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Study on large tonnage pile foundation load test system and field test of long rock-socketed pile

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Abstract. Large tonnage pile foundation load test system is designed in this paper by using pre-stressed technique to optimize the design of anchor pile reaction beam system, in which project pile can be successfully taken as anchor pile. The test results show that the cracks and excessive deformations of the prestressed anti-force device designed in this study have not occurred, and the prestressed tendons of the anchor pile ensure that the anchor pile will not be pulled and fractured, and the prestressed tendons can be reused, thus ensuring the safety and reliability of the test. This test method can directly test bearing capacity of long rock-socketed piles, and analysis bearing behaviors from test results of sensors which embedded in the pile. Through test studied, authors summarized the vertical bearing characteristics of long rock-socketed piles and the main problems that should be paid attention to during design and construction, and provided reliable solutions.

Keywords: load test system; long rock-socketed pile; vertical bearing capacity

1. Introduction

Along with the ongoing construction of large bridges, performance improvement of machinery and equipment, high bearing capacity of long piles are being used in large scale. Piles are prominently longer than commonly used pile. Different scholars have different references(Zhang *et al.* 2014), references on long pile can be roughly divided into three categories: ①according to the absolute length; ②according to the ratio of bottom resistance load and top load of pile; ③according ratio of length and diameter L/D determine. At present, most scholars agree that a pile with a length-to-diameter ratio (L/D) greater than 40 is long pile, otherwise is common pile. The publications (Li *et al.* 2016, Feng *et al.* 2016) pointed out that the characteristics of long piles are different from common piles , and should be specially studied. The papers (Cong and Zhijian 2015, Qian *et al.* 2013, Catal 2014) are shown that due to the influence of pile construction technology, soil properties, pile material, and load, the mechanism of pile-soil stress transmission is still a difficult point in design. The influence factors of long piles are relatively complex, and their deformation characteristics and load transfer mechanisms are difficult to determine. The publications (Dias 2016, Saha *et al.* 2015, Fattah *et al.* 2017) are indicated that no better calculation theory and method can be used to accurately quantify the stress of long piles and simulate the entire deformation process. Catal (2015) expressed that the load transfer mechanism of long rock-socketed pile is still in the research stage, and its design still uses the theory of common piles. The papers (Li 2015, Tung *et al.* 2015) has been described that the static load test of pile foundation is the most effective and reliable method to study the bearing behavior of long rock-socketed piles.

2. Large tonnage pile foundation load test system design

In this study, an independent test pile was set at the center of the pile group, and the engineering pile was used

Fig. 1 In-situ photo of anchor pile reaction system

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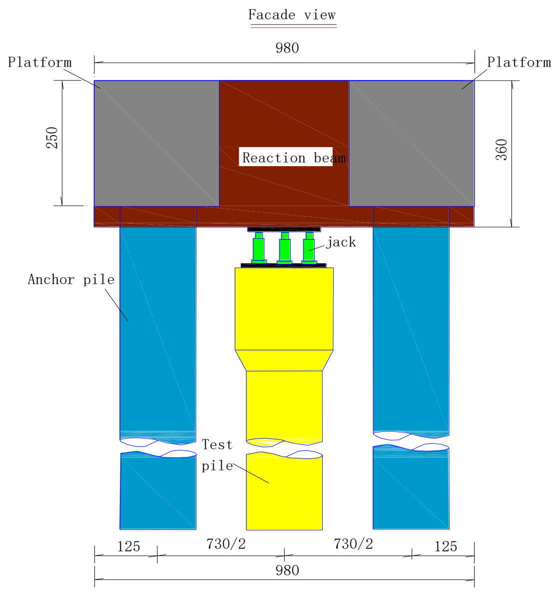


