Design and Engineering Test of Soil Filling Pile with Spiral Cone Foundation

Ming Fang¹, Guangxiu Fang¹* and Shifan Zhao², Shoujin Liu²
1Department of Civil Engineering, Yanbian University, Yanji, China, 133002
2Daxing Foundation Engineering Company, Yanji, China, China,133000
*Corresponding author’s e-mail: gxfang@ybu.edu.cn

Abstract. In this paper, through the comparative analysis of two different types of pile foundations, long auger bored cast-with-pressure concrete pile and Soil filling pile with spiral cone at the same engineering project and the same geological conditions in Western Liaoning Province, it is concluded that the soil filling pile with spiral cone compare with the long auger bored cast-with-pressure concrete pile, have obvious technical advantages in construction period and guarantee, reduce the construction expenditure. Moreover, the pile integrity testing is good, and has achieved good economic and social benefits. It is a new type of energy-saving and emission-reducing pile foundation with wide application prospects.

1. Soil filling pile with spiral cone technology
As a new type of pile foundation design and construction technology, soil filling pile with spiral cone is a kind of partial soil displacement cast-with-pressure concrete pile. It is on the basis of absorbing the advantages of the existing auger bored cast-with-pressure concrete pile (extruding soil) technology and re-innovating to overcome the shortcomings of few adapting layer, construction bit bouncing, drilling-burying, unextrusion-soil at end of pile, etc. The screw cone soil extrusion drill bit structure is provided, which matches the standard screw cone soil extrusion drill pipe. Driven by the high-torque power head piler, the drill bit is first extruded into small hole and then extruded into pile aperture. It is able to achieve the function of "squeezing when it could be, passing when it could not squeeze, and squeezing while passing", which can effectively improve the penetrating ability of construction hole formation, put an end to the phenomenon of bit bouncing and drilling-burying, compacted the rock-soil layer at the pile end, well solved the negative effect of soil compaction[1-2], and significantly improved the bearing capacity of pile formation.

The bearing capacity of single pile is high. Under the same conditions, compared with the traditional pile, the pile length and diameter are reduced, and the penetration power is weak[3].

Based on the geological conditions of Shuimu qinghua park and Dacheng international garden phase ii in Liaoxi district, Liaoning province, and based on the actual engineering conditions, this paper puts forward the design construction and engineering testing technology of soil filling pile with spiral cone, which is feasible in this area, and provides reference for similar engineering applications.

2. Design of soil filling pile with spiral cone foundation
The calculation of the vertical ultimate bearing capacity of single pile of soil filling pile with spiral cone is also based on the standard value Q_{sink} of the ultimate side resistance of the concrete precast pile in table 5.3.5-1 and the standard value Q_{pk} of the ultimate end resistance of the concrete precast pile in
table 5.3.5-2 of the *technical code for the building pile foundation* JGJ94-2008. In addition, as to the standard value of the ultimate side resistance, we through a large number of test piles and engineering construction experience, add an increase correction coefficient $\alpha_i$.

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

In the formula:

- $Q_{sk}$ — Standard value of total ultimate side resistance of single pile (kN);
- $Q_{pk}$ — Standard value of total ultimate end resistance of single pile (kN);
- $q_{sk}$ — Standard value of ultimate side resistance of the I layer soil pile on the pile side (kPa);
- $q_{pk}$ — Standard value of ultimate end resistance (kPa);
- $u$ — Pile circumference;
- $A_p$ — Area of pile tip;
- $l_i$ — Thickness of layer I soil around pile (m)

$\alpha_i$ — Increase correction coefficient of standard value of ultimate side resistance of the I layer soil on pile side: filled soil, cohesive soil and silt: $\alpha_i=1.0~1.2[4]$; Sand, breccia, cobble, pebble, fully weathered rock, strongly weathered rock: $\alpha_i=1.2~1.5$; Among them, the greater the compressibility of rock and soil layer is, the greater the value of "$\alpha_i$" is.

