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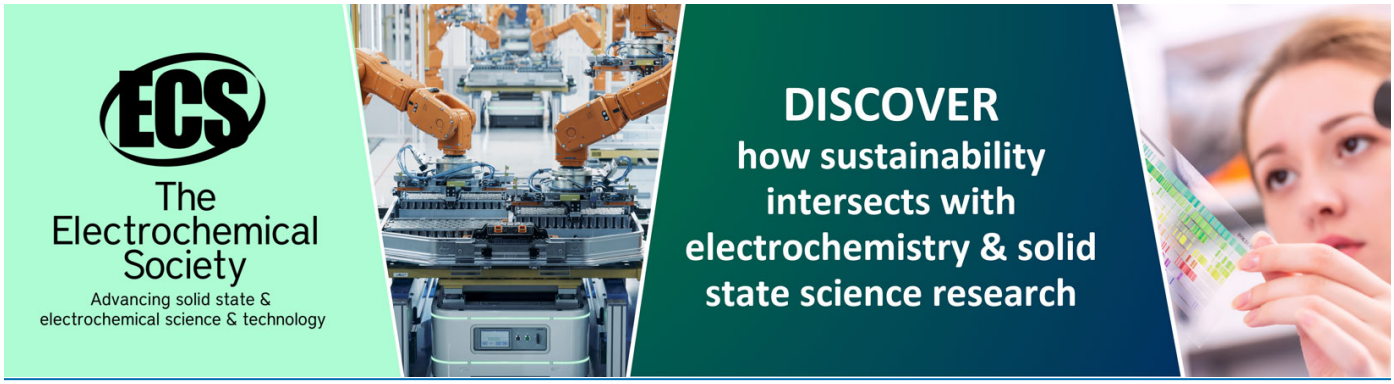

Experimental research on geotechnical engineering characteristics of coral reef in Xisha Islands

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Abstract. Coral reefs are widely distributed in Xisha Islands, which have special engineering properties. Coral reef geology from top to bottom is coral sand, coral gravel, coral reefs calcareous rock. Coral sand and coral gravel have the characteristics of mixed size particles, alternating accumulation of sand and gravel, great change of density and gradually coarsening from top to bottom. Coral reefs calcareous rocks are composed of loose bioclasts cemented, some of them are dense, and some of them are semi-cemented and weakly cemented. The geological age of the Xisha Islands within 50m was determined by carbon-14 radioisotope isotopic test. The bearing capacity and deformation characteristics of coral sand and coral gravel were analyzed by plate loading test, heavy dynamic penetration test, extra-heavy dynamic penetration test and standard penetration test. The physical and mechanical characteristics of coral reefs calcareous rock were studied by longitudinal wave velocity test, density test, porosity test and uniaxial compressive strength test.

1. Introduction

Coral reefs are widely developed in Xisha Islands, which is a kind of type with special engineering geological properties. With the development and protection of Marine resources and the needs of national defense construction, the strategic, scientific and economic significance of coral reefs is becoming greater and greater. For the rational planning, scientific design and safe construction of different types and scales of construction projects on coral reefs, it is necessary to study the engineering geological properties of coral reefs.

Based on the research on the geological characteristics of coral reefs, the bearing capacity and deformation characteristics of coral sand, and the physical and mechanical characteristics of coral reefs calcareous rock in Xisha Islands, this paper provides reasonable and feasible suggestions for the correct planning and layout, reasonable design, safe construction, normal operation, and obtaining the best economic and environmental benefits of engineering construction in Xisha Islands.

2. The experiment

2.1. Selection of experiment sites

According to the current plan, construction in the Xisha Islands will be concentrated on Yongxing Island, Zhaoshu Island, Bei Island, Jinqing Island and other islands inhabited by fishermen. Based on the comprehensive consideration of the experiment objectives, landforms, site conditions, equipment transport, cost, living, weather and sea conditions, Yongxing Island, Zhaoshu Island, Beidao Island, Shidao Island and Jinqing Island were selected as the experiment sites.

2.2. Experiment item

In order to understand the mechanical properties of coral sand of various geomorphic units, a total of 22 test sites have been arranged on Yongxing Island, Zhaoshu Island and North Island (10 on Yongxing Island, 6 on Zhaoshu Island and 6 on North Island), plate loading test, heavy dynamic penetration test, extra-heavy dynamic penetration test, standard penetration test have been selected.

