Particle breakage of coral sand in direct shear test

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Abstract. Due to its unique development environment and historical origin, coral sand often breaks up in the process of loading, which is quite different from ordinary siliceous land-based sand in mechanical properties. Therefore, it is of great significance to study coral sand. A particle analysis test was conducted on the coral sand from a reef in the South China Sea to study its particle size distribution, and then direct shear tests were conducted to study the influence of two factors, namely relative compactness and vertical normal stress, on the crushing of coral sand particles. The results show that when the vertical normal stress is constant, the particle breakage rate increases with the increase of the relative compactness, and when the relative compactness is the same, the increase of the vertical normal stress level can further increase the crushing of coral sand particles.

1. Introduction
Coral sand is an important material for marine engineering construction, and is widely used in port wharves, reclamation of islands, foundations reclamation, buildings and other infrastructures. The particle crushing of soil in the process of loading will seriously affect the mechanical deformation performance of soil. Particle breakage has an important impact on the compression deformation, shear characteristics and permeability characteristics of carbonate sediments. It has great influence on the actual project. Therefore, it has become the research focus of scholars[1-4].

Shahnazari and Rezvani carried out triaxial compression tests on calcareous sand at different locations in the Persian gulf (Bushehr Port and Hormuz Island) to study the influence of confining pressure, relative compactness, grain size distribution and other parameters on soil particle breakage. [1]. Through a series of ring shear tests, Coop et al. studied the development process of carbonate sand particle crushing. It was believed that the final gradation of particle crushing was related to the normal stress applied on the samples and the initial gradation of samples[5]. Miao G and Airey, D carried out ring shear test and one-dimensional compression test on carbonate sand, and the research results showed that the particle crushing law was consistent, but the limit stability state was significantly different[6].

Chen HD, Wei HZ, et al conducted triaxial consolidation drainage shear test on calcareous sand, analyzed the effect of relative compactness and confining pressure on particle crushing and studied the effect of particle crushing on shear performance of calcareous sand. The research results showed that under the condition of low confining pressure, the particle breakage of soil samples is less. With the increase of confining pressure, the particle breakage becomes more serious. However, the increment of particle breakage decreases until the particle breakage rate approaches a stable limit [7]. Cai ZY, Hou HYet al carried out triaxial consolidation drained shear test and uniaxial compression test under
different stress level and different compactness, research suggests that the soil particle breakage increases with the increase of relative compactness, and linear increase with increasing of confining pressure or vertical load[8].

As the mechanical properties of coral sand are greatly affected by the development environment, the crushing and mechanical properties of coral sand particles in different areas are different. For example, the yield strength of Bushehr Port sand is lower than that of Hormuz Island sand[1]. In this paper, the coral sand taken from a reef in the South China Sea was studied. Two variables, vertical normal stress and relative compactness, were set in the test to study the particle crushing condition under different test conditions. The research results of this paper are of great help to deeply understand the influencing factors of particle breakage of coral sand and explore the degree of particle breakage in the shearing process, which can provide useful help for practical engineering construction.

2. Materials and methods

2.1 Test material and sample preparation method

The coral sand comes from an island in the South China Sea, and the partial particle group is shown in the Fig1. Self-made sieves were used for screening test, and specific mesh diameter was shown in the Tab1. Since coral sand is a loose soil granule material, self-made sampler is used for sample pressing. The size of ring cutter is 61.8×20mm, and the sample preparation tool is shown in the Fig2.

| Diameter | 1.43- | 1.0- | 0.85- | 0.5- | 0.3- | 0.2- | 0.1- |
|----------|-------|------|-------|------|------|------|------|
| range    | 2.0mm | 1.43mm | 1.0mm | 0.85mm | 0.5mm | 0.3mm | 0.2mm |
| Proportion | 0.0563 | 0.0768 | 0.0918 | 0.1352 | 0.3592 | 0.1495 | 0.1311 |

![Fig 1. Coral sand](image1)

![Fig 2. Sample preparation tool](image2)

2.2 Test scheme

In order to study the influence of relative compactness and vertical normal stress on the crushing of coral sand particles, the traditional direct shear instrument was used for the test. The specific experimental scheme is shown in the Tab 2. Before and after the test, the particle analysis test was carried out. The water content of the samples was 25%.

| Vertical normal stress /kPa | Relative compactness D_r |
|----------------------------|--------------------------|
| 100 | P100-0.4 | P100-0.5 | P100-0.6 | P100-0.7 |
| 200 | P200-0.4 | P200-0.5 | P200-0.6 | P200-0.7 |
| 300 | P300-0.4 | P300-0.5 | P300-0.6 | P300-0.7 |
| 400 | P400-0.4 | P400-0.5 | P400-0.6 | P400-0.7 |
3. Test results and discussion

