The Study on Structure Design and Bearing Behavior Simulation of Pier Foundation for Variable Cross-Section and Post-installed Fastening by Spiral Spray Indentation

Han Shang-yu¹, Li Kai-ren¹, Yan Hao¹, Chen Jia-shen¹

¹College of Civil Engineering, Nanchang Hangkong University, Nanchang 330063, China

[Biography ] HAN Shang Yu (1978-), male, Doctor, Associate Professor. E-mail: 55932942@qq.com

[Corresponding Author] LI Kai Ren (1994- ), male, Master Graduate Student. E-mail: 1587441573@qq.com

Abstract: According to the stress characteristics of pier foundation, the research designs a structure of pier foundation for variable cross-section and post-installed fastening by spiral spray indentation, and its mechanical characteristics and construction technology is analyzed. By means of finite element analysis, structure of pier foundation for variable cross-section and post-installed fastening by spiral spray indentation and conventional pier foundation structure in vertical compressive bearing capacity and uplift bearing capacity of differences are analyzed. It is found that the new design structure is better than the conventional pier foundation, and the vertical load-bearing capacity and the load bearing capacity are improved, and the new design structure engineering benefits are verified.

1. Introduction

In civil engineering, the foundation form of the foundation mainly consists of a shallow foundation and a pile foundation. The shallow foundation depth is usually less than 3 meters, and the length of the pile foundation is usually greater than 6 m. For foundation treatment projects with a foundation depth of 3 m to 6 m, if the design is based on a shallow foundation, the bearing capacity of the foundation is difficult to meet the design requirements; if the design is based on the pile foundation, the pile foundation cannot fully exert its bearing capacity, resulting in a certain Engineering waste. In order to better solve such ground treatment engineering problems, mechanical drilling or manual digging can be used to form holes, and the concrete is poured into a pier foundation having a length of more than 3 m and less than 6 m or a length of less than 6 times.

At present, scholars have studied the design points, bearing characteristics, failure modes and construction techniques of pier foundations. For example, Wang Jihui et al. [1-5] have defined the definition of pier foundations and studied the design points and construction measures of pier foundations; Liu Zhongchang et al. [6] studied the new failure model of the bearing capacity of the pier foundation on the cohesive soil; Shen Yongli et al. [7] studied the construction technology of the pier foundation in the water according to the characteristics of bare rock bed and low pile cap; Shi Jiuzhou et al. [8] relied on the Luojiajiawan Bridge project to study the foundation construction plan of the main pier of the bridge; Ying et al. [9] reviewed the research progress of the bearing characteristics of...
large-diameter piles for the test and theory of large-diameter piles. The above research shows that although the pier foundation has been widely used in geotechnical engineering and achieved certain engineering application benefits, due to the small depth of the pier foundation, it is difficult to effectively exert the bearing capacity of the pier end and the pier side soil. To some extent, the promotion and application of the pier foundation has been restricted, and there are still some gaps and certain limitations for the research of the foundation of the variable section pier. In view of this, based on the structural characteristics of the existing pier foundation, this paper designs a basic structure of the anchor pier after the rotary jet injection into the variable section, and analyzes the construction technology and bearing capacity of the structure.

2. Design of pier foundation for variable cross-section and post-installed fastening by spiral spray indentation

2.1 construction technique
In order to give full play to the bearing capacity of the soil at the side and bottom, and improve the uplift performance of pier foundation, the structural improvement design of pier foundation is carried out, and the schematic diagram of the design is shown in Fig 1.

![Schematic diagram of structure cross-section](image)

(Note: 1 - design pier; 2 pier top cap; 3- pier top cap steel bar; 4-anchor bar; 5-anchor; 6- pier top anchor pad; 7- swirling anchor hole; 8- pier side grouting body; 9- bottom connection body; 10-sole side connecting rib; 11-dock bottom anchoring hole; 12-designing pier surrounding soil; 13-designing pier bottom soil)

2.2 Structural stress performance characteristics
(1) The structure is provided with the bottom connection body at the bottom of the design pier and the pier side grouting body on the outer side, which can effectively improve the bearing capacity of the design pier and surrounding soil and improve the stress characteristics of the design pier.

