Engineering design and static load test of Soil filling pile with spiral cone foundation

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Abstract. This paper introduces the innovative soil filling pile with spiral cone technology, and through the soil filling pile with spiral cone foundation static load detection of phase 4 project of Bishui Gardens, Yanji City, Jilin Province, proposed the following design suggestions: When the diameter of the pile is 500mm, the length of the pile is 12-20m, the maximum settlement interval is 28.04 ~ 44.85mm; the vertical ultimate bearing capacity of single pile is 3600~4000KN. The pile can speed up the construction period, ensure the project quality and reduce the project cost. It has obvious technical advantages and has obtained good economic and social benefits. It is a new type of energy-saving and emission-reduction pile foundation with extensive application prospects.

1. Introduction

The technology of soil filling pile with spiral cone is an innovative pile technology successfully developed through comparative analysis, trial and summary, detection, and engineering practice based on absorbing the technical advantages of the rotary filling pile, screw pile, and the like. Matching with a standard spiral cone drill pipe and under the drive of a power pile driver with large torque, the patented spiral cone bit extrudes the hole from a small diameter to a pile diameter, which can significantly improve the construction hole's penetration ability, effectively compact the rock and soil layer at the pile end, and control the negative effect of soil squeezing [1-2].

The single pile bearing capacity of the soil filling pile with spiral cone is high. Compared with traditional piles under the same conditions, their pile length and diameter are reduced [3], thus ensuring the project quality, speeding up the construction period, and reducing the project cost. The construction process is as follows: (1) Align the pile driver with the pile position; (2) Start the pile driver’s power head. Under the large torque power head and pressure action, the drilling tool performs vertical downward rotary soil squeezing drilling to thoroughly squeeze the rock and soil layer at the bottom and wall of the hole; (3) Pump and pour concrete first, then slowly lift the drilling tool that continues to rotate, and keep the pump and pouring amount matching the lifting speed of the drilling tool until the designed pile top elevation; (4) Remove the drilling tools, place the reinforcing cage and press it into the designed elevation with a vibrator.

Based on the geological exploration data of the Phase IV Project of Bishui Garden in Yanji City, Jilin Province, this paper puts forward a design scheme of technology of soil filling pile with spiral cone, and concludes that the ultimate bearing capacity is significantly improved through the static load test results of the project.
2. Engineering Geology and Investigation

2.1. Phase IV Project of Bishui Garden in Yanji City, Jilin Province

2.1.1 Regional Geological Background
Yanji City is located in the eastern part of Yanji Basin and is one of the largest Mesozoic inland lake basins in the mountainous area of eastern Jilin Province, covering an area of 1500 square kilometers. The planning area's underlying bedrock is mainly Cretaceous Longjing Formation K2L, It is distributed on both sides of the valley and hilly areas of the Burhatu bira. The construction of the soil filling pile with spiral cone in the Phase IV Project of Bishui Garden is shown in Figure 1.

![Figure 1 Construction of Soil Filling Pile with Spiral Cone](image)

2.1.2 Geotechnical Engineering Investigation Report
The maximum depth controlled by this survey is 24.50 m, and the strata are miscellaneous fill, round gravel, and Cretaceous strongly weathered argillaceous siltstone and moderately weathered argillaceous siltstone. The physical and mechanical properties of rock and soil are divided into the following 5 layers.

The first layer is miscellaneous fill: mottled, loose, and slightly wet, and its composition is cohesive soil, fine silty sand, construction waste, and a small amount of domestic waste, The thickness exposed by the borehole is 0.50~11.00m.

The second layer is silty clay: brown, dark brown, wet, plastic state, and moderately compressible; This layer's thickness exposed by the borehole is 0.40~8.60m.

The third layer is fine sand: grayish brown, slightly wet, and slightly dense. The mineral composition is mainly quartz feldspar, and the particles are sub-angular, with low sorting and rounding. The layer thickness is 1.20~9.00m.