3.1 Particle breakage index

Fig 3. Relative particle breakage rate index

The determination of particle crushing index is of great significance to measure the influence level of various factors on samples. For the definition of particle crushing index, many scholars have put forward their own determination methods, such as $B_{15}$ proposed by Lee and Farhoomand [9], $B_{ef}$ proposed by Einav [10]. In this paper, the crushing index $B_r$ proposed by Hardin is adopted [11], and its formula is defined as follows:

$$B_r = \frac{B_{po}}{B_t}$$

(1)

The specific area range diagram of $B_{po}$ and $B_t$ is shown in the Fig 3.

3.2 Particle breakage rate

Fig 4. Relative breakage rate $B_r$

Before and after the test, the particle size distribution of the samples was confirmed, and the particle breakage rate under the condition of relative compactness and vertical normal stress was acquired. The relationship between the dual influence indexes of relative compactness and vertical normal stress and the particle breakage rate was plotted in a three-dimensional figure, as shown in the Fig 4. The influence of the dual influence indexes on the test results could be directly displayed.
It can be seen from the comparative analysis of the test results that the particle breakage of coral sand gradually increases with the increase of relative compactness. The results of the experiment under a certain vertical normal stress condition can be obtained arbitrarily. For example, when the vertical normal stress is 100kPa. The vertical normal stress also has an important impact on the particle breakage of coral sand. Under the condition of the same relative compactness, the particle breakage rate increases with the increase of the vertical normal stress, such as the particle breakage rate under various stress conditions when Dr=0.5.

4. Conclusion
Coral sand has become an important engineering material for the construction of ocean and port infrastructure due to its rich reserves and easy access. However, because of its high calcium carbonate content, it is prone to particle breakage under stress, and its mechanical properties are different from those of land-based sand. Therefore, it is of great significance to conduct research on the particle breakage of coral sand.

In this paper, the particle analysis of coral sand from a reef in the South China Sea was carried out, and the direct shear test was carried out to study the crushing condition of coral sand particles under different influencing factors. The results show that the relative compactness and vertical normal stress have significant effects on the particle breakage of coral sand. At the same vertical normal stress, particle breakage increases with the increase of relative compactness. According to the comparison and analysis of the same relative compactness, the increase of vertical normal stress will increase the particle breakage of coral sand. The research results of this paper are of great significance to further understand the particle breakage of coral sand.

Reference
[1] Habib Shahnazari, Reza Rezvani. Effective parameters for the particle breakage of calcareous sands: An experimental study [J]. Engineering Geology, 2013, 159(9): 98-105.
[2] Wang X Z, Jiao Y Y, Wang R, et al. Engineering characteristics of the calcareous sand in Nansha Islands, South China Sea [J]. Engineering Geology, 2011, 120(1-4): 40-47.
[3] Ma L, Li Z, Wang M, et al. Effects of size and loading rate on the mechanical properties of single coral particles [J]. Powder Technology, 2018.
[4] Lv Y, Liu J, Xiong Z. One-dimensional dynamic compressive behavior of dry calcareous sand at high strain rates [J]. Journal of Rock Mechanics and Geotechnical Engineering, 2018.
[5] Coop M R, Sorensen K K, Bodas Freitas T, et al. Particle breakage during shearing of a carbonate sand [J]. Géotechnique, 2004, 54(3): 157-163.
[6] Miao G, Airey, D. Breakage and ultimate states for a carbonate sand [J]. Geotechnique, 2013, 63(14): 1221-1229.
[7] Chen HD, Wei HZ, Meng QS, et al. The study on stress-strain-strength behaviour of calcareous sand with particle breakage [J]. Journal of Engineering Geology, 2018, 26(06): 85-93. (In Chinese)
[8] Cai ZY, Hou HY, Zhang JX, et al. Experimental study on the influence of density and stress level on particle breakage of coral sand [J]. Journal of Hydraulic Engineering, 2019, 50(2): 184-192. (In Chinese)
[9] Lee K L, Farhoomand I. Compressibility And Crushing Of Granular Soil In Anisotropic Triaxial Compression [J]. Canadian Geotechnical Journal, 1967, 4(1): 68-86.
[10] EinavI. Breakage mechanics—Part I: Theory [J]. Journal of the Mechanics and Physics of Solids, 2007, 55(6): 1274-1297.
[11] Hardin, Bobby O. Crushing of Soil Particles [J]. Journal of Geotechnical Engineering, 1985, 111(10): 1177-1192.