Research Background and Mechanism of Soil Filling Pile with Spiral Cone Technology

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Abstract. This paper introduces the research background of soil filling pile with spiral cone technology. It is a new type of energy-saving and emission-reducing construction pile foundation design and construction technology. The foundation pile is a kind of soil filling pile with spiral cone which has the technical advantages of rotating extrusion cast-in-situ pile and bidirectional short spiral extrusion soil pile. At the same time, the mechanism is expounded. The soil compaction of the bit and the secondary diameter-retaining drill pipe is sufficient, the penetrating force is strong, and the geological conditions are widely adapted. The effect of the rock and soil around the pile on the pile is fully improved, thus the bearing capacity of the pile is increased and the construction cost is reduced. When calculating the vertical ultimate bearing capacity of a single pile, the value of the correction factor for the increase of the same rock and soil layer around the pile increases gradually from the soil displacement screw pile, rotating extrusion cast-in-situ pile and soil filling pile with spiral cone, and the vertical ultimate bearing capacity of the three piles increases sequentially.

1. Research Background of Soil Filling Pile with Spiral Cone Technology

1.1. Types and Characteristics of Existing Pile Foundations
The most basic requirements of building pile foundation are the bearing capacity and settlement of pile, of which the bearing capacity of pile is the key point. The construction technology of pile foundation plays a very important role in the bearing capacity of pile, and the bearing capacity of pile formed by different construction methods under the same engineering geological conditions is also different. In the existing construction of building pile foundation, precast piles and cast-in-situ concrete piles are mainly used. Precast piles are mainly static pressure prestressed pipe piles. Limited by pile conveying equipment and engineering geological conditions, the characteristic value of pile bearing capacity is generally below 2500KN, and pile extension is required when the pile length is long. For pile foundations with a load requirement more than 2500kN, pile raft structures are mostly adopted to meet the design requirements, resulting in high construction cost and long construction period[1]. Cast-in-situ piles are mostly continuous flight auger pile. In recent years, the application of screw piles, rotating extrusion cast-in-situ piles and bidirectional short spiral extrusion soil piles has also been gradually popularized.

(1) Continuous flight auger pile: it occupies a large number of pile foundation market shares due to its advantages of wide geological conditions, simple construction equipment, strong controllability and high pile forming quality. However, it has the disadvantages of producing a large amount of residual
soil in the construction process, leaving virtual soil at the bottom of the pile forming hole to reduce the bearing capacity of the pile, etc. It belongs to cast-in-situ pile with soil dumping.

(2) Screw pile[2]: It uses the synchronous technology of pile-forming equipment to squeeze soil into threaded holes and pump concrete into different diameter piles to improve the stress mechanism of the rock-soil layer on the pile side and increase the vertical force of the rock-soil layer on the pile body. It is only suitable for construction under medium-soft rock-soil geological conditions.

(3) Rotating extrusion cast-in-situ pile: it is a further expansion on the basis of screw pile. It uses the pile-forming equipment of screw pile to extrude soil into full threaded hole by synchronous technology, and adopts asynchronous technology to extrude the completed full threaded hole into cylindrical hole in the process of lifting, drilling and pressing concrete to form equal diameter concrete cast-in-situ pile[3].

The drilling tool for the rotating extrusion cast-in-situ pile is a screw pile machine drilling tool, which consists of a screw drill bit and a screw drill rod for the rotating extrusion cast-in-situ pile. The screw drill bit consists of a screw cylinder soil extrusion blade, a cylinder core pipe, a drill tip, a joint and the like, as shown in Fig. 1. A notch is arranged on the soil extrusion blade of the screw pile body.

There is a concrete passing-through pipeline in the drilling tool. When constructing pile holes, the drill tip on the screw drill bit rotates to cut the rock and soil body, and the cut rock and soil body is transported from bottom to top along the F-plane in the screw cylinder soil extrusion blade (as shown in Fig. 2). In the process of transportation, the D-plane, E-plane, F-plane and notch in the screw cylinder soil extrusion blade (as shown in Fig. 2) all have radial squeezing force on the rock and soil body, realizing squeezing while transferring, compacting the side wall of the pile hole, and finally some soil body is discharged to the outside surface of the hole. It is required that the rated output torque of the power head of the construction pile driver shall not be less than 250kNꞏm and the rotating speed shall be 3~6 r/min.