Fig. 2 Elevation of anchorage reaction system

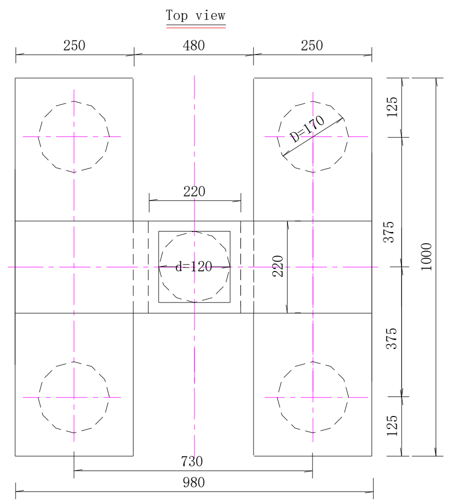


Fig. 3 Plane layout of anchor pile reaction system

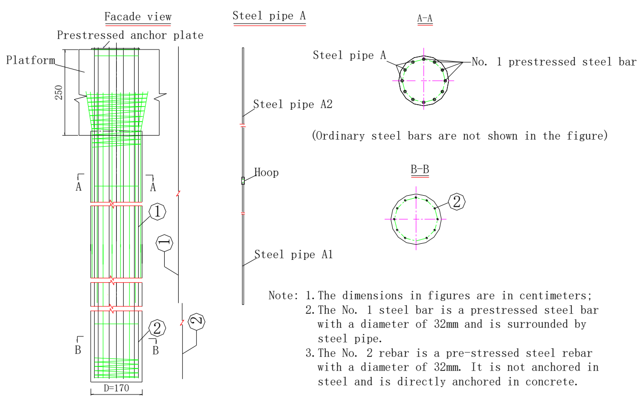
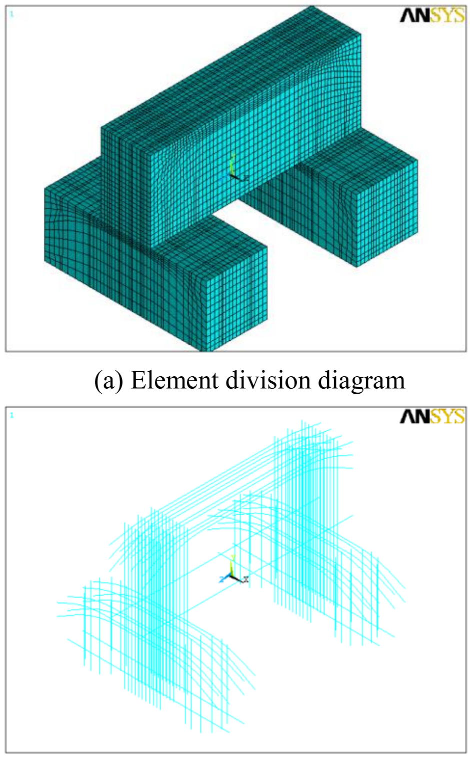


Fig. 4 Anchored pile prestressed steel bars layout

as the anchor pile. The diameter of the test pile is the same as the diameter of the engineering pile, as shown in Figs. 1-4. In order to overcome the shortcomings of traditional testing methods, the precise prestressing technology in this study greatly improved the crack resistance of the anchor pile. After the test, the prestressed steel bars can be removed and reused. In order to avoid the instability of the test load and the damage of the test pile concrete during the loading process, a reinforced concrete pile cap is added to the pile. The round pile is converted into a square pile cap according to the size of the jack.

3. Finite element simulation analysis

The ANSYS finite element software is used to establish the calculation and analysis model. The finite element model has a total of 38607 elements. The calculation analysis model is shown in Fig. 5.