The fourth layer is round gravel: yellowish-brown, medium dense to dense, wet to saturated, The content of pebble and gravel are 19 ~ 44% and 30 ~ 41% with good gradation, respectively, The grain composition is granite and andesite, which are subcircular. The site is widely distributed and has a specific thickness. The thickness exposed by the borehole is 0.30~7.00m.

The fifth-1 layer is strongly weathered argillaceous siltstone (K2L): brown-red, gray, grayish-white, strongly weathered; Weathering fissures development, Cretaceous Longjing Formation strata; The thickness exposed by the borehole is 3.70~13.40m.

The fifth-2 layer is moderately weathered argillaceous siltstone (K2L): brownish red, gray, grayish-white, moderately weathered, Fracture development, The maximum thickness exposed by the borehole is 8.00m.

2.2. Foundation Design Scheme
According to the geology and investigation of the project, the foundation of the soil filling pile with spiral cone is finally adopted through the comparative analysis of foundation types.
3. Foundation Design of Soil Filling Pile with Spiral Cone

The vertical ultimate bearing capacity estimation of a single pile of soil filling pile with spiral cone shall be calculated according to the standard value $q_{sik}$ of ultimate lateral resistance of concrete precast piles in Table 5.3.5-1 and the standard value $q_{pk}$ of ultimate end resistance of concrete precast piles in Table 5.3.5-2 in "Soil Filling Pile with Spiral Cone" DB22/T5008-2018 and "Technical Code for Building Pile Foundation" JGJ94-2008. The selection of the correction coefficient is essential [4-5].

$$Q_{uk} = Q_{sk} + Q_{pk} = u \sum \alpha_i q_{sik} l_i + q_{pk} A_p$$

Where:
- $Q_{uk}$ - The standard value of total ultimate lateral resistance of single pile (kN);
- $Q_{pk}$ - The standard value of total ultimate end resistance of single pile (kN);
- $q_{sik}$ - The standard value of ultimate lateral resistance of soil layer $i$ on the pile side (kPa);
- $q_{pk}$ - The standard value of ultimate end resistance (kPa);
- $u$ - The perimeter of the pile body;
- $A_p$ - The pile end area;
- $l_i$ - Thickness of soil layer $i$ around the pile (m);
- $\alpha_i$ - The correction coefficient of increasing the standard value of pile side ultimate lateral resistance of soil layer $i$: fill soil, cohesive soil, and silt: $\alpha_i = 1.0 \sim 1.2$ [4]; Sandy soil, breccia, round gravel, pebble, fully weathered rock, and strongly weathered rock: $\alpha_i = 1.2 \sim 1.5$; Where the greater the compressibility of rock and soil layer, the greater the $\alpha_i$ value.

4. Engineering Inspection of Soil Filling Pile with Spiral Cone

4.1. Vertical Compressive Static Load Test of Single Pile for Foundation Pile

The purpose of carrying out the vertical compressive static load test of a single pile of soil filling pile with spiral cone was to determine the vertical compressive ultimate bearing capacity of a single pile and provide a basis for design verification and engineering acceptance. According to "Technical Code for Testing of Building Foundation Piles" JGJ106-2014 [6], the number of tests was determined to be 11, and the quick maintenance load method was adopted, which could reduce the trial time and testing cost.

4.1.1 Test Methods and Instruments and Equipment

(1) Test Methods

A test device for the anchor pile reaction beam is adopted, and the static load test device is shown in Figure 2. With BZ high-pressure oil pump, the load is automatically controlled by the pressure sensor through the "RS-JYC" pile foundation static load testing and analysis system. Settlement observation adopted four displacement sensors with a measuring range of 50mm and an accuracy of 0.01mm, automatically measured by the "RS-JYC" pile foundation static load testing and analysis system.
(2) Observation Time and Stability Standard
The quick maintenance load method for pile foundation was adopted for all 11 piles in the trial. The pile top settlement was measured at the 5th, 10th, 15th, 15th, and 15th min after each loading grade before adding the next grade.

