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Analysis and Research on the Superlong Prestress of PHC Pipe Piles in Soft Soil Foundation

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Abstract: *Because of its high compressibility, low bearing capacity and low shear strength, many industrial factory floors in coastal areas have serious settlement, cracking and inclination after completion, which leads to the failure of normal production. PHC construction technology is a common construction technology in soft soil foundation treatment, which has many advantages such as stability, reliability and high bearing capacity, but it needs quality control from many aspects. The design of super-long piles in the current code is not based on the bearing deformation mechanism of super-long piles. The contradiction between theory and practice makes it not only the need of the development of pile foundation theory itself, but also the urgent requirement of engineering. In this paper, the advantages of PHC pipe pile are comprehensively expounded, and the construction stage of PHC pipe pile in soft soil foundation is introduced from the construction stage of PHC pipe pile applied to civil engineering foundation in soft soil foundation, and the super-long prestress of super-long PHC pipe pile in soft soil foundation is analyzed and discussed.*

Keywords: *Soft soil foundation; PHC pipe pile; Prestressing force*

1. Introduction

Press-stressed high-strength concrete pipe-pile (PHC) pipe pile has many advantages, such as strong bearing capacity, stability and convenient construction, and is widely used in land pile foundation engineering [1]. In the engineering of bridge foundation, hydraulic structure, port wharf and offshore platform, the pile foundation bears horizontal load as well as vertical load. The pile top is subjected to lateral load, and the failure behavior of pile and foundation is different due to the differences of pile geometry size, pile top constraint conditions, pile material strength and foundation soil characteristics [2]. PHC, as a new precast pile type, embodies the progress of modern concrete technology and the high-tech concrete products, which are made of centrifugal pipe-making technology and prestressed technology. According to the tensioning sequence of prestressed tendons, prestressed pipe piles can be divided into pre-tensioning PHC and post-tensioning PHC [3]. Because soft soil generally has the characteristics of large thickness, high water content, large void ratio, low strength and high compressibility, the bearing capacity of soft soil foundation is low, and the deformation after bearing load is large. A little negligence in construction will inevitably lead to cracking, even damage and instability of buildings [4]. As far as the actual construction situation is concerned, there are still some problems in the use of PHC pipe piles in soft soil foundation, such as the stability of pipe piles caused by soft soil displacement, the uneven settlement of buildings caused by soil squeezing effect and friction resistance [5]. It is of great significance to study the solutions to these problems for the application and development of pipe piles.

PHC can be divided into pre-tensioned prestressed pipe piles and post-tensioned prestressed pipe piles according to the tensioning process. Generally speaking, PHC refers to pre-tensioned prestressed pipe piles, that is, hollow cylindrical precast concrete members [6] made by pre-tensioned prestressed centrifugal molding process under the condition of high temperature and high pressure steam curing. The axial load borne by the pile is supported by the pile side friction acting on the soil around the pile and the pile end resistance of the pile end stratum, and the horizontal load is supported by the lateral resistance of the soil around the pile [7]. Prestress transfer performance refers to the performance of prestressed members to realize stress transfer by self-anchoring of high-strength steel bars in concrete without anchor fixture [8]. Its main index is the prestress transfer length, that is, the length to establish the prestress value required by the design by the concrete gripping force at the end when the prestressed reinforcement is relaxed, that is, the distance from the end to the place where the stress in

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the high-strength reinforcement reaches the constant value of effective stress [9]. For the case of poor or poor shallow soil, it is necessary to use special construction methods and machines to build the foundation, so that the deep soil layer can be used for bearing. Such a foundation is called deep foundation [10]. According to the experimental study of different pile cutting methods such as pre-tensioning PHC upsetting release, cutting, hammer drilling and pneumatic pick drilling, this paper puts forward the advantages of PHC high-strength prestressed pipe pile in engineering projects, analyzes the super-long prestress of super-long PHC pipe pile in soft soil foundation, and provides reliable experimental basis for design.

2. Application advantages of PHC pipe pile

The design of super-long piles in the current code is not based on the bearing deformation mechanism of super-long piles. The contradiction between theory and practice makes it not only the need of the development of pile foundation theory itself, but also the urgent requirement of engineering.

