}(mm)	D_r
A			1.34					0.77
B	1.131	1.421	1.26	0.46	0.41	0.33	0.24	0.51
C			1.18					0.20

(in which $D_r = \dfrac{e_{max} - e}{e_{max} - e_{min}}$, e_{max}, e_{min}, e are maximum pore ratio, minimum pore ratio and pore ratio of samples, respectively.)
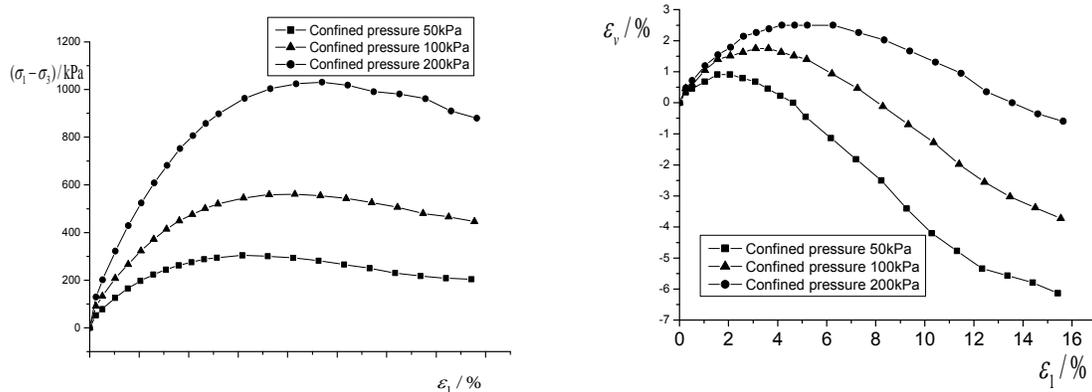
(a) Deviatoric stress~axial strain curves

under different confined pressures

(b)   volume strain~axial strain curves

under different confined pressures

Fig. (2). The CD experimental curves of sample **B**.

Table 4. The Strength Indexes of Samples Under Different Densities

ρ_d/g / cm^3	1.34	1.26	1.18
C (KPa)	0	0	0
$\varphi(°)$	48.2	47.7	46.4

axial strain under the confined pressure of 200kPa. It can be seen that the volume is almost shrinkage under the confined pressure of 200kPa. The reason is that the calcareous sand is easy to be break up. With the increase of confined pressure, the peak stress and strain increase, for example, the peak stress is 1000kPa and the corresponding axial strain is 9% and the volume strain is 2.5% (dilatant) when the confined pressure is 200kPa, while the peak stress is 250kPa and the corresponding axial strain is 6% and the volume strain is -1% (shrinkage) when the confined pressure is 50kPa. The cohesions C and internal friction angles under different densities are shown in Table **4**.

RESULTS OF TRIAXIAL EXPERIMENTS OF ARTIFICIAL CALCAREOUS SAND

Preparation of Artificial Samples

In this paper, gypsum, calcite and Portland cement are used as the cementation media, respectively. Plaster powder is 400 mesh size. The calcite powder is 400 mesh size. The grade of the portland cement is P32.5.

Generally, calcareous sand may be cemented using the methods of ejection, mixture and electro-thermal. Although sintered method are used first, the cementation caused by this method is small, thus no samples made by this method is used in experiments. During preparing samples for the following experiments, the cementation media, calcareous sand and water are mixed according to a designed proportion first. The mixture is then put into modulus with a designed density. The samples are laid for three days for complete cementation before starting experiments.

Results with Calcite as Cementation Media

Fig. (**3**) shows the changes of stress-strain when the samples cemented by 5% mass of calcite. These experiments are carried out under the confined pressures of 50kPa, 100kPa and 200 kPa, respectively. The peak stress increases about 15% with cementation but the residual stresses are almost the same as that without cementation. The reason is that the increase of strength is caused by the cementation. The cementation by calcite is not very strong. Once the cementation is damaged, the cementation disappears totally. Thus the residual strength is the same for either the sample with and without cementation. The internal friction angle and the cohesion are 48.5 degree and 0, respectively. The internal friction angle increases only a few relative to the samples containing no calcite. If we want to prepare samples with weak cementation and low increase of strength, calcite is a kind of appropriate cementation media.