(2) The anchoring reinforcement is set between the design pier and the soil at the bottom of the design pier, and the tensile force is applied to the anchor steel bar, which can effectively improve the ability of the design pier to resist lateral load.

(3) The structure connects the anchor steel bar and the pier top cap steel bar, and then the concrete pier of the pier cap platform can greatly improve the connection strength between the design pier and the upper structure.
3. Construction Technology Analysis of pier foundation for variable cross-section and post-installed fastening by spiral spray indentation

3.1 Construction process

The construction process of the pier foundation for variable cross-section and post-installed fastening by spiral spray indentation is shown in Figure 2.

1) Construction preparation
   - Site engineering survey
   - Prepare construction materials
   - Excavation mud storage pool

2) Design pier preparation
   - Size by design
   - Preset corresponding component

3) Design pier sinking
   - Drilling bottom anchor hole
   - Insert anchor bar
   - Grouting at the bottom anchor hole

4) Anchored steel bar construction
   - Set pressure water ring
   - Pressure design pier

5) Pier bottom joint construction
   - Post-injection pipe
   - Pressure grouting

6) Anchored steel bar

7) Pier side grouting construction

8) Pier cap construction

Fig. 2 Construction process flow chart

3.2 Construction quality control points

1) Design pier preparation: According to the bearing requirements of the design pier, we can determine the height and section size of the design pier, prepare the design pier with variable cross section in the prefabrication plant, and set the internal swirling anchor hole along the ring direction. The pier side connecting ribs and the pier side grouting pipes are set on the outer side of the design pier. The pier top anchor pad plates are arranged at the top of the design pier.

2) Design pier sinking: firstly set 2~3 water stop rings on the side wall of the pressure water pipe, then insert the pressure water pipe into the swirling anchoring hole, pressurize the pressure water pipe through the high pressure water injection equipment, and wash the soil surrounding the design pier; While flushing the soil around the design pier, the static pressure device is used to apply vertical downward pressure to the design pier and press to the design depth. The structural section of the design pier is completed as shown in Fig 3.
Fig. 3 Schematic diagram of the structure section of the design pier foundation sinking
(Note: 1 - design pier; 6 - pier top anchor plate; 7 - swirling anchor hole; 10 - pier side connecting rib; 12 - design pier surrounding soil; 13 - design pier bottom soil; 14 - pressure water pipe; 15-water ring)

3) Anchored steel bar construction: After the design pier sinks to the set depth, the pressure water pipe is taken out, and the drilling anchor hole is drilled along the rotary injection anchor hole to the bottom of the design pier. The anchor hole at the bottom of the pier is cleaned and then swirled. Anchoring steel bars are inserted into anchor holes and anchor holes in the bottom of the pier, and the anchoring holes are formed by grouting the anchor holes in the bottom of the pier.

4) Construction of pier bottom joint: grouting is applied to the bottom of the design pier through the post-grouting pipe to solidify the bottom sediment and form the pier bottom joint to improve the bearing capacity of the design pier. The structural section of the pier bottom joint is completed as shown in Figure 4.

Fig. 4 Schematic diagram of the construction of the bottom connection of pier foundation
(Note:1 - design pier; 4-anchor bar; 6 - pier top anchor plate; 7 - swirling anchor hole; 9- bottom connection body;10 - pier side connecting rib; 11-dock bottom anchoring hole; 12 - design pier surrounding soil; 13 - design pier bottom soil)

5) Anchoring steel bar tension: Check the spatial position of the design pier. After the anchoring section of the anchored steel bar forms the strength of the slurry, the anchoring steel bars of the free section of the pier are designed to be synchronously tensioned, and the anchoring steel bar and the pier
5) The top anchor pad are passed through the anchor. The connection with the clip is firm.