3. Engineering Test of Soil filling pile with spiral cone

3.1. *Shuimu Tsinghua park, Liaoning province*

At the beginning of 2014, the soil filling pile with spiral cone technology began to be applied. The first project is *Shuimu Tsinghua park* in Kizuo county, Liaoning province. The pile diameter is 500mm, the pile depth is 12m, the pile concrete design strength grade is C35, the characteristic value of bearing capacity of single pile is 1800KN, the pile end bearing layer is medium-weathered shale, and the maximum settlement detected by static load is 10.03mm.

3.1.1. Geotechnical stratification of each layer

According to the survey report provided by the engineering survey of Liaoxi, Liaoning province, this survey found that, within the control depth of the borehole, the geotechnical stratification of each layer of the site is as follows:

Layer ① is plain fill: 1.20~3.10m thick, mixed color, loose accumulation, main components are construction waste block stone and concrete, no structure, not suitable for natural foundation.

Layer ② is silty clay: it is widely distributed in the site. The depth of the roof of layer is 1.20~3.10m, and the thickness of the layer is 5.70~8.60m. It is brown and plastic. The dry strength and thoughness of the soil is medium, slightly glossy, no shaking response, the upper hole is relatively developed, with a small amount of gravel locally, high-compressibility.

Layer ③ is cobble: it is widely distributed in the site, the depth of the roof of layer is 8.50~9.90m, and the thickness of the layer is 2.20~3.90m. It is of mixed color and medium density, generally sorted, with good roundness. The parent rock composition is mainly quartz sandstone, granite and limestone. Medium-weathered or un-weathered, disordered arrangement, sand filling.

Layer ④ is completely weathered shale: it is widely distributed in the site, the depth of the roof of layer is 10.80~12.50m, the thickness of the layer is 0.60~1.00m, gray yellow, gray green, fully weathered, the original rock structure has been completely weathering destroyed, the structural bedding is not clear, the core is sand-like, fragment-like, could be crushed by hand, impact drilling is possible.

Layer ⑤ is strongly weathered shale: it is widely distributed in the site. The depth of the roof of
layer is 11.80~13.10m, and the thickness of the layer is 3.00~4.00m. gray yellow-gray green. Strong weathering, weathering crack development, the core is fragmented, can be broken by hand force, impact drilling is difficult.

Layer ⑥ is moderately weathered shale: there are exposed in the site drill hole. The depth of the roof of the layer is 16.20 ~ 16.30m, the thickness of the exposed layer is 4.50 ~ 6.30m, gray yellow, gray green, moderate weathering, clast structure, layered structure, weathered cracks generally developed, the core is columnar, long columnar, dehydrated after air drying is fragmented, could easily broken by hammer. Rocks generally occur at 50-60° < 25-30°.

3.1.2. The situation of pile formation
According to the construction data, the relevant parameters are shown in table 1.

| Pile no. | The pile diameter (mm) | Buried pile length (m) | Characteristic value of bearing capacity of single pile (KN) | Pile end bearing layer |
|----------|------------------------|------------------------|-------------------------------------------------------------|-----------------------|
| 1#       | 500                    | ≥12.0                  | 1800                                                        | 6000KPa               |
| 2#       | 500                    | ≥12.0                  | 1800                                                        | 6000KPa               |
| 3#       | 500                    | ≥12.0                  | 1800                                                        | 6000KPa               |

3.1.3. Detection Equipment and Principle
(1) Loading method
This test adopts test pile anchorage and counterweight to form a loading reaction system, as shown in Fig. 1.

![Fig. 1](image)

Fig. 1 Test pile anchorage and counterweight constitute a loading reaction system
A 5000KN oil-pressure jack is used for loading.

3.1.4. Test Loading
(1) Test standard: according to JGJ106-2014.
(2) The rapid maintenance load method is adopted to load step by step. The first stage is loaded by 2 times. After each stage of load reaches relatively stable, the next stage of load is added.
(3) Settlement observation: four displacement sensors are installed on both sides of the pile top to measure the settlement according to the specified time.

3.1.5. Test Results
The test results are summarized in Table 2.
| Test pile number | Pile diameter (mm) | Pile length (m) | Characteristic value of bearing capacity of single pile (KN) | Maximum settlement (mm) | Test maximum load value (KN) |
|------------------|-------------------|----------------|--------------------------------------------------|------------------------|-----------------------------|
| 1#               | 500               | 12.0           | 1800                                           | 9.81                   | 3600                        |
| 2#               | 500               | 12.0           | 1800                                           | 10.54                  | 3600                        |
| 3#               | 500               | 12.0           | 1800                                           | 10.03                  | 3600                        |

(1) No. 1 test pile
When the test is loaded to 3600KN, the total settlement is 9.81 mm, the settlement is not large, and the Q-S curve is gentle without obvious steep drop.