(a) Element division diagram

(b) Prestressed steel bars

Fig. 5 Computational analysis model

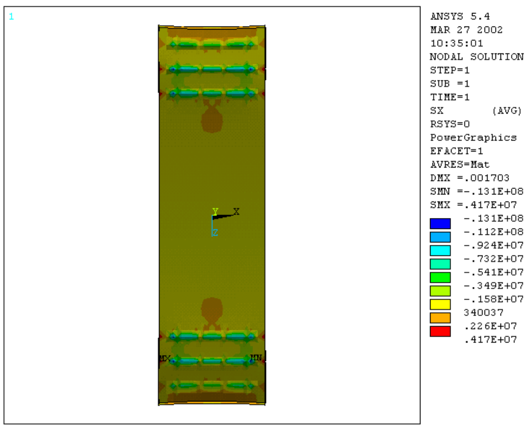


Fig. 6 Normal stress distribution on top surface of reaction beam

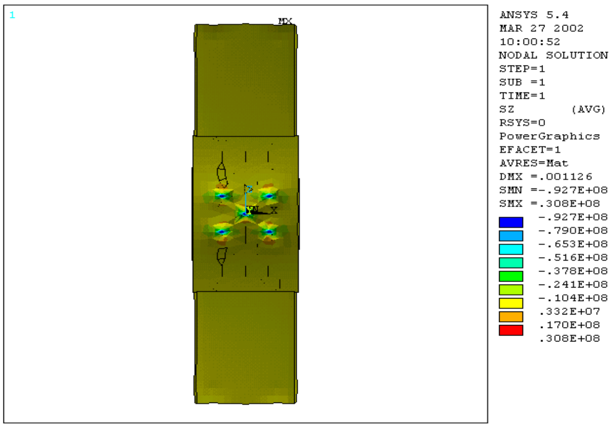


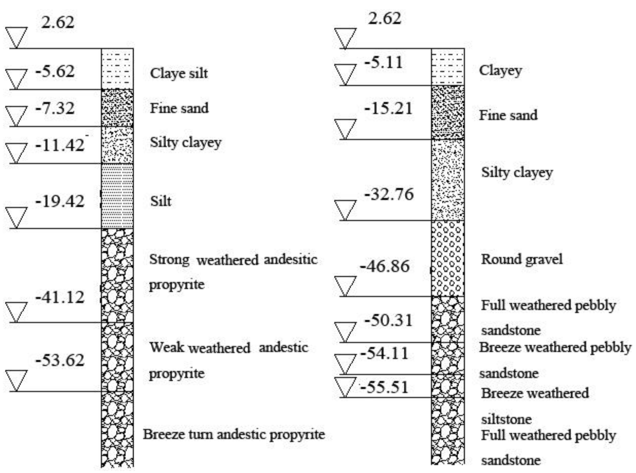
Fig. 7 Normal stress distribution at the bottom of reaction beam

The calculation results show that the reaction force system can meet the needs of experimental testing. In the case of prestressed load (Simulated by temperature), self-weight and test load, the normal stress distribution on the top and bottom of the reaction beam is shown in Figs. 6 and 7, respectively.

4. Test pile design

4.1 Engineering geological condition

According to the soil conditions and engineering geology characteristics, two representative test piles (2#, 3# test pile) were selected for testing. The geological conditions of the test piles are shown in Fig. 8.



(a) 2# test pile (b) 3# test pile

Fig. 8 Geologic columns of test piles (unit: m)

Table 1 2# test pile parameters

Pile type	Amount	Design length (m)	Diameter (m)	Concrete grade	Load (kN)
Test pile	1	63.32	1.2	C30	33000
Anchor pile	4	63.50	1.7	C30	

Table 2 3# test pile parameters

Pile type	Amount	Design length (m)	Diameter (m)	Concrete grade	Load (kN)
Test pile	1	63.32	1.2	C30	30000
Anchor pile	4	63.50	1.7	C30	

4.2 Test pile design

4.2.1 Test piles design

Through detailed calculation, the maximum load of 2# pile is determined as 33000 kN and the maximum load of 3# pile is determined as 30000 KN. The diameter and length of the test piles are shown in Tables 1 and 2.

4.2.2 Test loading system

The loading system consists of anchor piles, pile caps and counter-forced beams and can withstand a concentrated load of 36,000 kN. With jack loading, the maximum vertical load capacity is designed to be 40000 kN.

5. Test measuring system

In order to test the accurate pile top settlement value, a special benchmark beam was installed as the base of the displacement sensor and separated from the test pile reaction force system. The load test layout is shown in Figs. 9 and 10.