(4) Bidirectional short spiral extrusion soil pile: it uses the special structure of bidirectional short spiral drill bit to rotary cut off the rock and soil body, then squeeze the side wall of pile hole through cone core pipe, and pump concrete into pile during lifting and drilling. Due to insufficient soil squeezing of drill cone core pipe, it is only suitable for construction in medium-soft rock and soil layer.

The bidirectional spiral extruding and expanding drill bit consists of a lower conical structure, a preserving diameter structure, an upper conical structure, a drill tip, a joint and the like. The outer diameters of the three parts of the upper conical structure, the preserving diameter structure and the lower conical structure are the same, and are pile forming pore diameters. Cutting teeth are arranged at the lower end of the forward spiral blade. Drill pipes are composed of cylindrical core pipes and joints.
The hole-forming drilling tool for the soil displacement screw pile consists of a bidirectional spiral extruding and expanding drill bit and a drill rod, as shown in Figs. 3 and 4. During pile hole construction, a forward rotating bidirectional spiral extruding and expanding drill bit is adopted to drill, cutting teeth at the lower end of the forward spiral blade rotate to cut rock and soil bodies, and the cut rock and soil bodies are transmitted upwards along the upper curved surface of the forward spiral blade; In the process of transmission, the rock and soil body is subjected to the radial extrusion force on the outer surface of the lower conical structure, and the rock and soil body is extruded to the side wall of the pile hole to compact the hole wall, thus increasing the limit side resistance standard value of the pile after the pile is formed. The preserving diameter structure in the middle of the drill bit, first is to limit the upward transmission of rock and soil in the lower conical structure. The second is to assist extrusion to formed diameter of the pile and keep it unchanged. When the drill is lifted and pumped to pour concrete, it still rotates forward, and the upper cone structure in the drill bit extrudes and expands the formed pile hole again.

Screw pile, rotating extrusion cast-in-situ pile and bidirectional short spiral extrusion soil pile all belong to partial extrusion cast-in-situ pile. Due to the technology of pile-forming and the characteristics of drilling tools, the engineering geological conditions suitable for the three pile types are limited, and the construction pile-forming hole is difficult in rock and soil layers with small compressibility such as hard rock layers.

1.2. Technical Analysis of Existing Pile Foundation Types
It can be seen from the above-mentioned four kinds of construction technological processes of squeezing soil piles that they are different in the formation of pile holes.

(1) Precast pile: it belongs to completely squeezed soil pile. The rock-soil layer on the precast pile side is in a squeezed state. The standard value of the ultimate side resistance \( q_{usk} \) and the standard value of the ultimate end resistance \( q_{pk} \) of the rock-soil layer around the foundation pile are higher than those of long spiral dry operation bored piles. See Table 5.3.5-1 and 5.3.5-2 in "Technical Code for Building Pile Foundation" JG94-2008.

(2) Screw pile: it belongs to partial soil squeezing cast-in-situ pile. The main part which extruding soil into threaded hole is the screw cylinder soil extrusion blade with trapezoidal cross section on the drilling tool. it is only suitable for the rock and soil layer with medium and soft geology.

(3) Rotating extrusion cast-in-situ pile: it is a derivative of screw pile. Its adaptation to geological conditions is the same as that of screw pile.

(4) bidirectional short spiral extrusion soil pile: the hole forming is to use a bidirectional spiral soil extruding drill bit consisting of a spiral blade with a rectangular cross section and a short cone core pipe to drill and squeeze soil. In the process of lifting the drill, the upper cone core pipe continues to
extrude the rock and soil on the hole wall and to extrude it again, pumping the concrete at the same time. finally, placing the reinforcement cage to form a pile. only suitable for rock and soil layers with medium soft plasticity and large geological conditions.

Shandong province's "Technical Code for Construction of Soil Displacement Screw Pile" DBJ14-091-2012[4]; Henan Province's "Technical Specification for Half-screw pile" DBJ46 -026-2013[5], Chongqing's "Technical Specification for Rotating Extrusion Cast-in-situ Pile" DBJ50/T-207-2014[6], etc., have proposed estimation formulas for the calculation of the standard value of vertical ultimate bearing capacity of single pile. The common point is that in the estimation of the standard value of the ultimate bearing capacity, the standard value q_{sik} 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 in the “Technical Code for Building Pile Foundation” JGJ94-2008 are adopted to calculate[7], and the increase correction coefficient α(αis greater than 1) is added to the standard value of the ultimate side resistance, and different values are taken for different pore-forming methods and different rock and soil layersα.

2. Soil Filling Pile with Spiral Cone Technology

2.1. Basic Requirements
(1) higher bearing capacity; (2) Wide adaptability to geological conditions; (3) simple construction and strong operability; (4) low cost; (5) environmental protection and energy conservation.

