Experimental study on bearing characteristics of pile foundation in loess area of Longdong

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Abstract. In order to study the bearing characteristics of pile foundation in the deep loess layer of Longdong area, field tests were carried out on the basis of a project in Huachi County, Qingyang City. Three test cast-in-place piles of the basement were selected for static load tests. The Q-S curve of the three test piles was gentle, without obvious steep drop. The S-lgt curve was arranged in a gentle and regular way, with high bearing capacity, uniform and small settlement. So it can be used as the foundation of buildings bearing large loads. In the test, the load is mainly borne by the reaction force provided by the side friction of the pile; the axial force distribution of the pile body with depth is not only related to the load on the top of the pile, but also to the nature of the soil around the pile.

1. Introduction
In recent years, with the western development continued to advance and the development of urban construction in the western region, the proportion of high-rise and large load buildings in the construction projects is growing. Pile foundation is widely used because of its high bearing capacity, small settlement and other excellent performance. At present, many experts, scholars and engineers mainly start with the collapsibility of loess for studying the pile foundation in the area of super thick loess, analyze the characteristics of negative friction on the side of pile and the methods of foundation treatment, and make some achievements. Such as Zhu Yanpeng et al.[1] analyzed the change characteristics of negative friction on the side of pile and the settlement process of soil in different depth and range through the immersion test of pile foundation. Huang Xuefeng et al.[2] concluded that there was no clear corresponding relationship between the negative friction value and the site's collapsible type and collapsible amount. Yang Xiaohui et al.[3] studied the treatment depth and collapsible evaluation for collapse loess foundation with large thickness. Fei Hongqing[4], Xie Yongjian [5], Wang Donghong[6], etc. studied the engineering performance of super long bored pile in loess foundation. For pile foundation, Zhang Yan et al.[7-8] believed that the distribution of pile side friction along the pile body has no negative friction in general. But at present, the study of pile foundation performance on loess layer is very scarce in Qingyang area, and there is no systematic theoretical method. Therefore, it is necessary to study and analyze the bearing capacity and settlement of pile body in detail through field test.
2. The field test

2.1. The general situation of engineering
In order to define the vertical compressive bearing capacity of single pile and determine whether the pile foundation can provide sufficient bearing capacity for the upper structure, the field test is carried out based on a project in Huachi County, Qingyang City. The foundation soil is slightly corrosive to the concrete structure and the steel bars in the concrete structure, belonging to the self weight collapsible loess site, with the collapsible grade of II and the collapsible degree of medium. The building belongs to class C. The standard depth of frozen soil is 820mm. Drilling within the control depth, the mechanical properties of the site soil layer from top to bottom are shown in Table 1.

Table 1. Statistical table of stratigraphic stratification

| stratigraphic numbering | stratigraphic name | average thickness (m) | Characteristic value of bearing capacity | ultimate friction of pile end (kpa) | ultimate friction of pile side (kpa) |
|-------------------------|--------------------|-----------------------|------------------------------------------|-----------------------------------|-----------------------------------|
| 1                       | miscellaneous fill soil | 6.06 | 80 | -- | -10 |
| 2                       | loess silt | 5.59 | 105 | -- | -10 |
| 3                       | breccia | 0.65 | 230 | 2200 | 135 |
| 4                       | silty mudstone | 1.28 | 200 | 1240 | 140 |
| 5                       | pelitic siltstone | 5.33 | 500 | 3000 | 160 |

2.2. Experimental scheme
Three test piles of the basement are selected. They are cast-in-place piles with mechanical holes. The concrete grade is C30, and the thickness of reinforced concrete protective layer of piles is 50mm. The bearing stratum at the pile end is argillaceous siltstone of moderately weathered-slightly weathered. The diameter of pile is 800mm, the length is 11m, the diameter of expanding bottom is 1600mm, and the characteristic value is 2450kN. During pile construction, piles are formed at one time without construction joints.