3. Stratigraphic lithology

Coral reef engineering geological environment is a complex system, which is composed of Marine hydrodynamic environment, ecological environment and geological environment. Coral reefs in different geological environments have different environmental characteristics, structural characteristics and engineering geological characteristics due to their different biological components, degree of diagenesis, heterogeneity, sediment particle size, porosity ratio, degree of diagenesis, cementation, and development of fractures and pores.

3.1. Coral sand & coral gravel

Coral sand and coral gravel are mainly composed of debris from coral reefs, dead corals and shells, the remains of reef-building organisms that have been shattered by the impact of the sea. It contains other Marine biological clasts, mostly granular or clastic, and its mineral components are mainly aragonite and high magnesium calcite. Its chemical composition is mainly CaCO3, its content is more than 97%, and all belong to carbonate soil or calcareous soil. The basic characteristics of coral sand are loose, porous, low hardness, low strength and brittleness. Its particle size is mixed, including some reef boulders with particle size greater than 5mm, and some coral-cladlike detritus with high angle, poor roundness and relatively void ratio.

Coral sand and coral gravel are composed of the broken and piled remains of coral and other reef-building organisms. Because it had not been transported long distance in the deposition process, it retains the fine pores in the protozoan skeleton, and forms the characteristics of the particles with many pores, irregular shape, easy to break and poor cementation. As a result, the size of particles of Coral sand and coral gravel is mixed, gravel and sand are interbedded, and the compactness of debris varies greatly, as shown in Figure 1 and Figure 2. The particle size gradually coarsened from top to bottom. The grain size, grain size composition, relative compactness, content of coral reef blocks and degree of cementation of surface sediments all affect the bearing capacity and deformation characteristics of ground.

Figure 1. Coral boughs with coral sand

Figure 2. Coral blocks with honeycomb holes

3.2. Coral reefs calcareous rock

Coral reefs calcareous rock is a special geotechnical type. One is due to the particularity of its composition; the other is due to the particularity of its development environment. The mineral composition of coral reef is aragonite and high magnesium calcite, which determines that its physical and mechanical properties are significantly different from those of quartz sand: loose, porous, brittle,

low hardness, and has a certain self-cementing effect. Coral reefs are constantly subjected to the effects and influences of the Marine dynamic environment. The reef flat is in the intertidal environment which is submerged at high tide and dried out at low tide. Marine dynamic factors directly shape the topography and landform of the reef, and also affect the engineering properties of the coral reef.

Coral reefs calcareous rocks are composed of loose bioclasts cemented, some of them are dense, and some of them are semi-cemented and weakly cemented. The cementing material is thick and slippery, and the structure is loose, as shown in Figure 3, 4 and 5. The drill core is mainly in bulk and massive shape. Coral reefs calcareous rocks mostly contain holes and grooves, with well-developed pore fissures and good connectivity, as shown in Figure 6. Coral reefs calcareous rocks with such holes and fissures tend to be loose, broken and low in strength, which has an adverse effect on the application of pile foundation in large-scale engineering construction.

Figure 3. Dense coral reefs calcareous rock

Figure 4. Semi-cemented coral reefs calcareous rock

Figure 5. Weakly consolidated coral reefs calcareous rock

Figure 6. With holes, grooves coral reefs calcareous rock

4. Geologic age

4.1. Isotopic testing of carbon-14 radioactivity

A group of coral reef carbon-14 radioisotope isotopic test samples were taken in Zhaoshu Island and North Island respectively, and 3 samples were taken from top to bottom in each group, a total of 6 samples were taken. The coral reef age samples were soaked in water and washed in testing laboratory, and the salt and surface impurities were initially removed. The samples were processed into small pieces of about 10g each, and then dried in an oven. Phosphoric acid method was used to extract CO2 gas in the experiment, and graphite was synthesized from the purified CO2 gas by "improved Zn

method". The graphite sample was measured by accelerator mass spectrometer, and the measurement accuracy was better than 3‰. The test results are shown in Table 1.

Table 1. Radioisotope test results by carbon-14 method.

Number	Depth(m)	Geotechnical category	$\delta^{13}C$ test result(‰)	^{14}C(pMC)	^{14}C age(a.BP)
Age-1	5.9	Coral sand	-5.20	78.70	1916±38
Age-2	16.2	Coral gravel	-0.55	38.60	7637±44
Age-3	42.2	Coral reefs calcareous rock	-1.27	0.81	38674±521
Age-4	4.6	Coral sand	0.95	83.16	1480±42
Age-5	23.8	Coral gravel	-3.98	38.55	7656±69
Age-6	48.8	Coral reefs calcareous rock	-1.02	0.40	44312±1132

According to the experimental results, the geological age of coral sand and gravel is Quaternary Holocene, and the geological age of Coral reefs calcareous rock is Quaternary Late Pleistocene.

