Experimental study on vertical bearing capacity of pile foundation in east Gansu Province loess area

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Abstract. To explore the vertical bearing capacity of pile foundations in the loess area, relying on the new construction project, a single pile vertical compressive bearing capacity field test was conducted on three test piles, and the Q-S curve and S-lgt curve of the single pile vertical static load test. The analysis and research showed that the axial force of the three test piles had not been transmitted to the pile end, and the load was mainly borne by the reaction force provided by the frictional resistance of the pile side. The distribution of the axial force of the pile with depth is not only related to the size of the pile top load, but the nature of the soil around the pile is related to the typical friction pile characteristics, and the Q-S curves all show a slow-change type with no obvious steep drop. When loading 4900kN, none of them reached the ultimate failure, and the settlements of the three trial-installed piles were 12.24, 15.44 and 18.64mm, respectively. By comparing the test results with the design requirements, the bearing capacity of the single pile meets the requirements, indicating that in the loess area, the single pile has a higher bearing capacity, and the settlement is more uniform and the settlement is small, which can be used as a building foundation to bear a larger load.

1. Introduction
Loess is a terrestrial soil-like deposit formed during the Quaternary period, with a grayish yellow, brownish yellow, or brownish red color, large porosity, and vertical joints and tubular channels. The loess structural strength is higher under natural water content and can maintain a high vertical slope, but the loess is rich in carbonates and has weak corrosion resistance. The newly formed loess is collapsible and is easily eroded by running water. [1]. Loess is widely distributed in the world, covering more than 2.5% of the global continent, and is distributed in a belt from east to west in the temperate semi-arid and desert frontal zone. The loess landform mainly includes loess gullies, loess valleys and unique loess eroded landforms, which can be divided into loess plateaus, beams, ridges, valley terraces, alluvial or flood plains [2]. China's loess area is about 640,000 square kilometers, which is the most widely distributed area in the world, mainly distributed in the northwest region and the middle reaches of the Yellow River. Among them, Gansu, Shanxi, Shaanxi, Henan and other places are typical loess distribution areas with a wide area and thickness. The loess is comprehensive and continuous, followed by the North China Plain and the southern part of the Northeast, while the loess layer in the Qingyang area of northwest China is the thickest and most complete with continuous distribution. Its
characteristics are more typical. Loess is inseparable from the multiplication of human civilization and social production and development.

In recent years, with the continuous advancement of the western development and the development of urban construction in the western region, the construction of large-scale construction projects such as high-rise buildings, highways, and high-speed railways has continued to land in Gansu Province. Pile foundation is widely used because of its high bearing capacity, small settlement and other excellent properties. However, the bearing characteristics and settlement characteristics of different soils and their interaction with piles are also very different. Considering the soil near the actual engineering foundation the resistance and friction at the bottom of the bearing platform can already largely resist the horizontal load transmitted by the superstructure [3]. Therefore, the focus of the bearing capacity of the pile foundation should be on the vertical load problem. In the study of pile foundation abroad, some theoretical and numerical calculation methods for single piles and group piles under vertical load have been perfected, such as the finite element method adopted by Guo and Randolph in 1999 [4] and Salgado in 2013 Iterative method of variational method [5], etc.; Hua Zummeng et al. [6] When designing pile foundations in this area, most of the values adopt the parameters recommended by the current pile foundation codes, such as the characteristic value of single pile bearing capacity The lateral friction resistance of the layered loess is the initial value of the static sounding test in the reference regulation [7]. This is inevitably inconsistent with the actual situation, and the standard value is generally conservative, which is likely to cause greater waste. According to the requirements of the current specification [8], for the Grade A building pile foundation and the Grade B building pile foundation with more complicated site conditions, the vertical ultimate bearing capacity of a single pile should be determined by a single pile static load test. Based on the above situation, accurately determining the bearing capacity of the pile foundation in this area, and researching and analyzing the working performance of the pile foundation under the geological conditions in this area are urgent problems to be solved at this stage. As for the pile foundation, Zhang Yan et al. Believe that under normal circumstances, the distribution of pile-side frictional resistance along the pile body has no negative frictional resistance [9-11]. At present, there is very little research on the performance of pile foundations on the loess layer in Qingyang area, and there is no systematic theoretical method. Therefore, it is necessary to conduct detailed research and analysis on the vertical bearing capacity and pile settlement of the pile through field tests.

