Exploration of Structural Design and Construction Methods of Pneumatic Thorn Piles

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Abstracts. In order to solve the bearing problem of poor foundation, thorn piles were proposed, however, the construction of precast thorn piles is still in the blank stage in the project. In this paper, the research on the engineering realization method of precast thorn piles is carried out. Inspired by telescopic rod, the method of prefabricated pile body and pneumatic pressure pushing into thorns is adopted, which effectively solves the key technological problems of pile thorn stabilization at the piling formation stage, the overall air tightness of piles, and pile thorn rebound, and finally a sleeve-type thorn piles is designed. The research results can provide a theoretical basis for the research and development of precast thorn pile molding equipment, and lay the foundation for the subsequent engineering application of precast thorn piles.

Keywords-Thorn pile; Precast pile; Engineering Realization Method; Pneumatic pressure

1. Introduction

In recent years, with the rapid development of economic construction, pile foundation construction technology has gained broader application[1-5]. With the improvement of construction level, higher requirements on bearing capacity and settlement resistance of pile foundation have been put forward[6]. At present, in the industry, the raised structure is mainly added to increase the pile side resistance to increase the capacity of pile foundation bearing capacity and settlement resistance level, and the thorn pile is a typical representative. Thorn pile, consisting of two parts: the pile body and many thorns covering the pile body, is a new pile structure designed by conceptualizing and researching on the characteristics of tree root's resistance to compression and pulling action. Its vertical bearing capacity is composed of pile end resistance, pile side friction resistance and pile side thorns resistance. The bearing capacity of thorn pile is relatively large, and the ultimate bearing capacity of the single square concrete can reach 600kN/m^3 ~ 900kN/m^3, which is about twice that of the plain pile and comparable with the cast-in place pile with branches & plates[7]. Moreover, some scholars have conducted relevant experiments[8-9] and engineering applications[9-10], which have preliminarily verified the effectiveness of its engineering.

However, there are few researches on the molding of pile at present. Wu Weicheng[11], Cao Xia[7], Gou Guojing[12] proposed the construction technology of thorn-shaped cast-in-situ pile and its form squeezing machine. After the hole formation of conventional filling piles is

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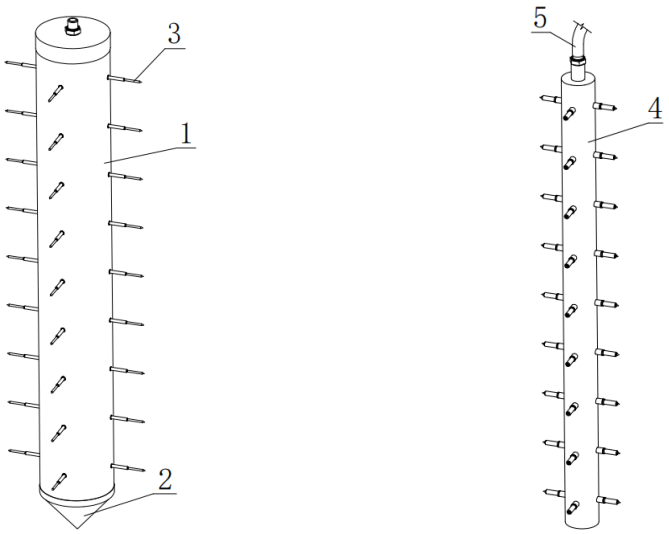
completed, six special hydraulic cylinders and their top caps are used to squeeze and push the hole wall, which can form six pile thorn spaces; by adjusting the upper and lower positions and repeating the squeezing action, numerous pile thorn spaces can be squeezed regularly throughout the entire depth of the hole; finally, the holes are cleared, and concrete is poured after lowering the reinforcement cages, which is thorn pile. Chen Xin et al.[13] , on the other hand, integrated several angular convex thorns on the outside of the two support plates, and then utilized an oil pressure system to squeeze the support plates toward the hole wall to form a thorn, which improved the construction efficiency. Feng Tian et al.[14] designed a semi-prefabricated molding device for cast-in-place thorn piles by penetrating steel bars into soil. The guide columns are used to apply hydraulic pressure to the radial hydraulic channels of the guide discs so that the rebars attached to the ends are pierced into the soil, and the lateral rebars are partly located in the soil and partly in the concrete after the construction of the piles is completed.

