Performance of expansive concrete pile in indoor calcareous sand foundation under vertical load

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ABSTRACT

Calcareous sand is a special kind of marine sediments with high calcium carbonate content. The common piles have low side resistance in calcareous sand foundation due to the properties of grain crushing, high compressibility and cementation action. Expansive concrete cast-in-place pile is proposed to solve the difficulty in low bearing capacity of piles buried beneath the calcareous sand ground, in which the dosage of expansive agent is 10%~30%. In laboratory model test, the load-settlement curves, shaft axial force, skin friction and load-sharing between end-bearing capacity and skin resistance under a vertical load are measured and analyzed. The result is compared with traditional cast-in-place pile. Results show that with the increasing in expansive agent, the frictional resistance increases rapidly, and pile-sand interaction becomes more obvious. During loading, skin friction gradually develops with the depth and plays a significant part in bearing capacity. In addition, the expansive concrete pile with 25% expansive agent can improve almost 20% bearing capacity of piles due to the expanding extrusion. This study provides a reference for the pile foundation projects in calcareous sand foundation.

Keywords: calcareous sand; expansive concrete pile; model test; bearing capacity; pile-sand interaction

1 INTRODUCTION

The offshore engineering has drawn extensively wide concerns for recently years. Calcareous sand is a kind of marine sediment which is widely distributed in the South China Sea, the Red Sea and the North Arabian Gulf (Bai *et al*., 2010). The organism and shell are of fine porous nature, after crushing, transportation, and accumulation, leading to a property of irregular shape, easily crushed friability and high compressibility (Qin *et al*., 2016). Therefore, it is not surprising that pile foundation constructed in calcareous sand has a special bearing performance, which is worthy being investigated. Angemeer *et al*. (1973) found that vertical bearing capacity of the pile in calcareous sand was obviously less than that in siliceous sand. Results of in situ tests on calcareous sand indicated the skin friction of driven pile was merely 20% of it for ordinary abrasive (McClelland *et al*., 1974). Pile-soil interaction mechanism and the failure model of the pile were illustrated (Qin *et al*., 2014) based on the laboratory tests. Zhou *et al*. (2013) proved the side resistance was also influenced by the forming method through the numerical simulation and model tests. In addition, the results of model piles showed that the main reason for the reduction of the side resistance of the pile was the particle breakage (Jiang *et al*., 2009).

A new kind of pile i.e. expansive concrete pile, has gained its popularity recently in civil engineering by adding expansion agent in the concrete to make the pile expand. Adding the dosage of 10%~30% expansive agent in the concrete could provide 50% higher side resistance of the pile, further to reduce its settlement (Shamin *et al.*, 1984). Through further experiments, Shamin *et al.* (1986) reported that strength and stiffness of the pile were significant increased when the expansion agent was added for over 2 years.

Distinguished from these researches, the study on bearing capacity of expansive concrete pile in calcareous sand is examined. The test models include four single piles by adding varying content expansive agent to concrete. The effect of the dosage of expansive agent to concrete on bearing capacity is also evaluated.

2 LABORATORY MODEL TEST

2.1 Model test equipment

The model test facility is comprised of a model container, loading system, and measuring system. Four model piles are built in model laboratory test tank which size is 1m×0.8m×0.8m.

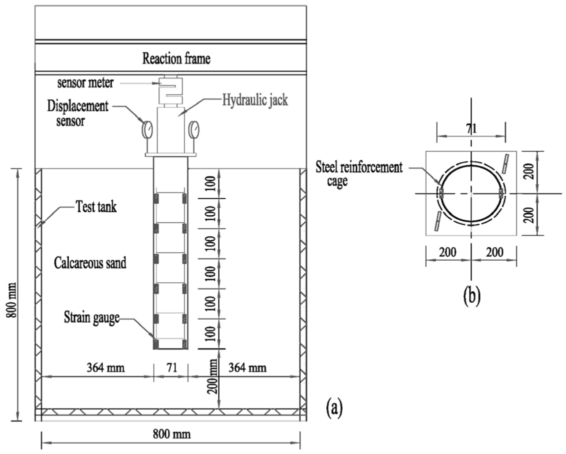

Fig. 1. The experimental Schematic diagrams of the static load test (a) side view (b) top view.