2. In-situ test of vertical bearing capacity of pile foundation

2.1. project profile

In order to determine the vertical compressive bearing capacity of the single pile at the site, and to determine whether the pile foundation can provide sufficient bearing capacity for the superstructure, the field test relied on the construction of the first middle school (new construction) of Huachi County, Qingyang City. The test site It is Class II, without liquefied soil layer, and no groundwater is exposed within the survey depth. The foundation soil is slightly corrosive to the concrete structure and the steel bars in the concrete structure, and belongs to the self-weight collapsible loess field. The collapsible level is II. The degree of collapsing is moderate. The building is a Class C building. The standard depth of frozen soil is 820mm. Drilling within the controlled depth, the soil layer of the site from top to bottom is:

1. Miscellaneous fill soil layer: mottled, slightly wet, loose.
2. Loess-like silty layer: yellowish brown, slightly wet, slightly dense, hard plastic, mainly silty, with collapsibility.
3. Boulders: variegated, relatively uniform, slightly dense-medium dense, slightly wet.
4. Silty mudstone: amaranth-brown-red, massive, sandy structure, slightly wet.
5. Muddy siltstone: off-white to dark gray, massive, this layer is the bearing layer at the pile end. Its mechanical properties are shown in Table 1.1.
Table 2.1 Stratification statistics table

| Layer number | Layer name               | The average thickness (m) | Characteristic value of bearing capacity (kPa) | Pile ultimate resistance (kPa) | Pile ultimate side friction resistance (kPa) |
|--------------|--------------------------|--------------------------|-----------------------------------------------|-------------------------------|---------------------------------------------|
| 1            | Miscellaneous soil layer | 6.06                     | 80                                            | -10                           | -10                                         |
| 2            | Loess-like silty layer   | 7.59                     | 105                                           | -10                           | -10                                         |
| 3            | Breccia                  | 0.65                     | 230                                           | 2200                          | 135                                         |
| 4            | Silty mudstone           | 2.28                     | 200                                           | 1240                          | 140                                         |
| 5            | Argillaceous siltstone  | 5.33                     | 500                                           | 3000                          | 160                                         |

2.2. Test plan

Three test piles in the basement of the teaching building are selected. The test piles are made of C30 concrete piles with mechanical hole filling and the reinforced concrete protective layer thickness is 50mm. The bearing layer at the pile end is moderately weathered-slightly weathered muddy siltstone. The diameter of the pile is 800mm, the length is 11m, the diameter of the expanded base is 1600mm, and the characteristic value is 2450kN. The piles were piled at one time during construction, and no construction joints were left. The inspection results showed that the piles were all Class I piles. During the process of digging holes, rainwater and surface water shall be strictly prevented from flowing into the pile holes. Before the foundation construction, the ground mixed soil is rolled to a compaction coefficient of not less than 0.94. The natural ground after the ground rolling is lower than the pile top elevation by plain soil backfill to 600mm above the pile top elevation. The backfill soil is divided into compact once every 1m of thickness until the compaction coefficient is not less than 0.94, and then position the piles. The middle part of the foundation to the building surface is backfilled with plain soil and compacted in layers. When backfilled to 1.2m away from the building surface, 2: 8 lime soil is used to backfill to the building surface and compacted in layers.

3. Test operation requirements

3.1. Flat static load test

The test adopts the stacking method. The stacking platform is composed of truss, main beam, I-beam and springboard. The loading reaction system of the test is to stack concrete blocks on the stacking platform, as shown in Figure 2.1. The hydraulic jack is used for loading, and the pressure value is read by the calibrated pressure gauge. Displacement observation uses a reference beam and a more sensitive dial indicator. During the entire static load test process, the static load tester always records the pressure value automatically. The pile top settlement Q-S and other curves are automatically drawn by the instrument. A steel wire rope is welded at the pile end. The wire rope is led out of the pile head. During the static load test, the drop distance of the wire rope is the settlement of the pile end. The test adopts the method of slow-maintenance load loading. After the load of each stage reaches relative stability, the next-stage load is applied until the load of the test pile reaches the ultimate bearing capacity or the pile body fails, and then the unloading is graded to. In the test, the static load test loading and observation methods are as follows:

1. Hierarchical loading: Hierarchical loading is carried out in accordance with 1/10 to 1/15 of the estimated limit load, and the first-stage load is twice that of the hierarchical load.

2. Settlement observation: after the loading of each stage, the pile top settlement is read every 5min, 10min and 15min, and then the pile top settlement is recorded every 15min, and the data is read every 0.5h after 1h.