Moreover, the above thorn piles are concentrated in the cast-in-place piles, and there are a series of disadvantages in the process of pushing and squeezing. First of all, the cylinder and hydraulic pipeline need to be transported to various heights of the drilled hole and constantly expanding and retracting, which is a cumbersome and laborious operation; secondly, the hole wall is not stable, even if there is a slurry wall protection, but the steel tip retraction from the small pits or extrusion of the hole wall at other heights of the action will result in the perturbation, which will lead to the collapse of the small pits that have already been molded, and ultimately lead to the later pouring of the pile body of the concrete of the various spurs of the shape of the irregular, consequently, it is difficult to guarantee the quality of the pile. In addition, the existing methods are in the hole using hydraulic equipment to push the rigid body into the thorns, thorn length is limited, the pile side resistance gain is limited. What's more, the existing technical solutions all need to develop matching thorn pile molding equipment, which is complicated to operate and expensive, and the construction equipment needs to be maintained and serviced, which increases the cost again. In order to overcome the drawbacks of the above piles and some technical problems in construction, and considering the broad market prospect of precast piles, a new forming method and equipment for prefabricated thorn piles were researched and designed using the principle of telescopic rod and the method of pneumaticr pressure extrusion. The construction method of prefabricated thorn piles was also explored, laying the foundation for subsequent field tests and engineering applications.

2. Molding design of precast thorn piles

Precast piles are easy to make, quick to form piles, easy to control the quality of pile body, high bearing capacity, and can be made into different shapes, sizes and lengths according to the needs, and are not affected by groundwater, and there is no mud discharge and other problems. In order to effectively solve the problem of thorn length, inspired by telescopic rod, a sleeve-type thorn pile[15] was designed by the method of prefabricating the pile body and squeezing and pushing into thorn by pneumatic pressure. The thorn pile is a precast concrete pile body on the basis of a core tube, a multi-section sleeve is bolted to the core tube, and the upper end of the core tube is connected to an air compressor via a gas pipe, the conceptual design of which is shown in figure 1. The sleeve-type thorn pile can effectively solve the problem of shorter thorns, pile body and thorns are prefabricated more environmentally

friendly and economical, and no need to develop new construction equipment, just pneumatic pressure the thorns into the soil.



(a) Overall construction diagram (b) Core tube construction diagram

Figure 1. Conceptualized design of precast thorn piles
Note:1. Prefabricated pile body 2. Pile tip 3. Multi-section sleeve 4.Core tube 5.Gas pipe

3. Precast thorn pile molding key technology

(1) The design of the multi-section sleeve effectively increases the length of the thorns and substantially improves the pile lateral resistance. The construction details of the sleeve-type pile thorns are shown in figure 2.

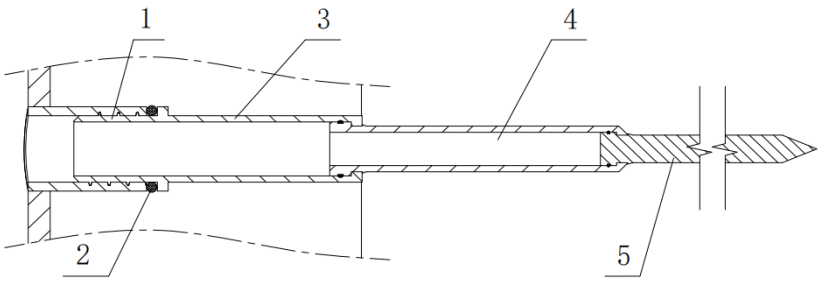


Figure 2. Construction diagram of sleeve-type pile thorns
Note: 1. Threaded section 2. Sealing ring 3. Outer sleeve 4.Inner sleeve 5.Thorn root