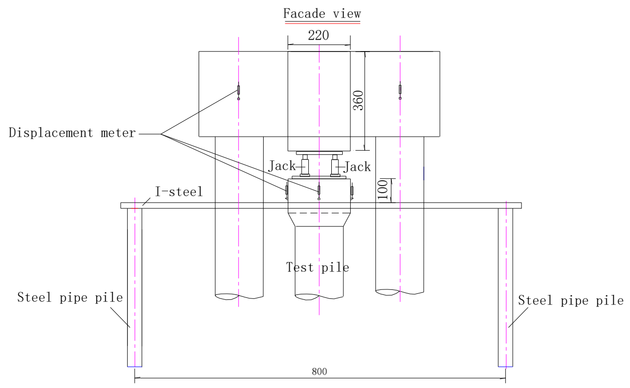


Fig. 9 Load test layout elevation view

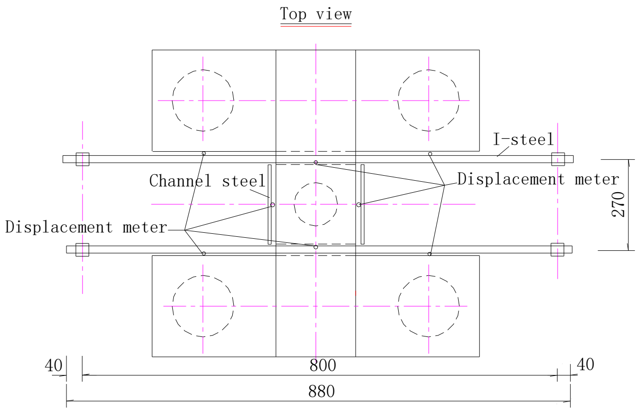


Fig. 10 Load test layout plan view

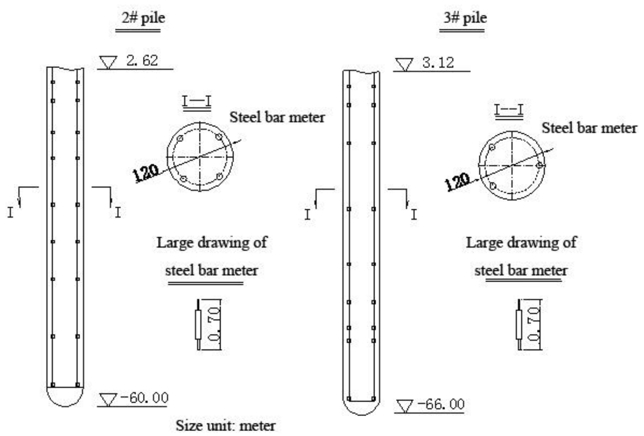


Fig. 11 Steel bar meter layout position

5.1 Loading system

Use static load system to controll load process: multi channel sensor were installed on jack to controll each class of load and supplementary load automaticly.

5.2 Displacement measuring system

(1) Benchmark beam

To ensure accuracy of displacement measurement, benchmark beam need to have enough stiffness and stability. In this study, the benchmark beam was made of I-beam and four steel pipe piles were used as the foundation of benchmark beam.

(2) Settlement measurement

Four vertical displacement sensors were installed on the pile top to measure the vertical displacement of the pile. The displacement sensor range was 100 mm and the accuracy was 0.01 mm.

(3) Anchor pile pullout quantity monitoring

Four pillars type displacement sensors were installed on the top of anchor pile to observe pullout displacement of anchor pile.

(4) Reaction beam deformation monitoring

Displacement sensors are mounted on the top surface, bottom surface, and side height surfaces of the reaction beam to monitor its deformation.

5.3 Stress measuring system

Reinforced steel stress sensors were used to test the stress of steel bars in the pile foundation section. Load sensors and flat jacks were used to test the pile bottom reaction force. Four steel stress sensors, steel stress sensors and steel bars are installed at the interface of each soil layer. Set the position as shown in Fig. 11.

6. Test results analysis

6.1 Anchor pile pull-out displacement monitoring results

Under the maximum load, the pull-out displacement of the two test anchor piles is shown in Table 3. The test results show that the pull-out displacement of the anchor pile is small and much smaller than the standard value, no large deformation of the anchor pile has occurred, and the anchor pile can be used as a construction pile.