(3) Test Loading and Unloading Methods
(a) Loading: Loading in ten grades according to the estimated ultimate bearing capacity of 4000 KN (twice the design characteristic value), and the first loading is twice the graded load.
(b) Unloading: The unloading value of each grade is taken as twice the graded load during loading.

4.1.2 Description of Pile Formation
The foundation pile adopted a soil filling pile with spiral cone with a pile diameter of φ500 mm, and the design strength grade of pile body concrete was C35. The bearing stratum at the pile end was strongly weathered argillaceous siltstone, and the pile length was 12.00~ 20.00m. JZB-90 pile driver was used for construction.

4.2. Test Results and Analysis

4.2.1 Pile Integrity Quality Inspection
In addition to strength grade testing of reserved concrete specimens, on-site testing should be carried out, and the testing method should adopt a low strain method. The random numbers of testing should not be less than 30% of the total number of piles and less than 20.

4.2.2 Static Load Test
(1) Pile s-1: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400KN per grade and an actual load of 11 grades. When loading to 4000KN, the settlement was 3.10mm, and the cumulative settlement was 20.48mm. When loading to 4400KN, the settlement was 23.63mm, and the cumulative settlement was 44.11mm. As the pile top's settlement was more than 40mm, and the Q-S curve had a steep drop, as shown in Figure 3. (Due to space limitation, the following figure is omitted)

| Project Name: | Test pile number |
|---------------|-----------------|
| 4 phase of green water garden | s-1 |
| Test date: 2018-9-1 | Pile length 20.00m |
| | Pile diameter: 500mm |

Figure 3. Q-S Curve of Test Pile S-1 of Soil Filling with Spiral Cone

(2) Pile s-2: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400KN per grade and an actual load of 11 grades. When loading to 4000KN, the settlement was 2.16mm, and the cumulative settlement was 15.47mm. When loading to 4400KN, the settlement was 24.97mm, and the cumulative settlement was 40.41mm.
mm; As the pile top's settlement was more than 40 mm, and the Q-S curve had a steep drop, the loading was stopped.

(3) Pile s-3: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400 KN per grade and an actual load of 12 grades. When loading to 4400 KN, the settlement was 1.21 mm, and the cumulative settlement was 9.03 mm. When loading to 4800 KN, the settlement was 19.01 mm, and the cumulative settlement was 28.04 mm; Loading was stopped due to a steep drop in the Q-S curve.

(4) Pile s-4: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 4.19 mm per grade and a cumulative settlement of 28.60 mm; When loading to 4400 KN, the settlement was 13.75 mm, and the cumulative settlement was 42.35 mm. As the pile top's settlement was more than 40 mm, and the Q-S curve had a steep drop, the loading was stopped.

(5) Pile s-5: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400 KN per grade and an actual load of 10 grades.

When loading to 3600 KN, the settlement was 4.63 mm, and the cumulative settlement was 27.29 mm. When loading to 4000 KN, the settlement was 17.06 mm, and the cumulative settlement was 44.85 mm. As the pile top's settlement was more than 40 mm, and the Q-S curve had a steep drop, the loading was stopped.

(6) Pile s-6: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400 KN per grade and an actual load of 11 grades. When loading to 4000 KN, the settlement was 3.90 mm, and the cumulative settlement was 21.00 mm. When loading to 4400 KN, the settlement was 21.33 mm, and the cumulative settlement was 42.13 mm. As the pile top's settlement was more than 40 mm, and the Q-S curve had a steep drop, the loading was stopped.

(7) Pile s-7: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400 KN per grade and an actual load of 10 grades. When loading to 4400 KN, the settlement was 3.00 mm, and the cumulative settlement was 21.52 mm. When loading to 4400 KN, the settlement was 20.13 mm, and the cumulative settlement was 41.65 mm. Loading was stopped due to a broken pile top.

(8) Pile s-8: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400 KN per grade and an actual load of 10 grades. When loading to 3600 KN, the settlement was 3.60 mm, and the cumulative settlement was 22.16 mm. When loading to 4000 KN, the settlement was 18.52 mm, and the cumulative settlement was 40.68 mm. As the pile top's settlement was more than 40 mm, and the Q-S curve had a steep drop, the loading was stopped.