5. Experiment on bearing capacity and deformation characteristics of coral sand and coral gravel

5.1. Plate loading test (PLT)

A total of 66 plate loading tests were carried out on coral sand at Yongxing Island, Zhaoshu Island and North Island, and 17, 17, 16 and 16 load tests were carried out at depths of 0.5m, 1.0m, 1.5m and 2.0m, respectively. The typical *p-s* curve of is shown in Figure 7.

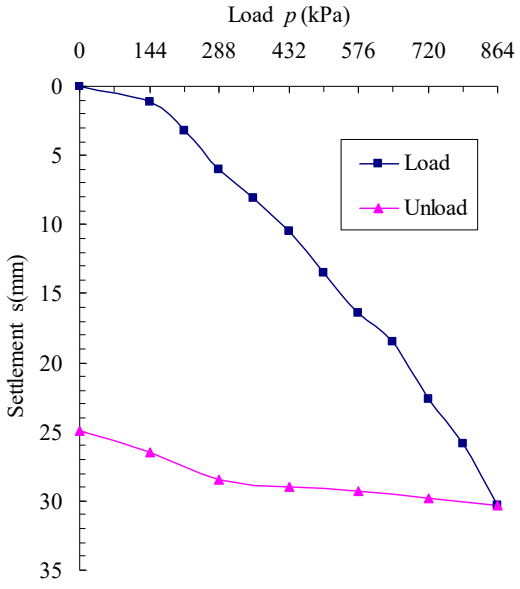

Figure 7. Typical *p-s* curve

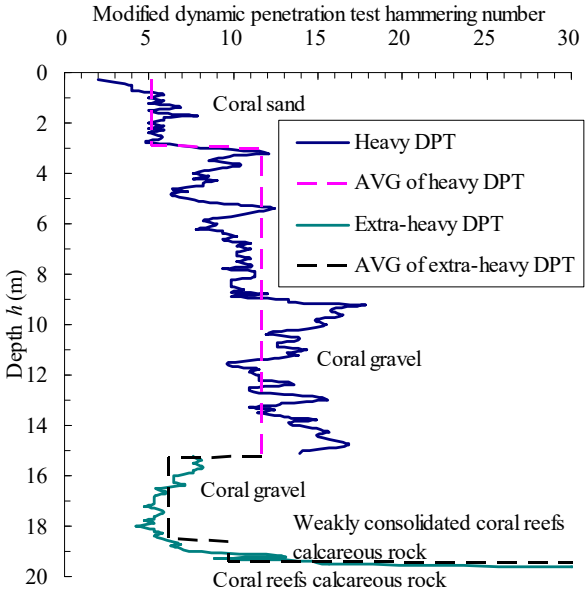

Figure 8. Typical $N_{63.5,120}$-*h* curve

According to the test results, the *p-s* curves of coral sand do not show a steep drop section, and the ratio of settlement to the width of plate is greater than or equal to 0.06 at the end of the test loading, and the settlement reaches 30mm. It can be seen from the unloading curve of *p-s* curve that the rebound of coral sand after unloading is very small, indicating that the deformation in the process of compression is almost an unrecoverable plastic deformation. The characteristic value of subgrade bearing capacity of coral sand at 0.5m, 1.0m, 1.5m and 2.0m increases successively with depth, and is between 107 ~ 307kPa, 125 ~ 331kPa, 140 ~ 342kPa and 160 ~ 358kPa, respectively.

The deformation modulus of plate loading test of coral sand, E_0 (MPa), can be calculated according to the following formula:

$$E_0 = I_0\left(1-\mu^2\right)\frac{pd}{s} \quad (1)$$

I_0, the shape coefficient of the rigid bearing plate, use 0.866, μ, Poisson's ratio of soil, use 0.3, d, the side length of the plate, p, pressure in the linear segment of the *p-s* curve, s, settlement corresponding to pressure p.

At the depth of 0.5m, 1.0m, 1.5m and 2.0m, the deformation modulus E_0 of coral sand increases successively, and is between 8.6 ~ 24.8MPa, 10.1 ~ 26.7MPa, 11.3 ~ 27.6MPa, 12.9 ~ 28.9MPa, respectively.

5.2. Dynamic penetration test (DPT)

The compactness and uniformity of coral sand and coral gravel can be evaluated by heavy dynamic penetration test ($N_{63.5}$) & extra-heavy dynamic penetration test (N_{120}). In the process of heavy dynamic penetration test, when the coral reef block with larger thickness and weaker cementing is encountered in the test depth range, extra-heavy dynamic penetration test is carried out until it passes through. The typical $N_{63.5,120}$-h curve of is shown in Figure 8.