Results with Portland Cement as Cementation Media

Experiments with Portland cement as cementation media are carried out under confined pressures of 50kPa, 100kPa and 200 kPa, respectively. Fig. (**4**) shows the curves of stress – strain. The brittleness of the samples increases with the mass increase of Portland cement, especially under low confined pressure. With the increase of confined pressure, the failure strain increases. For example, the peak stress reaches when the strain is less than 1% when the content of Portland cement is 15% and the confined pressure is 50kPa, while the peak stress reaches when the strain is 5% under the confined pressure of 200kPa.

The increase of Portland cement mass has small effects on internal friction angle, but has large effects on cohesion. The cohesions are 0, 10kPa, 50kPa, 100kPa and the internal friction angles are 46.4°, 46.4°, 45.0° and 45.0°, respectively, when the Portland cement masses are 0%, 5%, 10% and 15%, respectively. That means, Portland cement bonds the sand grains strongly except for its strong cohesion, so the cohesion increases greatly. If we want to prepare samples with largely increasing cohesion but few changes of internal friction, Portland cement is an idea cementation media. However, when the Portland cement mass is less than 5%, the cementation effect is small.

CONCLUSIONS

The main conclusions are as follows:

1. The internal friction angle of calcareous sand used here is as large as 48 degree. There occurs dilatancy at low confined pressure, especially with large density, but when the confined pressure increases to only 200kPa, the dilatancy disappears.

2. Different cementation material (calcite, Portland cement and gypsum) are used to investigate the effects of cementation media and the effects of cementation on the strength and stress-strain relation. According to experimental results Portland cement has obvious cementation effects. The strength of calcareous sand increases with the increase of Portland cement content.

3. The strength of the sample containing 15% Portland cement is 170% of that without Portland cement. The cohesions are 10kPa, 50kPa and 100kPa but the internal friction angle changes little when Portland cement contents are 5%, 10% and 15%, respectively. When using the calcite or gypsum as the cementation material, the cementation effects is little in the saturation condition.

4. Portland cement is a perfect cementation material for calcareous sand during preparing samples with strong cohesion. If samples with only a little increase of strength are required, calcite is suit. Different contents are required to prepare samples with different cementation degree.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.
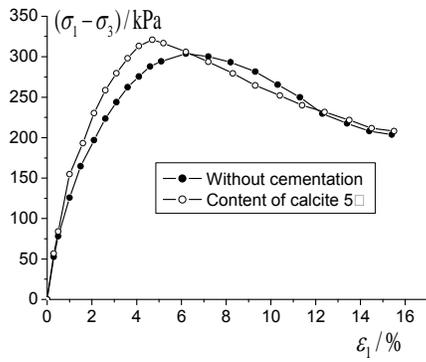
(a) Deviatoric stress~axial strain curves

under the confined pressure of 50kPa
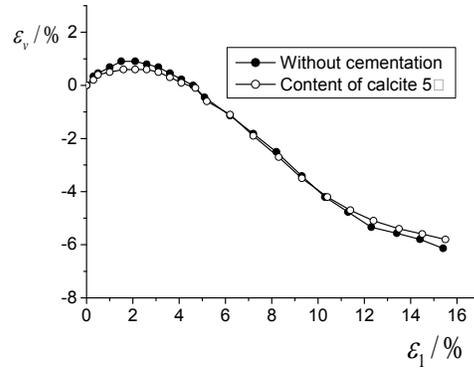
(b) Volume strain~axial strain curves

under the confined pressure of 50kPa
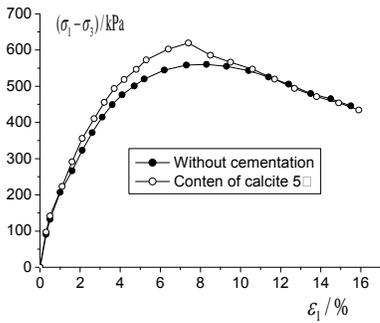
(c) Deviatoric stress~axial strain curves