2.3. Testing process
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2.3.1. Static load test. The stacking method is adopted in the test. The loading reaction system of the test is stacking concrete blocks on the loading platform. The hydraulic jack is used in the loading process, and the resultant force of the jack passes through the center of the test pile. A steel wire rope is welded at the tip of the pile, and the steel wire rope is led outside the pile head. During the static load test, the falling distance of the steel wire rope measured is the settlement of the pile. In the test, the method of slow maintaining load is adopted. After each level of load reaches relative stability, the next level of load is applied until the load of the test pile reaches the ultimate bearing capacity or the pile body is damaged, and then the load is discharged to 0 level by level.
2.3.2. The test on axial force. In order to measure the stress changes of concrete and steel bars in the whole test process, steel strain gauge is arranged in the pile body. For drawing forth the wire of connecting strain gauge and preventing the wire from being damaged during pile pressing, 3 round holes are drilled at the side of pile top. One strain gauge shall be pasted at an interval of 1m along the pile body, 12 in each row, 3 at the same height, 36 in total. Each test pile is vertically arranged with a steel strain gauge on the axial symmetrical steel bar and welded on the longitudinal steel bar of the test pile. The arrangement and distribution position of the pile body sensor are shown in Figure 1. In the process of the test, the automatic test system is used for the whole process of synchronous data collection, and the internal force of the pile body is observed, so as to clearly detect the changes of the internal force on each position of the pile body under the load.

Figure 1. Layout of strain gauge.

3. Analysis of test results

3.1. The settlement characteristics of single pile

Three test piles were tested for vertical compressive bearing capacity of single pile, and the Q-S curve and S-lgt curve of vertical static load test of single pile were obtained as shown in figure 2-4.

Figure 2. Q-S and S-lgt curve of No.1 test pile.

Figure 3. Q-S and S-lgt curve of No.2 test pile.
Figure 4. Q-S and S-lgt curve of No.3 test pile.

It can be seen that the three test piles show typical characteristics of friction piles. The Q-S curves are all of slow variation type, without obvious steep drop section. When the load is 4900 kN, the ultimate failure is not reached, and the settlement of three trial piles respectively is 12.24, 15.44 and 18.64 mm. According to the specific loading conditions of the test site, the maximum loading value of the test has reached the design requirements (The super high-rise building on the upper part requires that the bearing capacity of single pile is 2400 kN), so the lower load has not been loaded continuously due to comprehensive consideration. The similarity of Q-S curves of three piles is high, and they all have the trend of continuous development, so it is judged that the vertical ultimate compressive bearing capacity of single pile should be greater than 4900 kN. Dividing the vertical ultimate bearing capacity of single pile by safety factor 2 is the characteristic value of vertical bearing capacity, so it is judged that the characteristic value of vertical compressive bearing capacity of single pile is greater than 2400 kN. Through the comparison between the test results and the design requirements, the bearing capacity of single pile meets the requirements, which shows that the pile foundation can provide sufficient bearing capacity for the upper structure, and can be used as the foundation of super high-rise buildings. The bearing capacity of the test pile has not been fully developed. To some extent, there is still room for rise and no obvious steep drop section, so there is still a lot of surplus.

3.2. Distribution law of axial force

In the test, the strain of reinforcement at the corresponding depth can be measured directly, so the stress of a certain section on the pile body can be calculated indirectly by Hooke's law. By multiplying the obtained stress value of concrete and the corresponding section of the reinforcement by their respective cross-sectional areas, the internal force of the section from the reinforcement and the concrete can be obtained. The sum is the axial force of the pile body on the section. Similarly, the distribution curve of pile’s axial force along the depth can be obtained under each level of load, as shown in Figure 5.
Figure 5. The distribution curve of pile’s axial force along depth

Under the stage by stage load, it can be seen that the axial force of the three test piles decreases with the increase of depth and decreases at different speeds in different soil layers from figure 5.

4. Conclusion

Through the field static load test of single pile in Qingyang Loess Area, the following conclusions are obtained:

- The test results show that the single pile has a high bearing capacity, and the settlement is relatively uniform and small, which can be used as a building foundation bearing a large load. The Q-S curves of three test piles are gentle without obvious steep drop, and the S-lgt curves are arranged in a gentle and regular way, so the ultimate bearing capacity of each pile is not less than 4900kN, which is much larger than the ultimate bearing capacity of single pile calculated by design.

- The test pile belongs to friction pile, the axial force of the pile body is not transmitted to the pile end, the bearing capacity of the pile end is 0, and the load is mainly borne by the reaction force provided by the side friction of the pile; the axial force distribution of the pile body with depth is not only related to the size of the load on the top of the pile, but also to the nature of the soil around the pile.

Acknowledgements

This research was financially supported by Scientific research projects of colleges and universities in Gansu Province (Grant NO. 2016A-084) and Longdong University Youth Science and Technology Innovation Project (Grant NO. XYZK1803).
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