In order to solve the problem of limited land use in coastal cities, many land reclamation projects have been carried out, but most of the soil in these reclamation areas is loose soil, soft soil and miscellaneous fill. Because these soils are close to the sea area or planned to be used before, they all have some shortcomings, such as low strength and high compressibility. PHC high-strength prestressed pipe pile is sunk by static pressure method, which has no noise, vibration and impact, can realize 24-hour operation, increase construction time and shorten construction period, and the pile body is prefabricated in the factory, so it can be said that static pressure pile has entered the industrialization track of foundation treatment [11]. The selection of soft soil foundation treatment methods should also be considered from the aspects of project duration, economic benefits and project safety. For concrete mixing piles, the depth of pile reinforcement is limited, and the construction quality is not well controlled, and the number of tests after the completion of pile construction is large. In terms of pile sinking speed, PHC high-strength prestressed pipe pile has few pile sinking procedures and simple operation, such as hanging the pile in place, adjusting the verticality of the pile foundation and pile, applying pressure to check the verticality and continuing to apply pressure to the design elevation. If the foundation is treated by preloading method, considering the low strength of soft soil foundation, the loading speed should not be too fast, which will seriously affect the project progress and lose the economic benefits; During the construction of dynamic compaction method, because the soil is squeezed sharply, it has obvious effect on the soft soil stratum with good permeability, but not on the soft clay, and the clay and argillaceous soil foundation in coastal areas are not suitable.

PHC pipe pile is a finished pile, and the concrete has already reached the age when it leaves the factory, while other pile types (such as cast-in-place piles) cannot be inspected until the concrete reaches the age on site, which undoubtedly shows that the construction period of PHC pipe pile is better than other pile types. Compared with other methods, if pile foundation is used to treat soft soil foundation, its advantages are: stable pile quality, high bearing capacity, economical cost, flexible control of pile treatment depth, which can be used in different geological conditions, and can greatly enhance the stability of soft soil foundation, greatly improve the bearing capacity of foundation soil and reduce the deformation of foundation soil. During the static pressure construction of PHC pipe piles, there is no wet operation, no hole-forming and wall-protecting technology, no mud pool, no mud removal, no environmental pollution such as dust on the construction site and road spilling. In addition, the static pressure pile technology eliminates the pollution of construction noise. Under normal circumstances, the prestress of PHC pipe pile is transmitted from upsetting to steel plate at the end of the pipe pile, and then acts on concrete. Under the condition that the pipe pile is not damaged, there is no problem of prestress transmission length. However, due to various reasons in the construction site, it is necessary to cut piles. At this time, the preloading stress of concrete is transmitted by the anchoring force between steel bars and concrete, which leads to the problem of prestress transmission. Due to the static pressure construction of PHC pipe pile, it has a compaction effect on the foundation, which increases the passive earth pressure of the soil, so it has a positive impact on the side friction of the pile foundation. The design of PHC pipe pile considers the side friction and the end friction of the pile, so the pile length can also be shortened.

3. Problems existing in the construction of precast PHC

The phenomenon of broken piles can be caused by soil squeezing effect, blind excavation of

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foundation pit, unqualified pile quality, quality problems of pile connection and weld, inconsistency between the loading center of pile frame and the pile center, blind increase of pile pressing force and forced pile sinking, and mechanical reasons of pile foundation. There is a high pore water pressure in the vibration remolded area, and the seismic strength of the soil also decreases greatly. Generally, the greater the pile density, the greater the displacement of the soil, and the greater the adverse impact on the adjacent buildings or underground pipelines, and the squeezing effect is likely to cause the pile to float. Precast PHC belongs to soil squeezing pile, which has soil squeezing effect and will produce compressive tensile stress. When the compressive tensile stress exceeds the tensile strength of concrete, the pile body will produce circumferential cracks, which will further lead to pile breakage. Engineering geological investigation is an important part of pipe pile foundation engineering. The design and construction of pile foundation engineering need to know the engineering geology, hydrogeological conditions of the proposed site and the physical and mechanical properties of the foundation soil layer. Therefore, geotechnical engineers must put forward a reasonable investigation scheme according to the characteristics of the proposed project before designing the pile foundation. The building may be under the force of its own weight, and the soft soil may be drained and consolidated to some extent, which will lead to its uneven settlement; Due to the constant change of sedimentary environment, there are a few dense, coarse-grained silt or sand layers in the middle of soft soil layer, which leads to uneven settlement of building foundation.