(9) Pile s-9: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400 KN per grade and an actual load of 11 grades. When loading to 4000 KN, the settlement was 3.78 mm, and the cumulative settlement was 22.95 mm. When loading to 4400 KN, the settlement was 19.41 mm, and the cumulative settlement was 42.36 mm. As the pile top's settlement was more than 40 mm, and the Q-S curve had a steep drop, the loading was stopped.

(10) Pile s-10: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400 KN per grade and an actual load of 10 grades. When loading to 3600 KN, the settlement was 3.36 mm, and the cumulative settlement was 17.77 mm. When loading to 4000 KN, the settlement was 23.15 mm, and the cumulative settlement was 40.92 mm. Loading was stopped due to a broken pile top.

(11) Pile s-11: The bearing stratum at the pile end was strongly weathered argillaceous siltstone, with a load of 400 KN per grade and an actual load of 11 grades. When loading to 3600 KN, the settlement was 2.15 mm, and the cumulative settlement was 14.62 mm. When loading to 4000 KN, the settlement was 26.10 mm, and the cumulative settlement was 40.72 mm. Loading was stopped due to a broken pile top.

The test results of engineering piles are summarized in Table 1. The value of strongly weathered argillaceous siltstone is 1.5, and the load value corresponding to the starting point of the apparent steep drop was taken as the vertical compressive ultimate bearing capacity of the single pile according to the specification.
Table 1. Summary of Test Results of Engineering Piles

| Engineering pile number | Pile diameter (mm) | Pile length (m) | Bearing capacity of single pile characteristic value (KN) | maximum Settlement (mm) | Maximum loading value of test (KN) |
|-------------------------|-------------------|----------------|----------------------------------------------------------|-------------------------|----------------------------------|
| s-1                     | 500               | 20.00          | 2000                                                     | 44.11                   | 4000                             |
| s-2                     | 500               | 19.50          | 2000                                                     | 40.41                   | 4000                             |
| s-3                     | 500               | 18.00          | 2200                                                     | 28.04                   | 4400                             |
| s-4                     | 500               | 18.00          | 2000                                                     | 42.35                   | 4000                             |
| s-5                     | 500               | 18.00          | 1800                                                     | 44.85                   | 3600                             |
| s-6                     | 500               | 17.00          | 2000                                                     | 42.13                   | 4000                             |
| s-7                     | 500               | 17.00          | 2000                                                     | 41.65                   | 4000                             |
| s-8                     | 500               | 14.00          | 1800                                                     | 40.68                   | 3600                             |
| s-9                     | 500               | 14.00          | 2000                                                     | 42.36                   | 4000                             |
| s-10                    | 500               | 12.00          | 1800                                                     | 40.92                   | 3600                             |
| s-11                    | 500               | 12.00          | 1800                                                     | 40.72                   | 3600                             |

When the pile diameter was 500mm, the vertical ultimate bearing capacity of a single pile with a pile length of 19.5~20m, 18m, 17m, 14m, and 12m was 4000KN, 4000KN, 3800KN, and 3600KN respectively, which is significantly improved compared with the traditional pile.

5. Conclusions

(1) It provides the region's geotechnical engineering data and the geotechnical engineering parameters required for design and construction. Besides, design suggestions are put forward for foundation types and new pile foundation forms.

(2) It is concluded that the technology of soil filling pile with spiral cone has apparent advantages through engineering application. When the pile diameter was 500mm, and the pile length was 12~20m, the maximum settlement range was 28.04~44.85mm, and the vertical compressive ultimate bearing capacity range was 3600~4000 KN. The pile integrity test showed promising results. The pile ensures the engineering quality, reduces the engineering cost, and obtains good economic and social benefits. It is a new type of pile foundation with wide popularization and application prospects.

Acknowledgements

This paper is supported by the key research project of the Science and Technology Development Plan of Jilin Province Science and Technology Development Plan (20170204032SF).

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