There are six pairs of strain gauges used for each single pile. The detail arrangement of strain gauges is shown in Fig. 1. During the loading tests, different pressures are applied on the testing piles which are pressured by the hydraulic jack. In this procedure, pressure is shown by the stress meter, and settlement is recorded by displacement sensors. At different stages of pressures, data acquisition system collects the stress-strain data by the strain gauges.

2.2 Sand and model piles

Calcareous sand from the South China Sea, is used in the test. Soil layers in the model container are filled and compacted artificially. A dense homogeneous sand specimen with a relative density of 51% is achieved. The curve of sand gravel test is shown in Fig. 2.

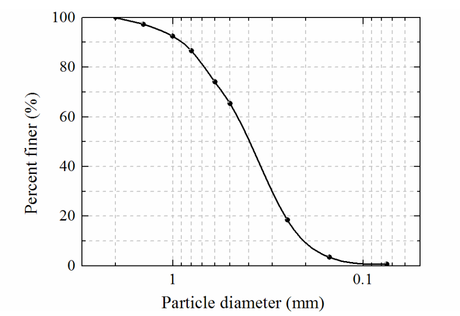

Fig. 2. Particle size distribution of the tested sand.

Table 1. Physical and Mechanical Parameter Indices of sand.

Materials	Calcareous sand
Proportion, G_s	2.78
Maximum dry density, ρ_{max} (g/cm^3)	1.70
Minimum dry density, ρ_{min} (g/cm^3)	1.22
Cohesion, C (kPa)	2.86
Friction angle, φ (°)	41.35

The physical and mechanical parameters of sand are shown in Table 1. Four circular piles of 600 mm length, 71 mm diameter are used. They are cast with cement and sand which mix proportion is 2:1. UEA expansion agent is used in this test. As is shown in Table 2, proportion of components in cement consists of 0%, 5%, 15%, 25% expansion agent. The reinforcement cage is composed of two symmetrically steel sheets which size is 20×1.5×550mm. Strain gauges are placed on the steel sheets to measure stress and strain. The displacement sensors are placed on the top of the pile. The test plans for the model tests are shown in Fig. 1.

Table 2. Material composition of test piles.

Materials	Pile A	Pile B	Pile C	Pile D
Cement (kg)	5	4.75	4.25	3.75
River sand (kg)	2.5	2.5	2.5	2.5
Expanding agent (kg)	0	0.25	0.75	1.25
The ratio of expanding agent	0 %	5 %	15 %	25 %

2.3 Test program

Multi-stage loading method is employed in this test with 0.25kN for each load grade. For each step, keeping each specific loading until the settlement is stable, and then recording the settlement and stress-strain of the pile. Terminal load is based on the following standard: (1) broken pile bodies; (2) the maximum loading ability; or (3) the rapidly increasing displacement under a constant loading. When the test condition reaches any of these criteria, the test should be stopped.

3 TEST RESULTS AND ANALYSIS

3.1 Expansion

After the model test, the piles were picked out of the test tank. The diameter of pile is measured by vernier caliper after the floating calcareous sand was scraped. Compared with the pile A, the expansion rate of expansive concrete pile was calculated as is shown in Table 3. We can see clearly that expansion increases with the amount of expansion agent in cement mortar and the ratio of horizon linear expansion can reach to 1.17%.

Table 3. The expansion rate of piles.

Test No.	Pile A	Pile B	Pile C	Pile D
The expansion rate	0%	0.35%	0.73%	1.17%

3.2 Load-settlement curve

Fig. 3 presents load–displacement curves of the piles with different expansion agent. At the preliminary stage of loading, the elastic compressed displacement occurs and displacement increases nearly linearly. When the load is applied by about 2 kN, the deflection increases rapidly. For the further loading, the piles experience shear failure. Notice that the bearing capacity of the model piles are 2.0 kN, 2.15 kN, 2.25 kN and 2.35 kN, respectively, which indicates that pile D has a higher bearing capacity than pile A e.g. the bearing capacity of pile D is increased by 17.5 % when 25 % expansion agent is added. The expansion of the pile could improve lateral earth pressure, leading to higher skin friction. After the static load test, the piles are complete, indicating that under the vertical load, the soil at the end of the pile was damaged by piercing.