In static pressure construction, when the clamping force is too large and the pipe pile wall is thin, the pipe pile will be crushed. When there is a deviation in the outer diameter of the pipe pile, stress concentration will occur at the clamping part of the clamp, which will lead to longitudinal crack, ring crack or damage. The low strength of pile body or the large loss of effective prestress of pipe pile are also the reasons for pile breaking. Compared with natural foundation investigation, the requirements for the layout of exploration points in pile foundation engineering investigation are higher, because the pile foundation has strict requirements for the fluctuation range of the bearing layer at the pile end, so the spacing of exploration points is relatively small; At the same time, the influence depth of pile foundation is deep, so the depth of exploration hole is deeper than that of natural foundation. The main reasons that lead to the imbalance of earth pressure are as follows: Earthwork is not transported out of the construction site in time, and piling up near the pile foundation will lead to uneven hands on both sides of the pile foundation, and the excavation of earthwork may change the surrounding groundwater level, resulting in the problem of uneven settlement of the ground and the displacement of the soil position. In addition, large-scale earth-digging machinery is easy to cause soil vibration in the construction site and reduce the seismic capacity of the soil. When the pile frame is pressed in a plane with uneven stacking load, the center of gravity of the pile frame is inconsistent with the center of the pile, resulting in eccentric force. When the pile frame is pressed to the ultimate load, it may tilt to the heavy part, and the pile frame will slightly shake or move, thus causing the pile pressing force to produce a bending moment on the pipe pile. When this bending moment exceeds the cracking bending moment, the pile body will break.

Other workload of exploration is higher than that of shallow foundation, so when the proposed building may adopt pile foundation, the exploration points should be arranged according to the requirements of pile foundation. In the stage of construction, when encountering thick interlayer or soft-hard alternating stratum, in order to prevent slipping, the pile clamping force is often too large, which makes the compressive stress too large and will also cause the damage of the pile. Due to the uniqueness of the material structure and composition of soft soil, the premise of pore water drainage is that under long-term load, with the drainage of pore water, soil particles move back to a more stable position, resulting in certain deformation of soil. Therefore, the influence of pipe piles in soft soil foundation also has many stability problems. When obstacles exist not far below the ground, the pile may tilt when sinking, which will lead to the fracture and damage of the pile body in serious cases; When the tonnage of the pile driver is large, there will be higher requirements for the bearing capacity of the construction site, especially in the newly filled soil, cultivated soil and the site soaked in water, the edge of the chassis will be plastically deformed, which will easily lead to the sinking of the pile, resulting in a large pile position deviation.

4. Analysis of super-long prestress of super-long PHC pipe pile

During the sinking stage of pipe pile, the soil equivalent to the pile volume is repelled around, and the surrounding soil will be seriously affected, and the soft soil in a certain range at the pile tip and around the pile will be strongly squeezed horizontally, resulting in large-scale deformation. Generally speaking, the faster the hammer hits the pile head, the stronger the force generated on the pile, so pay

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attention to maintaining appropriate penetration in order to reduce the hammer stress. The pile head gasket also has a direct effect on the hammering stress. Proper use can prolong the hammering time, reduce the hammering speed and reduce the hammering intensity. Due to the high compressibility of soft soil, after the pore water in the soil is discharged during piling, the soil shrinks, and the soil around the pile moves downward relative to the pile, which produces negative friction on the pile and causes the pile to float. In the stage of construction, the displacement mode will change with the increasing length of piles buried in the soil.

It is forbidden to pile up soil at the edge of foundation pit, and the excavated soil should be transported out of the construction site immediately. Making other forms of load by stacking at the edge of foundation pit will increase the sliding moment, destroy the balance and change, which will seriously affect the stability of pile. During the excavation stage of pile foundation, it may cause the imbalance of soil pressure on both sides, make the soil shift to the excavation side, and cause the distortion or deviation of pile foundation. In the excavation of pile foundation in soft soil foundation, the combination of small excavator and manual excavation can be used to avoid the liquefaction of soft soil caused by vibration caused by large mechanical operation, thus effectively improving the stability of pile. PHC construction technology is shown in Figure 1.