under the confined pressure of 100kPa
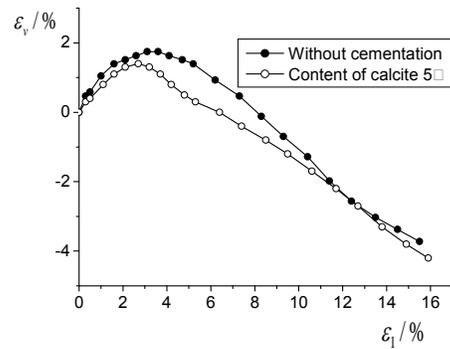
(d)   volume strain~axial strain curves

under the confined pressure of 100kPa
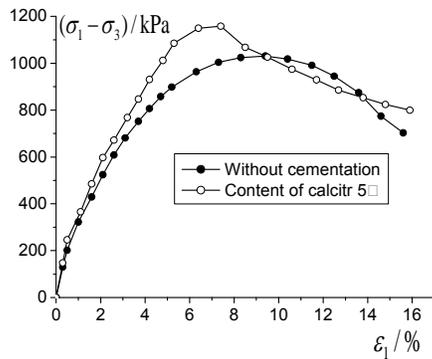
(e) Deviatoric stress~axial strain curves

under the confined pressure of 200kPa
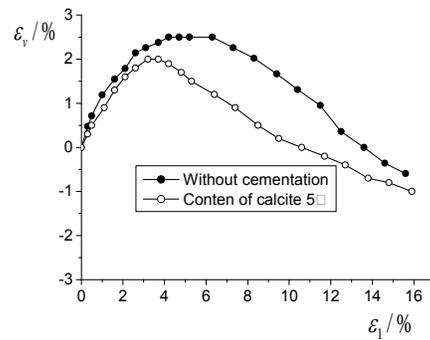
(f)   volume strain~axial strain curves

under the confined pressure of 200kPa

Fig. (3). Experimental curves under CD conditions for the samples cemented by calcite.
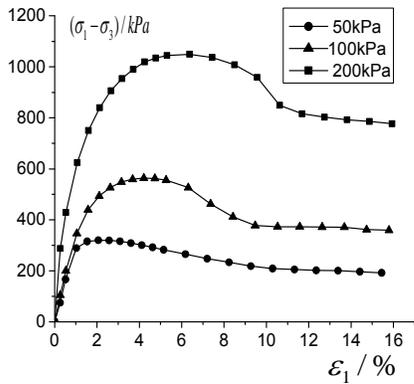
(a) Curves of deviatoric stress ~ axial strain

under different confined pressure

(Portland cement mass 5%)
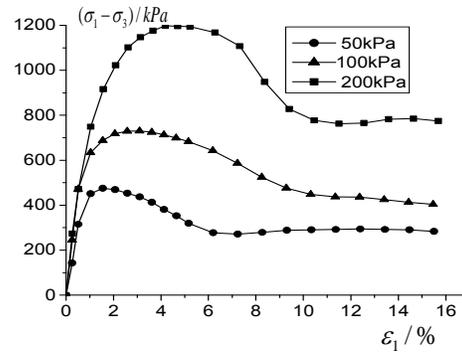
(b) Curves of deviatoric stress ~ axial strain

under different confined pressure

(Portland cement mass 10%)
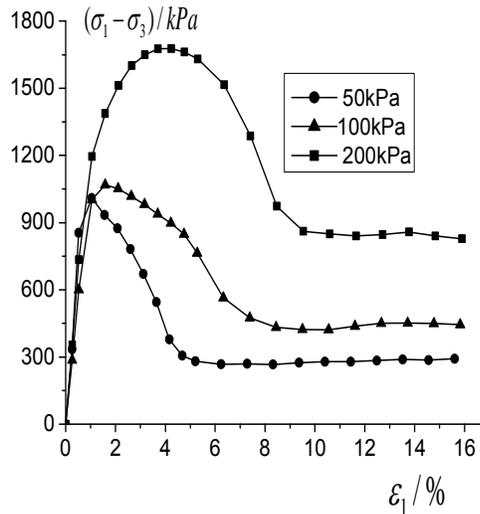
(c) Curves of deviatoric stress ~ axial strain

under different confined pressure

(Portland cement mass 15%)

Fig. (4). Experimental results under CD conditions for the samples contained cement.

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