(2) In order to ensure the horizontal stability of the sleeve (pile thorn) during pile sinking, solid grease is coated on the inner wall of the sleeve, which serves two purposes: firstly, to

avoid the accidental protrusion of the multi-section sleeve at room temperature; secondly, after the thorn pile has been formed, the solid grease is melted by the high-temperature air, which reduces the frictional resistance of the multi-section sleeve, and facilitates the thorns to penetrate into the soil on the side of the pile in a better way. The arrangement of solid grease is shown in figure 3.

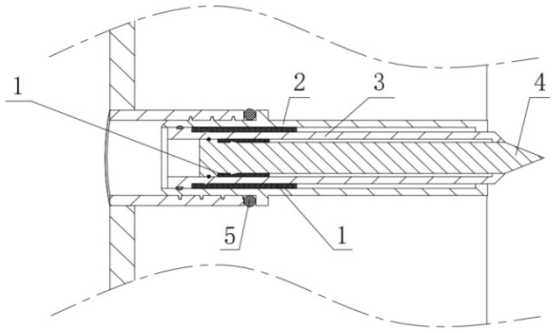


Figure 3. Arrangement of solid grease
Note: 1. Solid grease layer 2. Outer sleeve 3. Inner sleeve 4. Thorn root 5. Sealing ring

(3) To ensure the overall airtightness of the thorn pile, a core tube is designed and tightly bolted to the sleeve, while a rubber seal is added to the sleeve. The airtight design of precast thorn piles is shown in figure 4.

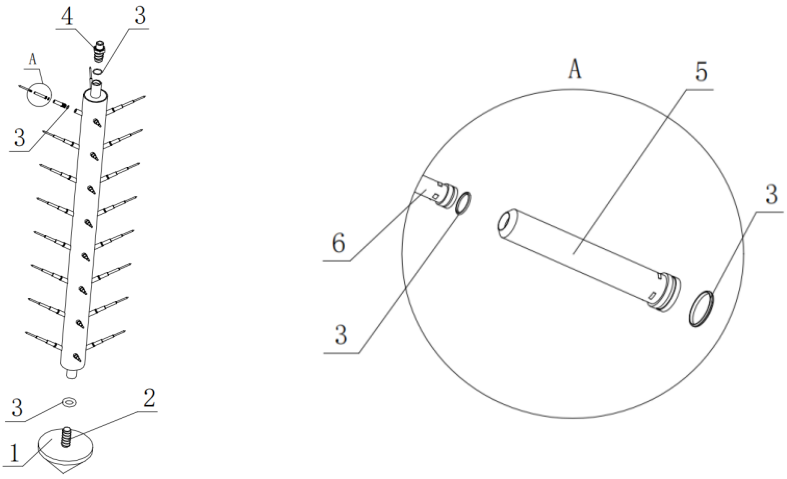


Figure 4. Airtight design of core tube
Note: 1. Pile tip 2. Screw 3. Seal ring 4. Joint 5. Inner sleeve 6. Thorn root

(4) In order to ensure that the sleeve can be fully extended under the action of pneumatic pressure, simulation tests are carried out on site to determine the value of pneumatic pressure required for the full extension of all thorns, and at the same time carry out molding inspection of the thorn piles.

(5) Multiple unidirectional teeth are provided in the sleeve to prevent the sleeve from springing back under the lateral pressure of the soil when the pneumatic pressure inside the core tube drops. The design details of the unidirectional teeth are shown in figure 5.