(2) No. 2 test pile
When the test is loaded to 3600KN, the total settlement is 10.54 mm, the settlement is not large, and the Q-S curve is gentle without obvious steep drop.

(3) No. 3 test pile
When the test is loaded to 3600KN, the total settlement is 10.03 mm, the settlement is not large, and the Q-S curve is gentle without obvious steep drop.

Single pile vertical compressive static load test 1#, 2#, 3# pilots all meet the design requirements.

3.2. Liaoning Dacheng International Garden Phase II

3.2.1. Geotechnical stratification of each layer
At the beginning of 2015, the second phase of Dacheng International Garden in Kazuo County, according to the survey report provided by Liaoning Liaoxi Engineering Survey, has the following geological overview:

Layer ① is plain fill: the layer thickness is 3.00~14.50 m, yellowish brown ~ reddish brown, the main components is clay, plastic ~ hard plastic state, newly loose accumulation, uncompacted, macropore, loose structure, disordered filling, large difference in physical and mechanical properties, locally containing block stone, brick and weathered rock layer, with the maximum block diameter >10cm.

Layer ② is silty clay: the buried depth of the roof of layer is 3.00~14.5 m, the layer thickness is 1.0 ~ 12.0 m, yellowish brown ~ light brown, plastic ~ soft plastic state, medium dry strength and toughness of soil, no root shaking reaction, and high compressibility. Silt and medium coarse sand interlayer are found locally.

Layer ③ is round gravel: the buried depth of the roof of layer is 9.80 ~ 18.0m and the thickness of the layer is 0.50 ~ 4.00 m. it is variegated, saturated, slightly dense state, with average grain size distribution and sub-round shape. the parent rock is mainly quartzite and ore rock, with random grain arrangement, Medium-weathered or un-weathered, partially filled with cohesive soil and containing a small amount of pebbles.

Layer ④ is completely weathered shale: the buried depth of the roof of layer is 4.0 ~ 18.0m, the thickness of the layer is 0.50~1.00 m, yellowish green ~ grayish green, completely weathered, the original structure has been completely destroyed, the weathering is strong, the core is in the form of soil, could be crushed by hand, impact drilling is possible.

Layer ⑤ is highly weathered shale: the buried depth of the roof of layer is 4.50~18.50 m, the thickness of the exposed layer 3.4~5.0 m, grayish green. Highly weathered, the thick rock structure has been largely destroyed, with strong weathering. The core is fragmentary, easy to break by hand and difficult to drill by impact.

Layer ⑥ is moderately weathered shale: all holes are uncovered in the site. The buried depth of the roof of layer is 9.0~23.0 m and the thickness is 2.0~7.0 m. It is grayish green, moderately weathered, of clastic structure, and layered structure, with generally developed weathered fissures. The core is columnar, and the hammering sound is hoarse and fragile. The occurrence of the rock formation is 160
< 30, and there are siltstone bands, with local interbedded distribution.

3.2.2. The original design of pile foundation is long spiral bored pile. It is recommended in the survey that large diameter bored piles (D≥800mm) be used as the foundation for pile foundation, and layer ⑧ of highly weathered shale should be selected as the bearing stratum. In the design part, according to the suggestion of geological survey, the pile foundation is designed as Φ 800 long spiral bored piles, the bearing stratum is highly weathered shale, the rock depth is not less than 2m, the characteristic value of single pile bearing capacity is 1800KN, and the design strength grade of pile concrete is C40.

3.2.3. The design of pile foundation is changed to soil filling pile with spiral cone. The pile layout and construction are redesigned by changing the pile diameter and pile spacing.