3. Standard for relatively stable settlement: Under the action of each level of load, if the pile top settlement is less than 0.1mm twice per hour, it can be regarded as stable.
(4) Termination loading conditions: when there is a steep drop section on the Q-S curve that can determine the ultimate bearing capacity, and the total settlement of the pile top exceeds 40mm; under the action of a certain level of load, the settlement of the pile top is not less than the previous level. Under the action, the settlement of the pile top is twice. And after 24h, the stability has not been reached; the pile top fracturing or other conditions indicate that the pile body has been crushed or reached the maximum load required by the design.

3.2. Pile axial force test

In order to measure the stress change of the concrete and steel bars of the pile during the whole test, a steel bar strain gauge was arranged in the pile. In order to facilitate the drawing of the wires connecting the strain gauges and to prevent the wires from being damaged when the pile is pressed, 3 round holes are drilled on the side of the pile top. Attach a strain gauge at a distance of 1m along the pile body, a total of 12 per column, and 3 at the same height, a total of 36. Each test pile is vertically arranged with steel strain gauges on axially symmetrical steel bars and welded to the test pile longitudinal bars. The arrangement and distribution of the pile body sensors are shown in Figure 2.2. In the test process, an automated test system is used to collect data synchronously throughout the process, and the internal force of the pile body is observed in order to clearly detect the change of the internal force of each position of the pile body under the load.

Conduct resistance measurement and calibration for each strain gauge; use a polishing machine to polish the surface of the pile body to the strain gauge smooth, fixed point number; Clean, then use 502 glue to paste the strain gauge on the inner wall of the pile body, and finally use the terminal to weld the lead wire and the strain gauge together; apply 703 glue on the surface of the strain gauge to ensure the insulation and moisture resistance of the strain gauge; after the strain gauge is pasted, Measure the resistance value of each one, and open the side of the pile top to lead the wire.

4. Analysis of test results

4.1. Load-settlement characteristics of single pile

Three vertical piles were tested for vertical compressive bearing capacity of single pile, and the Q-S curve and S-lgt curve of the single pile vertical static load test were obtained as shown in Figure 3.1 to Figure 3.3. The three test piles exhibited typical friction pile characteristics, and their Q-S curves all showed a slow-changing type without obvious steep drop. When loading 4900kN, none of them reached the ultimate failure, and the settlements of the three trial-installed piles were 12.24, 15.44 and 18.64mm, respectively.

According to the specific loading situation on the test site, it can be seen that the maximum load value of the test has reached the design requirement of 2400kN, and the lower load is not continued to be loaded due to comprehensive consideration. The Q-S curve similarity of the three test piles is
relatively high, and they all continue to develop. Therefore, the vertical ultimate compressive bearing capacity of a single pile should be greater than 4900kN. The vertical limit bearing capacity of a single pile is divided by the safety factor, which is the characteristic value of the vertical bearing capacity of a single pile. Therefore, the characteristic value of the vertical compressive bearing capacity of a single pile is judged to be greater than 2400kN. By comparing the test results with the design requirements, the bearing capacity of the single pile meets the requirements, indicating that the pile foundation can provide sufficient bearing capacity for the superstructure, and the bearing capacity of the test pile has not been fully exerted, and to some extent there is a certain safety reserve.

Figure 4.1 Q-S curve and S-lgt curve of 1 # test pile

Figure 4.2 Q-S curve and S-lgt curve of 2 # test pile

Figure 4.3 Q-s curve and S-lgt curve of 3 # test pile
4.2. Distribution law of axial force of pile body
In the test, the strain of the steel bar at the corresponding depth can be directly measured, so the stress of a concrete section of the pile body can be calculated indirectly by Hooke's law, and the obtained concrete stress value and the stress value of the corresponding section steel bar are multiplied by their respective cuts Area, you can get the internal force of the steel bar and concrete of the section, add the two, it is the axial force of the pile body of the section. Similarly, the distribution curve of the axial force of the pile body along the depth under each load can be obtained, as shown in Figure 3.4. The experiment proves that under the step-by-step load, the axial forces of the three test piles all show the law of decreasing with increasing depth and decreasing at different speeds in different soil layers.

5. Conclusion
The test results show that in this loess area, the single pile has a higher bearing capacity, and the settlement is more uniform and the settlement is small, which can be used as the foundation of a building that bears a larger load. The QS curve of the three test piles is gentle, and there is no obvious steep drop. The S-Igt curve is arranged gently and regularly, so the single pile ultimate bearing capacity of each pile is not less than 4900kN, which is better than the calculated single pile ultimate bearing capacity. Much bigger.

The test pile is a friction type 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 friction of the pile side; Related, and related to the nature of the soil around the pile.

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