According to the test results, the average of modified heavy dynamic penetration test hammering number by coral sand and coral gravel is 6.6 and 9.7, respectively. The average of modified extra-heavy dynamic penetration test hammering number by coral gravel was 16.8.

5.3. Standard penetration test (SPT)

Standard penetration test is the main index to evaluate the compactness and bearing capacity of coral sand. A total of 146 standard penetration tests were carried out in Yongxing Island, Zhaoshu Island and North Island. The field measured standard penetration test hammering number ranged from 6 to 34, with an average of 15.2, and the modified hammering number ranged from 6.0 to 28.6, with an average of 14.3.

6. Experiment on Physical and mechanical characteristics of coral reefs calcareous rock

6.1. Longitudinal wave velocity test

The longitudinal wave velocities of 167 coral reefs calcareous rock samples were tested under natural condition, 99 samples under dry condition and 68 samples under saturated condition. The experimental results show that the longitudinal wave velocities of coral reefs calcareous rock in natural, dry and saturated conditions are 2311 ~ 4230m/s, 2530 ~ 4167m/s and 2352 ~ 4190m/s, respectively. Under the influence of structural plane and pore water, the longitudinal wave velocity in the natural condition is larger than that in the dry condition, and the longitudinal wave velocity in the saturated condition is larger than that in the natural condition.

6.2. Density test

Combined with longitudinal wave velocity test, natural density of 167 coral reefs calcareous rock samples, dry density of 99 samples and saturated density of 68 samples were tested. The results show that the density of coral reefs calcareous rock in natural state, dry state and saturated state is 1.12 ~ 3.08, 1.11 ~ 2.92, 1.12 ~ 3.07g/cm^3 respectively. The density of the partial natural state is higher than that of the saturated state, because part of the debris falls off during the saturated process, resulting in the decrease of the saturated mass.

6.3. Porosity test

Coral reefs calcareous rock is formed by the remains of coral, various reef-attached shellfish and algae under the cementation of calcareous cements. During the cementation process, coral bones are filled with coral debris and biological debris, but there are a lot of pores that have not been filled. Due to the existence of pores, the longitudinal wave velocity of coral reefs calcareous rock is affected, and the

compressive strength of coral reefs calcareous rock is also reduced. The porosity test results show that the porosity of coral reefs calcareous rock ranges from 5.81 to 36.33%.

6.4. Uniaxial compressive strength test

Uniaxial compressive strength is an important index to classify rock hardness and study its mechanical properties. It is also an important basis for excavation classification and determination of drillability. In order to study the strength characteristics of coral reefs calcareous rock, uniaxial compressive strength tests were carried out on 131 samples from Yongxing Island, Zhaoshu Island and North Island. According to the test results, the uniaxial drying compressive strength of coral reefs calcareous rock ranges from 1.82 MPa to 27.42MPa, with an average of 9.15MPa, and the uniaxial saturation compressive strength ranges from 0.86 MPa to 18.94MPa, with an average of 7.30MPa. The average coefficient of softness of coral reef limestone is between 0.69 and 0.91.

7. Conclusion

The field tests and laboratory tests on Yongxing Island, Zhaoshu Island and North Island of Xisha Islands are mainly concluded from the following three aspects:

- According to drilling test results and formation genetic analysis, the top of the formation in the coral reef area is a loose coral sand or coral gravel, and the bottom is a well cemented coral reefs calcareous rock (partially semi-cemented and weakly cemented).
- The characteristic value of subgrade bearing capacity of coral sand increases with depth. The compactness and uniformity of coral sand and coral gravel can be evaluated by heavy dynamic penetration test. The compactness and bearing capacity of coral sand can be evaluated by standard penetration test.
- According to the results of longitudinal wave velocity test, density test, porosity test and uniaxial compressive strength test, coral reefs calcareous rock is a relatively complex heterogeneous anisotropic body, and its biological components, degree of diagenesis, heterogeneity, pore type and fracture development have a great influence on the physical and mechanical test results of reef limestone.
- In order to reasonably analyze and compare different laboratory test results and reduce the dispersion in the process of comparison and statistics, it is suggested to group the samples according to the longitudinal wave velocity test of coral reefs calcareous rock, select other laboratory test items in each group, and then make comparison, statistics and analysis of the test results to achieve the purpose of determining the best evaluation.

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