6) Pier side grouting construction: After the anchoring steel bar is tensioned, the outside of the design pier is pressure grouted by designing the pier side grouting pipe outside the pier, and the pier side grouting body is formed outside the design pier.

7) Construction of pier cap platform: After the anchor steel bar and the pier top cap steel bar are firmly connected, the concrete pouring construction of the pier cap platform is carried out to form the pier top cap.

4. Simulation analyses of bearing behavior of pier foundation for variable cross-section and post-installed fastening by spiral spray indentation

In order to compare and analyze the load-bearing characteristics of anchor pier foundation structure after rotary jet injection into the variable section, a three-dimensional model of conventional pier and design pier was established by using Midas/GTS finite element software. Vertical pressure test simulation and vertical drawing test simulation were conducted for the two models respectively.

4.1 Simulation analysis model establishment

The normal pier model has 1m diameter and 5m length. The newly designed pier model is 1m in diameter and 5m in length. The grouting body thickness of pier side and pier bottom is 0.25m, the free section of anchorage reinforcement is 5m, and the anchorage section of pier bottom is 2m. The type and thickness of the model soil layer were 4m of sandy powdery soil and 12m of soft rock. Three-dimensional model of pier soil is shown in Fig. 5 and Fig. 6.

According to the geotechnical investigation data of a project, the material parameters used in the calculation of the numerical model are determined, as shown in Table 1.

| Material name         | Elastic Modulus kN/m² | Poisson's ratio | Volumetric weight kN/m² | Cohesion kN/m² | Friction angle (°) | Constitutive model |
|-----------------------|-----------------------|-----------------|-------------------------|----------------|--------------------|--------------------|
| Sandy powdery soil    | 48000                 | 0.32            | 19                      | 18             | 30                 | Mohr-Coulomb       |
| Soft rock             | 120000                | 0.3             | 20.3                    | 50             | 30                 | Mohr-Coulomb       |
| Concrete              | 30000000              | 0.16            | 24                      | ——             | ——                 | Elasticity          |
| Cement mortar         | 20000000              | 0.25            | 23                      | ——             | ——                 | Elasticity          |
| Anchor cable          | 196000000             | 0.28            | 78.5                    | ——             | ——                 | Elasticity          |

To reduce the complexity of the model, the model adopts the following basic assumptions:
(1) All materials used in the calculation of the model are isotropic materials without considering the permeability of soil.
(2) The conventional pier model and the design pier model are simulated by concrete materials and the pier body strength is the same.

(3) The contact element is set on the pier soil contact surface, and the friction coefficient between the pier soil is unchanged in the analysis process.

(4) Anchoring effect of anchorage reinforcement is simulated by setting anchor cable to the design pier model.

4.2 Compressive bearing capacity and analysis of pier top deformation

In order to compare and analyze the performance of the anchor pier foundation structure against the vertical load settlement after the rotary jet pressing into the variable section, the vertical grading load test of the conventional pier and the design pier was carried out with a load of 382 kPa. The P-S curve of the pier is shown in Fig 7.

As can be seen from figure 7, when P is relatively small (less than 100kPa), the vertical settlement curves of conventional piers and design piers almost coincide under vertical load. With the increase of vertical load, the p-s curve of conventional piers first appears an inflection point, reaching its ultimate bearing capacity. Under the same vertical load, the settlement displacement of design pier top is smaller than that of conventional pier, the maximum settlement displacement of design pier top is 29.97mm and that of conventional pier top is 48.69mm.

This shows that under the same conditions, the design pier's compressive bearing capacity is higher than that of conventional pier, and its vertical ultimate bearing capacity is improved. The design of pier bottom connection and pier side grouting body effectively optimizes the compressive bearing capacity of pier foundation.