2.2. Basic Principles
Improve the standard value q_{sik} of ultimate side resistance and q_{pk} of ultimate end resistance of rock and soil around the pile through compressibility. To achieve the principle of squeezing when it could be, passing when it could not squeezing, and squeezing while passing is realized.

2.3. Mechanism and Construction Process
The hole-forming drilling tool for the soil filling pile with spiral cone consists of a spiral cone soil-extruding drill bit and a secondary soil-extruding diameter-preserving drill rod.

2.3.1. Spiral Cone Soil Extruding Bit for Soft and Hard Rocks
Spiral cone soil-extruding drill bits for soft and hard rocks are shown in Figs. 5 and 6.
It is consists of a spiral cone structure and a spiral cylinder structure. The spiral cone structure is composed of a cone core tube, screw cone soil extrusion blade and a drill tip, and bears the main soil extruding function when forming pile holes. The spiral cylinder structure consists of a cylinder core tube and a screw cylinder soil extrusion blade, the outer diameter and the cylinder core tube are the same as those of a spiral standard soil extruding drill rod, and the spiral cylinder core tube bears the auxiliary soil extruding function when forming a pile hole.
2.3.2. **Double soil extrusion and Diameter Preservation Drill Pipe**

It consists of a cylinder core tube, spiral cylinder blades and a joint. The cross section of the spiral cylinder blades is quadrangular, and the outer edge of the spiral cylinder blades is provided with a notch, as shown in Fig. 7.

It not only has the function of conveying rock and soil, but also has the function of assisting in radially extruding rock and soil body on the hole wall to compact the rock and soil on the side wall of the hole. Due to squeezing while passing, it is helpful to improve the physical parameters of soft soil layer within the hole depth. For pile-forming holes with different geological conditions, double soil extrusion and diameter preservation drill pipes with different notch sizes should be selected, and the drill pipes with small notch should be selected for rock and soil layers with high density.

![Fig. 7 schematic diagram of double soil extrusion and diameter preservation drill pipe](image)

2.3.3. **The Hole Drilling Tool and Soil Extruding Principle of the Soil Filling Pile with Spiral Cone**

During pile hole construction, the screw cone soil extrusion blades and cone core tubes (as shown in Fig. 8) on the spiral cone structure in the spiral cone soil squeezing drill directly squeeze the rock and soil mass. The surfaces A-plane, B-plane and M-plane all have radial squeezing force on the rock and soil mass. The C-plane has radial squeezing force on the rock and soil mass while transmitting the squeezed and stripped rock and soil mass. The spiral cone structure has a small bottom and a large top, and is extruded into small-diameter holes first, and then extruded and expanded into pile hole diameters to assume the main soil extruding function. The spiral cylinder structure and the Double soil extrusion and Diameter Preservation drill pipe re-extrude the hole diameter of the formed pile, and the screw cylinder soil extrusion blade completes the soil extrusion diameter-preserving function by utilizing the D-plane, E-plane, F-plane and notches on the blade (as shown in Fig. 9) in the process of transferring rock and soil. Drilling tools squeeze soil fully and have strong penetrating power.

The soil filling pile with spiral cone requires the rated output torque of the power head of the construction pile machine to be not less than 350KN·m and the rotating speed to be 3~7r/min.
2.3.4. **Construction Process of Soil Filling Pile with Spiral Cone**

According to the drilling tools and construction process required for construction of pile-forming holes, the soil filling pile with spiral cone has the following construction characteristics:

1. The cone core tube and the screw cone soil extrusion blade are taken as the main soil extruding components, and the double extrusion and diameter preservation drill rod is taken as the auxiliary soil extruding, so that the soil extruding could be sufficient.
2. The cone-shaped structure of the screw cone soil extrusion drill bit has strong penetration ability, is suitable for a wide range of rock and soil layers, is not affected by the underground water level, and has high construction efficiency[8].
3. The construction has no mud, no vibration and less soil discharge. Concrete is poured by pump pressure, and the bearing capacity of the pile is high[9]. It is a typical energy-saving and emission-reducing pile.