Table 3 Pullout quantity test of anchor piles under maximum load tonnage

Test pile number	Anchor pile number	W1	W2	W3	W4	standard value
2#	pull-out displacement /(mm)	1.807	1.546	1.371	1.581	100
3#	pull-out displacement /(mm)	2.130	1.819	1.686	2.020	100

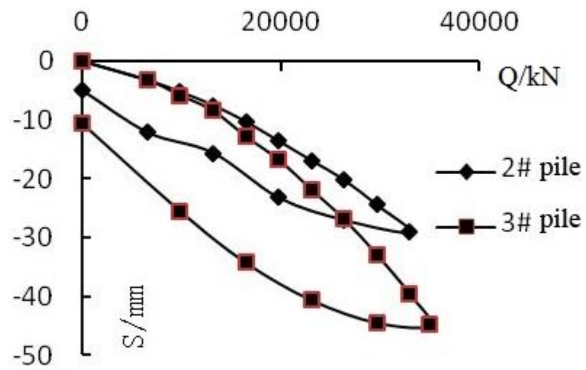


Fig. 12 Q-S curve of testing piles in vertical static load test (Q: load, S: settlement)

6.2 Vertical bearing capacity analysis

2# and 3# test piles maximum load capacity design value is 33000 kN and 30000 kN respectively. Actual load is up to 33000 kN for 2# pile and 35000 kN to 3# pile. The curve of the single pile vertical static load test of piles is shown in Fig. 12.

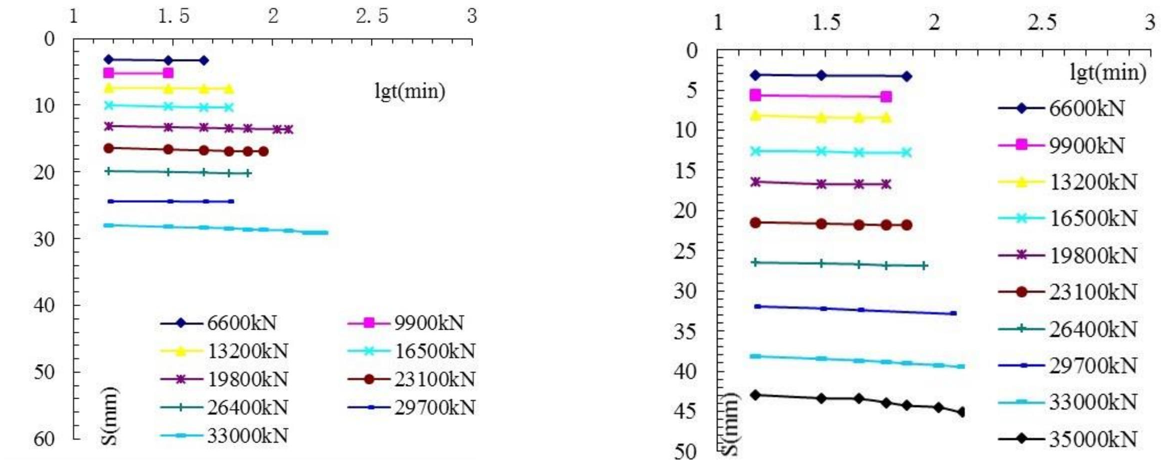
Test results analysis is as follows

(1) The Q-S curve of the two piles varies slowly, and has the characteristics of friction piles.

(2) Geological conditions on 2# pile is relatively better than 3# pile which is longer than 2# pile, And the settlement of 2# pile is significantly less than 3# pile under the same load. That means soil conditions have a greater influence on the pile settlement than pile length.