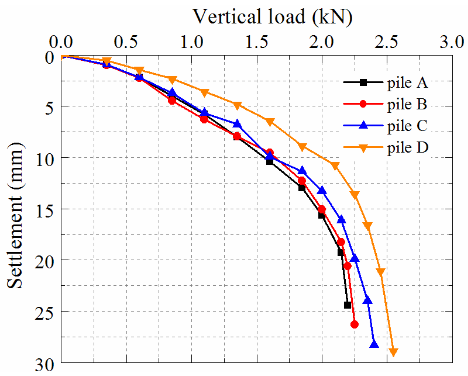

Fig. 3. Load−displacement curves of the tested piles.

3.3 Axial force

It is supposed that the strain of concrete is the same as that of steel sheet at any depth. Fig. 4 shows the axial force on the model piles. Notice that the axial force distribution of the expansive concrete pile is the same as the concrete pile without expansion agent. This indicates that the bearing mechanism of expansive concrete pile is similar with traditional cast-in-place pile.

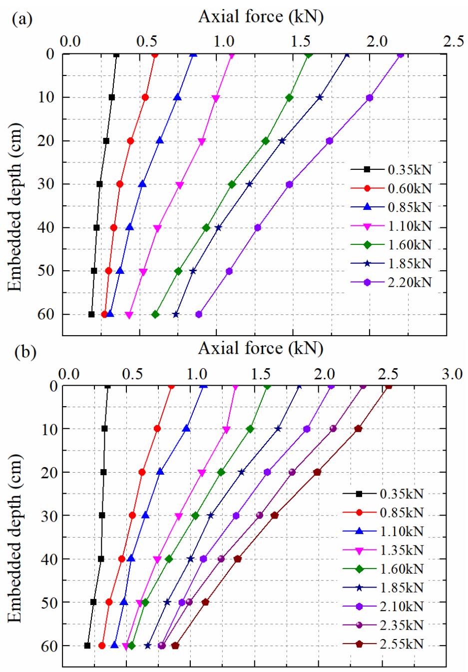

Fig. 4. Distribution of axial force of (a) pile A; (b) pile D.

The maximum value of the axial force occurs at pile head and the axial force decreases gradually with depth. This variation is trivial for the case of loads less than 1.2 kN. By contrast, when the load is larger than 1.2 kN, the axial force changes rapidly with depth. This is owing to the fact that the relative displacement between pile and soil is small at first, as pile bears most of load. When the load is increased, more load transfers to the soil.

3.5 Skin friction

The skin friction of pile A, D are respectively shown in Fig. 5. Two figures present a semblable trend. When the load is small, the change of skin friction is not obvious. When the load is larger than 1.1 kN, the skin friction rises at the beginning then reduces with depth. This is because lateral earth pressure increases with depth, while at the tip of the pile axial force acts a pivotal part with the sand compaction. The maximum skin friction of four piles at a region between 150 mm and 350 mm. The peak skin friction of pile D is 15 kPa, which is approximately 1.3 times of the pile A 11.7 kPa.

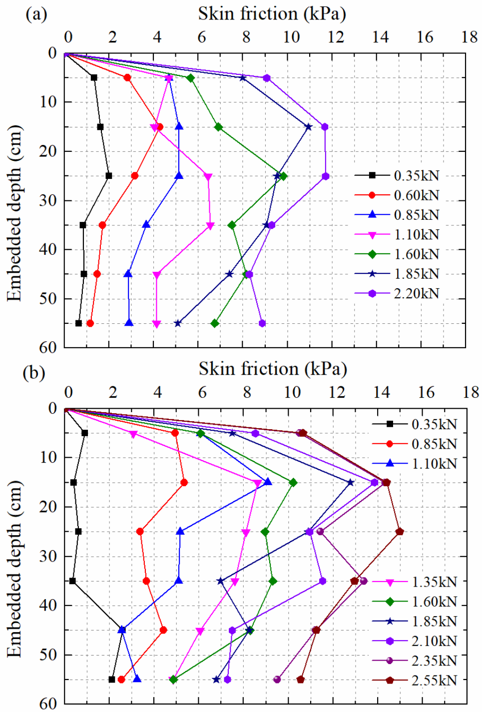

Fig. 5. Distribution of skin friction of (a) pile A; (b) pile D.