3.2.4. Reasons, Purposes and Methods of Detection
(1) Detection reason: After the foundation pile project is constructed, the bearing capacity of the engineering pile and the quality integrity of the pile body are checked and accepted for the long spiral bored piles and soil filling pile with spiral cone foundation.
(2) Detection purpose and method: Single pile static load test is used to detect whether the vertical compressive bearing capacity of single pile meets the design requirements; Low strain reflected wave method is used to detect the quality integrity of pile body.

3.2.5. Inspection Basis
Testing shall be conducted according to the requirements of national industry standard "Technical Code for Testing of building foundation piles" (JGJ106-2014) and Liaoning provincial local standard "Technical regulations for Testing of building foundation piles and compound ground" (DB21/T1450 -2015) [5].

3.2.6. foundation pile testing
(1) pile integrity testing.
1) Test equipment.
   RS-1616W(L) pile dynamic tester, sensor LC0154TA, force hammer.
2) Sampling of test piles.
   According to the standard, after supervisor sampling, the integrity of the pile body of the project was tested, and 117 piles were sampled in total.
3) Test principle and method.
   In this test, the reflected wave method was adopted.
   In this method, the vibration pick-up placed on the pile head receives the initial pulse signal and the reflected signal of the pile body, records them by the pile foundation dynamic tester and stores the waveform on the magnetic disk, which is processed by the computer.

3.2.7. Quality Classification Standard for Pile Body Concrete
Type I: pile body is complete, wave shape is regular and wave velocity is normal;
Type II: minor defects in the pile body, but will not affect the normal performance of the bearing capacity of the pile body structure;
Type III: The pile body has obvious defects (hole shrinkage or segregation), which affect the structural bearing capacity of the pile body.
Type IV: The pile body has serious defects with irregular waveform, so it cannot be used.

3.2.8. pile body integrity testing
The top of the pile is flat and compact, meeting the test requirements. Force hammer excitation is adopted, and the sensor is adhered to the pile top with couplant and perpendicular to the pile top
A total of 4 piles tested in this project are Class II piles with slight defects, and the remaining 113 foundation piles are Class I piles with complete pile body quality. The average wave velocity of the piles tested in this project is 3920m/s.

3.2.9. Vertical Compressive Static Load Test of Single Pile

(1) Test Equipment

Steel beam, 800T jack, displacement measuring range 50mm, reference beam, RS-JYC static load automatic acquisition and analysis system.

(2) Sampling of test piles

The number of samples is based on the standard, taking 3 samples.

(3) Static load detection

The block diagram of the test pile system is shown in Fig. 3. Bolt counterforce device and oil-pressure jack are used for loading. In this test, the rapid maintenance load method is adopted[6].

The vertical bearing capacity of single pile tested in this project meets the design requirements.

3.2.10 Q-S Curve of Long Spiral Bored Piles and Soil Filling Pile with Spiral Cone Foundation

(1) Q-S Curve of Long Spiral bored Pile

The q-s curve of static load test for long spiral bored piles is shown in Fig. 4.
From the Q-S graph, when meet the bearing capacity of single pile is 3600KN, the maximum settlement is 12.51mm.

(2) Q-S Curve of Soil Filling Pile with Spiral Cone
The Q-S curve of the static load test of the soil filling pile with spiral cone is shown in Fig. 5.
When φ500mm soil filling pile with spiral cone is used as pile foundation, the pile length of test pile 1107# is 16.40m, and the maximum settlement is 12.75mm when the ultimate bearing capacity of single pile is 3600KN.

4. Conclusion
Based on the comparison of two different types of pile foundation technologies, i.e. long spiral bored pile and soil filling pile with spiral cone, in the same project and under the same geological conditions
in western Liaoning province, soil filling pile with spiral cone technology has obvious advantages. When the bearing capacity of a single pile is 3600KN, the pile diameter of the long spiral bored pile foundation is Φ 800, the test pile length is 16.20 m, and the maximum settlement is 12.51mm; When the pile diameter of soil filling pile with spiral cone foundation is Φ 500mm, the test pile length is 16.40m and the maximum settlement is 12.75 mm. The integrity test of pile body is good. Compared with the long spiral bored pile, it speeds up the construction period, ensures the engineering quality, reduces the engineering cost, saves 35 ~ 40% of the construction cost, obtains good economic and social benefits, and is a new pile foundation with wide popularization and application prospects.

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