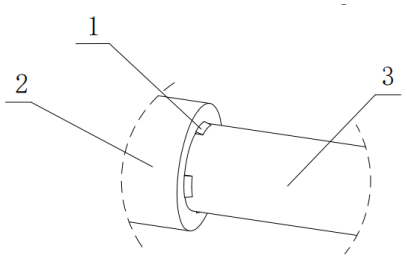


Figure 5. Detailed construction of unidirectional teeth
Note: 1. Unidirectional tooth 2. Outer sleeve 3. Inner sleeve

4. Construction process of precast thorn piles

(1) Prefabricated pile forming. Prefabricate the barometric and temperature controlled thorn pile body in site or factory. First, each base casing is welded on the core tube, and the shrinkable overlapping external expansion casing is connected with the corresponding base casing sealing thread. Then tie the reinforcement cage and pour and ram the precast pile concrete.

(2) Pile sinking. Before the pile is sunk, it is necessary to clear the obstacles, level the site, carry out the pile driving test, lay out the line and set the pile position. The precast pile body is hoisted to the predetermined pile position, and the pile is driven to the set elevation by hammer, static pressure or vibration, and the quality of the pile is controlled according to the specifications.

(3) Pressure push into thorns. The air compressor is started on the ground, and air is delivered to the core tube through the gas pipe, and the air is heated to the melting point temperature of the solid grease through the heating tube. In this way, after the high temperature air reaches each lateral hole, it will push the graded outer expansion casing outward into the pile side soil, and form a stable thorn structure after being fixed by a unidirectional tooth.

(4) Cap construction. After the thorn is formed, remove the air compressor and then cut the pile head and construct the cap.

The specific construction process is shown in Figure 6.

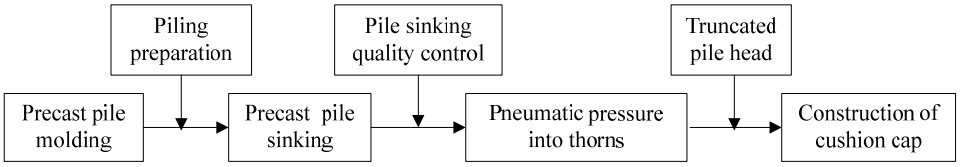


Figure 6. Construction process of precast thorn pile

5. Discussion

Pneumatic thorn pile is a method that uses high-pressure air as power to extrude and push the pile thorn, replacing the existing hydraulic driving mode. It naturally eliminates a series of disadvantages caused by hydraulic extrusion, such as water leakage, dilution of pile side soil, increased probability of steel corrosion, and reduced durability of pile concrete structure. However, further in-depth research is still needed in the following aspects:

(1) Pneumatic pressure control method. In the process of extrusion, the control of pressure includes the establishment of pressure path, pressure rate, stable pressure value, and stable pressure time, which need to be further verified through indoor and on-site testing, in order to design a complete system for pressure application.

(2) Quality testing method for pile thorn forming. The pile body of the pneumatic thorn pile has high quality and strong bearing capacity. However, the process of thorn forming belongs to underground concealed engineering. The expansion effect of the thorn structure and the final quality need to be verified by mature and reliable testing methods.

(3) Thorn length problem. Through indoor testing verification, the bearing capacity of the foundation pile is positively correlated with the length of the thorn. The longer the pile thorn, the higher the compressive and tensile bearing capacity. The sleeve-type thorn structure can effectively increase the thorn length to about 1 times the pile diameter, but how to achieve a longer thorn length depends on a more optimal design scheme.

6. Conclusion

Thore pile is a new type of pile with high bearing capacity and has great market potential. In this paper, inspired by telescopic rods, a sleeve-type thorn pile is designed by the method of prefabricating the pile body and squeezing and pushing into thorn by pneumatic pressure. This method can effectively overcome the problems of hole collapse, lack of thorn length and sashimi quality. There are several innovations as follows:

- Solid grease material was selected to ensure that the pile thorns protruded during the pile sinking stage;
- The overall airtightness of the precast thorn pile is effectively solved by installing a core tube;
- One-way snap teeth are provided in the sleeve to avoid the rebound of the pile thorns after the pressure is removed;
- Precast thorn piles are a technological innovation for pile foundations, providing a new treatment method for solving poor foundations.

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