3.6 Distributions of side resistance and end-bearing capacity

Conventionally, the bearing capacity of a pile is composed of axial force and skin friction. Fig. 6 provides variations of the load-sharing of four piles with applied loads. The load-sharing of the side resistance increases with the increasing load, which demonstrates that more load distributes to the skin friction with the higher load. Inspection of the four plots of intersection finds that pile A reaches the earliest; while pile D is the last. This implies that the skin friction of pile D develops quickly than the others. For each pile, the load-sharing of axial force reaches the maximum in the initial loading. With the development of skin friction, end-bearing capacity decreases with load. Under various loads, the value of the side resistance of pile A is smaller than that of pile

D. When load is larger than 2.1kN, the growth rate of side resistance becomes stable. At the tip of pile, the ratio of side resistance is 59.75 %, 60.02 %, 62.16 %, 65.44 % under the ultimate load. This result demonstrates the expanded concrete pile could enhance the skin friction.

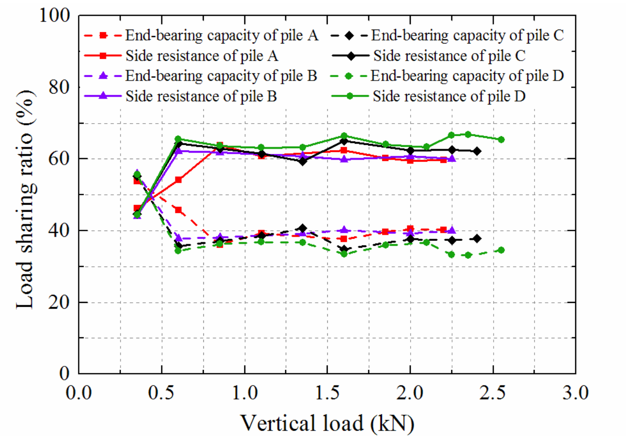

Fig. 6. Load-sharing ratio of side resistance and end-bearing capacity for tested piles.

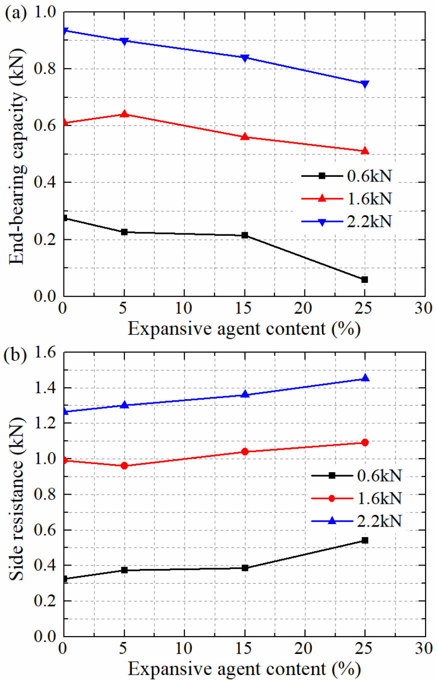

Fig. 7. Under the same loads, (a) the end-bearing capacity and (b)side resistance of piles.

Fig. 7 shows end-bearing capacity and side resistance of the model piles under the same loads. It shows end-bearing capacity reduces with the increasing of the addition to the cement mortar. In other words, the side resistance of pile D plays more important role than others. Adding 25% expansion agent could increase approximately 16% side resistance than traditional pile.

4 CONCLUSION

The performance of expansive concrete pile in indoor calcareous sand foundation test has been studied with the findings concluded as:

1. Expansive concrete pile has the similar trend of load–displacement curve with traditional cast-in-place pile, while with better bearing capacity due to its expansion principle. The ratio of horizon linear expansion reaches 1.17% and the bearing capacity can enhance almost 17.5% when 25% expansion agent is added.
2. The axial force reduces with depth and the axial force changes more rapidly with the higher load; the skin friction rises at the beginning then reduces with depth. Under the same load, the skin friction resistance of expansive concrete pile works faster than traditional cast-in-place pile.
3. Expansive concrete pile has the characteristics of a friction pile. The side resistance plays more important role in bearing capacity. Adding 25% expansion agent can increase about 16% side resistance.

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