3. **Comparative analysis of the increasing correction coefficient α of each pile type**

3.1. **Vertical Ultimate Bearing Capacity of Single Pile of Soil Filling Pile with Spiral Cone**

The estimation of vertical ultimate bearing capacity of single pile of Soil Filling Pile with Spiral Cone proposed in this paper is also calculated by using the standard values $q_{sik}$ of limit side resistance of concrete precast pile in Table 5.3.5-1 and $q_{pk}$ of limit end resistance of concrete precast pile in Table 5.3.5-2 in "Technical code for building pile foundations" JGJ94-2008[7]. On the standard values of limit side resistance, the correction coefficient $\alpha$ is increased through a large number of test piles and engineering construction experience.

$$Q_{sk} = Q_{sik} + Q_{pk} = u \sum \alpha_{is} q_{sik} l_{i} + q_{pk} A_{p}$$

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);
- $q_{sik}$ — Standard value of ultimate side resistance of soil pile in $i$-layer on pile side(kPa);
- $q_{pk}$ — Standard value of ultimate end resistance(kPa);
- $u$ — Perimeter of pile body;
- $A_{p}$ — Pile end area;
- $l_{i}$ — Thickness of $i$-layer soil around pile(m);
- $\alpha_{is}$ — The increasing correction coefficient for the standard value of the pile-side ultimate side resistance of the $i$-layer soil is as follows: filled soil, cohesive soil and silt: $\alpha_{i} = 1.0 \sim 1.2$; Sand, breccia, cobble, pebble, fully weathered rock, strongly weathered rock: $\alpha_{i} = 1.2 \sim 1.5$[10]; Among them, the greater the compressibility of rock and soil layer, the greater the value of $\alpha_{i}$.

3.2. **Comparison of Increasing Correction Coefficient α of Three Piles**

The increasing correction coefficients $\alpha$ of the three kinds of piles are sorted as follows:

1. Spiral soil squeezing cast-in-place pile: fill, clay, silt: $\alpha_{i} = 1.0 \sim 1.15$; Sand, breccia, round gravel, crushed stone, pebble, fully weathered rock and strongly weathered rock: $\alpha_{i} = 1.1 \sim 1.25$.
2. Rotary extrusion cast-in-place pile: fill soil, clay, silt and dense sand: $\alpha = 1.0 \sim 1.2$; Loose ~ medium dense sandy soil, breccia, round gravel, crushed stone, pebble, fully weathered rock and strongly weathered rock: $\alpha_{i} = 1.2 \sim 1.5$.
3. Soil filling pile with spiral cone: fill soil, cohesive soil and silt: $\alpha_{i} = 1.0 \sim 1.2$; Sand, breccia, cobble, pebble, fully weathered rock, strongly weathered rock: $\alpha_{i} = 1.2 \sim 1.5$;
4. Conclusion

(1) The rotating extrusion cast-in-situ pile adopts a screw cylinder soil extrusion blade as a main soil extruding component; soil displacement screw pile adopts upper and lower cone core pipes as main soil extruding parts; soil filling pile with spiral cone technology uses three parts as the main soil extruding parts: cone core pipe, screw cone soil extrusion blade and screw cylinder soil extrusion blade. During the construction of the hole, the screw cone soil extrusion pile has the function of “squeezing while passing” through the screw cone soil extrusion blade, which can realize the extruding between different rock and soil bodies, improve the physical parameters of the rock and soil around the pile, and squeeze the soil most fully into the pile hole.

(2) Rotating extrusion cast-in-situ pile and soil filling pile with spiral cone technology have drill pipes for diameter preserving and soil extrusion in the process of pile hole formation, and are not affected by underground water level. However, in the process of forming pile hole, the drill pipe of the soil displacement screw pile technology only has the function of transmitting torque, and cannot keep the diameter of the formed pile hole from shrinking. The construction is affected by the underground water level. The soil filling pile with spiral cone technology is most suitable for the rock and soil layer and has the strongest penetrating power.

(3) The bidirectional spiral extruding and expanding drill bit only uses shorter cone core pipe to extrude soil, which is not sufficient; Rotating extrusion cast-in-situ pile uses screw drilling tools to squeeze soil in the whole range of hole depth, which is only completed by screw cylinder soil extrusion blades. The extruding of soil is not sufficient, but it is better than The bidirectional spiral extruding and expanding drill bit. The drilling tool for the soil filling pile with spiral cone integrates the advantages of the above two kinds of soil extrusion, organically combines the cone core pipe soil extruding and the screw cylinder blade soil extruding together, and increases the screw cone blade soil extruding at the same time, so that the effect is obviously improved. When calculating the vertical ultimate bearing capacity of a single pile, the value of the increasing correction coefficient for the same rock and soil layer around the pile should be: the soil displacement screw pile, the rotating extrusion cast-in-situ pile and the soil filling pile with spiral cone pile gradually increase in sequence.

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