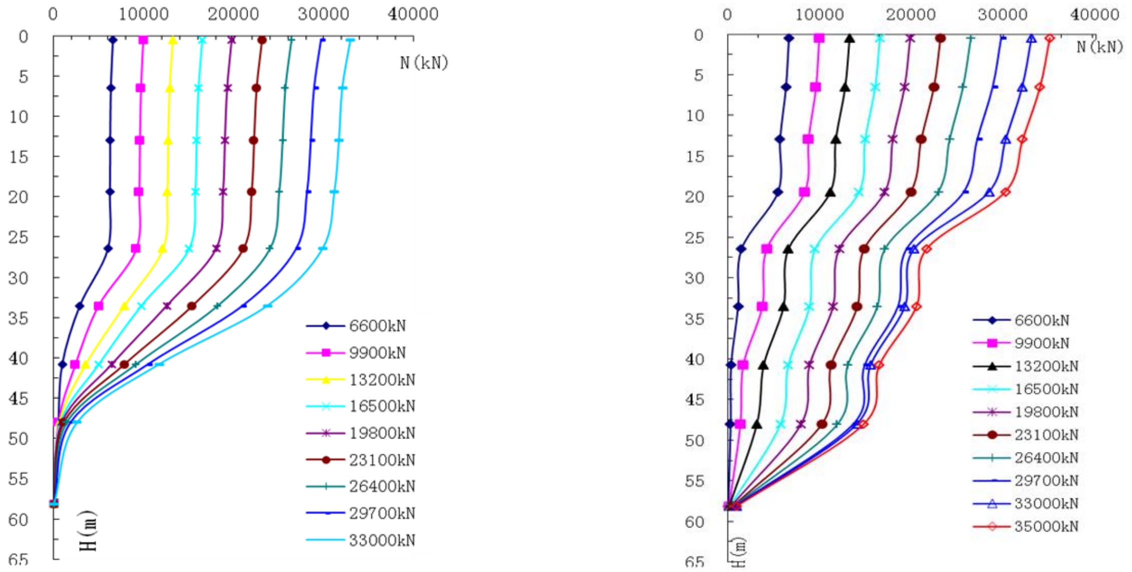
(3) The bearing capacity of 2# pile has greatly exceeded the theoretical calculated value. Apparent steep fall point has not been found from the Fig. 12 Q -S curve, visible bending down has not been found on tail in Fig. 13 curve, so taking a maximum load of 33000 *kN* as the ultimate bearing capacity of piles, corresponding settlement of pile is 29.1 mm.

(4) The bearing capacity of 3# pile has also greatly exceeded the theoretical calculated value, Apparent steep fall point has not been found from the Fig. 12 Q -S curve, visible bending down has not been found on tail in Fig. 13 curve. But the settlement is relatively large, to ensure safety taking Q= 33000 kN as ultimate bearing capacity. And corresponding settlement is S = 40 mm.



(a) 2# pile (b) 3# pile

Fig. 13 S-Logt curve of vertical static load



(a) 2# pile (b) 3# pile

Fig. 14 Section axial force diagram

6.3 Axial force diagram analysis

Section axial force distributing under vertical static load of test piles are shown in Fig. 14.

(1) Axial force decrease with increase of depth into soil of pile at all levels of load. And axial force at the pile end is very small, even for the rock-socketed piles, showing the mechanical properties of friction pile, which is completely different from the mechanical properties of short pile.

(2) Axial force of 2 # pile decrease fast in section under 25 m, which correspond to the engineering geology that the lower soil condition is better. The experimental results showed that the lower soil layer undertake the most of the upper loads.

7. Conclusions

According to the in-situ large tonnage load test study on vertical bearing capacity of long rock-socketed piles, conclusions and implications can be drawn as follows:

(1) The large tonnage pile foundation load test system designed in this study is reliable. The test results show that the cracks and excessive deformations of the prestressed anti-force device designed in this study have not occurred. The prestressed tendons of the anchor pile ensure that the anchor pile will not be pulled and fractured, and the prestressed tendons can be reused, thus ensuring the safety and reliability of the test;

(2) The long rock-socketed piles are not synchronous with the side resistance and bottom-resistance, that is, the lateral resistance is played before the bottom-resistance, and the long rock-socketed piles generally show the bearing characteristics of the frictional end bearing piles;

(3) The settlement of pile tops of long rock-socketed piles includes the compression, flexural deformation, and settlement of pile ends;

(4) Load-settlement curve of long rock-socked pile do not have significant damage points, settlement at the top surface of pile should be adopted as control index when confirming vertical bearing capacity.

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