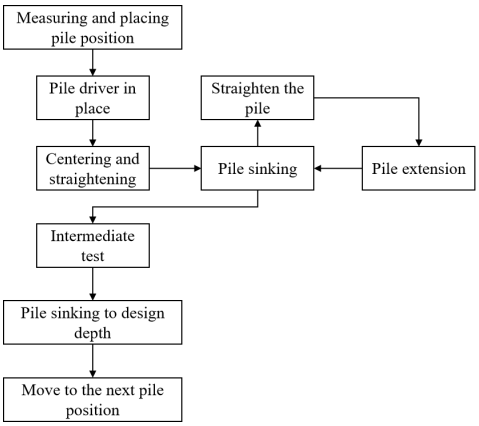

Figure 1: PHC construction technology

When choosing the pile length, it should be based on the composition of the foundation soil layer, according to the principle of crossing the soil layer with the highest compressibility as far as possible, and the bearing layer at the pile end is relatively low in compressibility, and it is required that the pile can still give full play to and continue to maintain its full ultimate bearing capacity under the condition of allowable settlement of the pile cap. The constitutive model of concrete in this paper is as follows:

Ascending segment:

$$\sigma = \sigma_0 \left[2\left(\frac{\varepsilon}{\varepsilon_0}\right) - \left(\frac{\varepsilon}{\varepsilon_0}\right)^2 \right], \varepsilon \le \varepsilon_0 \tag{1}$$

Descending section:

$$\sigma = \sigma_0 \left[1 - 0.15\left(\frac{\varepsilon - \varepsilon_0}{\varepsilon_u - \varepsilon_0}\right) \right], \varepsilon_0 \le \varepsilon \le \varepsilon_u \tag{2}$$

Under the action of working load, the axial compressive stress of super-long piles will generally not exceed the strength of their concrete, so the constitutive equation is derived from parabolic curve:

$$E_T = \frac{\partial \sigma}{\partial \varepsilon} = \frac{2\sigma_0}{\varepsilon_0}\left(1 - \frac{\varepsilon}{\varepsilon_0}\right) = \frac{2\sigma_0}{\varepsilon_0}\sqrt{1 - \frac{\sigma}{\sigma_0}} \tag{3}$$

Because PHC has pre-stress before the load from the superstructure. Assume that the initial preloading stress of pipe pile is σ_{pc}, and the initial pressure of pipe pile is generally written in the product manual of pipe pile. If it is not indicated in the manual, it can be $\sigma_{pc} = 5MPa$. The

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corresponding initial tangent elastic modulus is:

$$E_{T0} = \frac{2\sigma_0}{\varepsilon_0}\sqrt{1-\frac{\sigma_{pc}}{\sigma_0}} \tag{4}$$

The Poisson's ratio of concrete has no obvious relationship with the strength grade of concrete, and generally $\mu = 0.2$ can meet the accuracy requirements.

In the stage of pile foundation excavation, if it is found that the pile is excessively displaced or inclined, the excavation should be stopped immediately and corresponding measures should be taken to deal with it. When selecting the pile section, the allowable bearing capacity of a single pile determined by the structural strength of the pile should be matched with the ultimate bearing capacity of the foundation soil to the pile, so as to give full play to the bearing capacity of the pile material.

5. Conclusion

Using PHC group piles to strengthen the foundation and the overall stability of steel pipe columns, the construction difficulties of high support, urgent construction period and poor geological conditions during cast-in-place beam construction are effectively solved, the safety risks are reduced, the construction progress is accelerated, and remarkable economic and social benefits are achieved. PHC effectively improves the bearing capacity of soft soil foundation and reduces the settlement of foundation through the joint action of piles, soil between piles and cushion, thus ensuring the normal use of terrace. Using PHC pipe pile in soft soil foundation can improve the stability of foundation. PHC has obvious advantages in soft foundation treatment. In practical application, we should combine the actual situation of the project, optimize the construction scheme and strengthen the supervision and management of the construction process, so as to ensure the construction quality and create excellent projects. The successful application of this method can be used for reference for the construction of cast-in-place bridges with high supports in soft soil areas.

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