4.3 Analysis of uplift bearing capacity and pier top deformation

Fig. 9 reflects the corresponding relationship between the top displacement and the displacement S of the pier under the vertical pulling load P of each group.
Fig. 8 P-S curve of conventional pier and design pier

It can be found from the p-s curve that, when the initial load is relatively small, the uplift displacement of the pier top of the conventional pier and the design pier increases very little, and the pier position remains almost stable. With the increase of vertical uplift load, the displacement of pier top increases continuously. Conventional pier displacement of the pier top of S overall growth rate is faster than design pier, and the vertical load increasing, conventional pier top displacement S growth rate gradually increase, design of pier top displacement S growth rate remained stable, design of pier top on the maximum displacement is 13.17 mm, conventional pier is 21.03 mm, pulling displacement did not appear on both increased dramatically. Under the same uplift load, the uplift displacement of design pier is smaller than that of conventional pier. The design pier is superior to the conventional pier under the same pier top displacement variation.

When the vertical uplift load is applied to the top of the pier, the conventional pier mainly relies on the lateral friction resistance of the pier to provide the pulling force and resist the vertical uplift displacement of the pier. The design pier structure is provided with the grouting body at the pier side, and the anchorage reinforcement at the pier bottom. The pier side friction resistance plays a major role in the uplift of the restricted pier, while the anchorage tension and pier end resistance play a secondary role, and the three works together to improve the design pier's uplift bearing capacity.

5. Conclusions

In this paper, the research designs a structure of pier foundation for variable cross-section and post-installed fastening by spiral spray indentation, and the bearing characteristics, construction process and quality control points of the structure are systematically analyzed, and the numerical simulation results of bearing characteristics of the structure are compared, and the following conclusions are obtained.

1) Based on the bearing capacity of pier foundation structure and combination with the engineering practice, we design a rotary spray anchor pier foundation structure after pressure into the variable cross-section. The process principle of the structure is analyzed, and the construction quality control points of the structure are discussed in detail. Then the engineering practical of the design pier foundation is illustrated.

2) Through comparative analysis of the three-dimensional model load bearing characteristics simulation results of the conventional pier and the design pier, it is shown that the compressive load bearing characteristics and the tensile load bearing characteristics of the design pier structure under the same conditions are significantly superior to those of the conventional pier, and the rationality of the structural design is demonstrated.

References
[1] Wang Jihui. Talking about pile foundation and pier foundation [J]. Doors &
8

Windows,2017,(2):119-119.

[2] Shui Mia,Tang Haiyan,Hou Ximing,Xu Xiaoyun. Design and Application of Pier Foundation [J]. Chinese & Overseas Architecture,2015,(10):128-129.

[3] Wu Min. Discussion and application of pier foundation design method [J]. Engineering and Construction,2011,(3):385-387.

[4] Zou Rongbing. Analysis on the design and application of pier foundation [J]. Fujian Building Materials,2017,(6):26-29.

[5] Liu Yinmao, Yan Xianggang. Discussion on foundation design of pier [J]. Chemical Engineering Design,2015,(2):39-42.

[6] Liu Zhongchang, Zhu Fusheng, Lu Tiejun, Liu Junlin. Bearing Capacity Test of Pier Foundation in Cohesive Soil [J]. Journal of Shenyang Jianzhu University(Natural Science),2008,(5):783-787.

[7] Shen Yongli. Construction technology of pier foundation in bare rock river bed [J]. World Bridges,2016,(2):16-19.

[8] Shi Jiuzhou, Ren Yi, Ye Yisheng, Liu Qiang. Construction Technology of Main Pier Foundation for Deep water Thin Overburden in Luojiawan Bridge [J]. Construction Technology,2017,(20):54-57.

[9] Ying Yifan, Xiong Liangxiao. Review on the research progress of bearing characteristics of large diameter piles[J].Journal of Geological Hazards and Environment Preservation,2014,(2):104-112.