

Billing Principles and Economic Analysis of Helical Anchor Foundations for Transmission Lines

-- A Case Study on a 750 kV Transmission Line Project in Xinjiang

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Abstract

With the wide application of mechanized construction and increasingly stringent environmental & water conservation requirements for transmission line projects, a variety of new foundation types have been popularized with prominent comprehensive advantages. Helical anchor foundations feature short construction cycles, high mechanized construction efficiency, zero concrete consumption and zero earth excavation works. Based on the construction procedures and test specifications of helical anchor foundations, this paper proposes the billing criteria for main structure construction and test costs. Taking the application of helical anchor foundations in a 750 kV transmission line project in Xinjiang as the research case, cost comparisons with conventional foundation types are conducted to calculate the economic threshold for adopting helical anchor foundations.

Keywords

Helical anchor foundation, billing principle, cost estimation analysis.

1. Introduction

The earliest application of helical anchors dates back to 1833, when they were adopted as lighthouse foundations around tidal estuaries in England. Systematic research on helical anchors commenced in the 1950s. Domestic and overseas scholars have carried out extensive experimental and theoretical research on vertical bearing performance, horizontal bearing performance and combined bearing performance of helical anchor foundations. Rao et al. [1] conducted pull-out tests on four model helical anchors with different quantities and spacing ratios of helical plates in soft marine clay to investigate uplift bearing capacity. The cylindrical failure surface assumption was adopted, and the influence of helical plate spacing was taken into account. Yenumula[2] performed field horizontal loading tests on helical piles with varying numbers of helical plates in clay, and drew the following conclusions: the horizontal bearing capacity of helical piles rises with the increase of buried depth and soil shear strength; the bearing capacity of multi-helical-plate piles is higher than that of single piles, and increases with the number of helical plates. Shi Qian et al.[3] carried out model tests on double-helical-plate anchors in sand, and found that the uplift bearing capacity increases with the growth of helical plate spacing and buried depth. Zhang Qi et al.[4] mainly adopted empirical formula method, static load test method and static cone penetration test method to analyze the influence of multiple variables on the reliability index of ultimate bearing capacity of single helical piles

under inclined loads, studied the calculation modes of ultimate bearing capacity, and derived the limit state equation.

Although abundant mechanical performance research achievements of helical anchor foundations have been accumulated at home and abroad, the application of helical anchor foundations in transmission line projects is still in the initial stage, and there is no unified standard for expense billing. Therefore, a complete set of billing rules for helical anchor foundations is urgently needed to guide practical engineering work.

This paper briefly introduces the structural form of helical anchor foundations first, then puts forward quota billing standards for helical anchor main body installation and full-scale test fees. On the basis of practical data of helical anchor foundations adopted in a 750 kV transmission line project in Xinjiang, cost comparison with conventional foundations designed under identical site conditions is implemented to calculate the economic threshold of helical anchor foundations, providing cost reference for further popularization and application of helical anchor foundations.

2. Overview of Helical Anchor Foundations

A helical anchor foundation is an anchoring assembly composed of helical anchors and upper steel bearing caps, which resists loads transmitted from superstructures relying on deep soil layers.

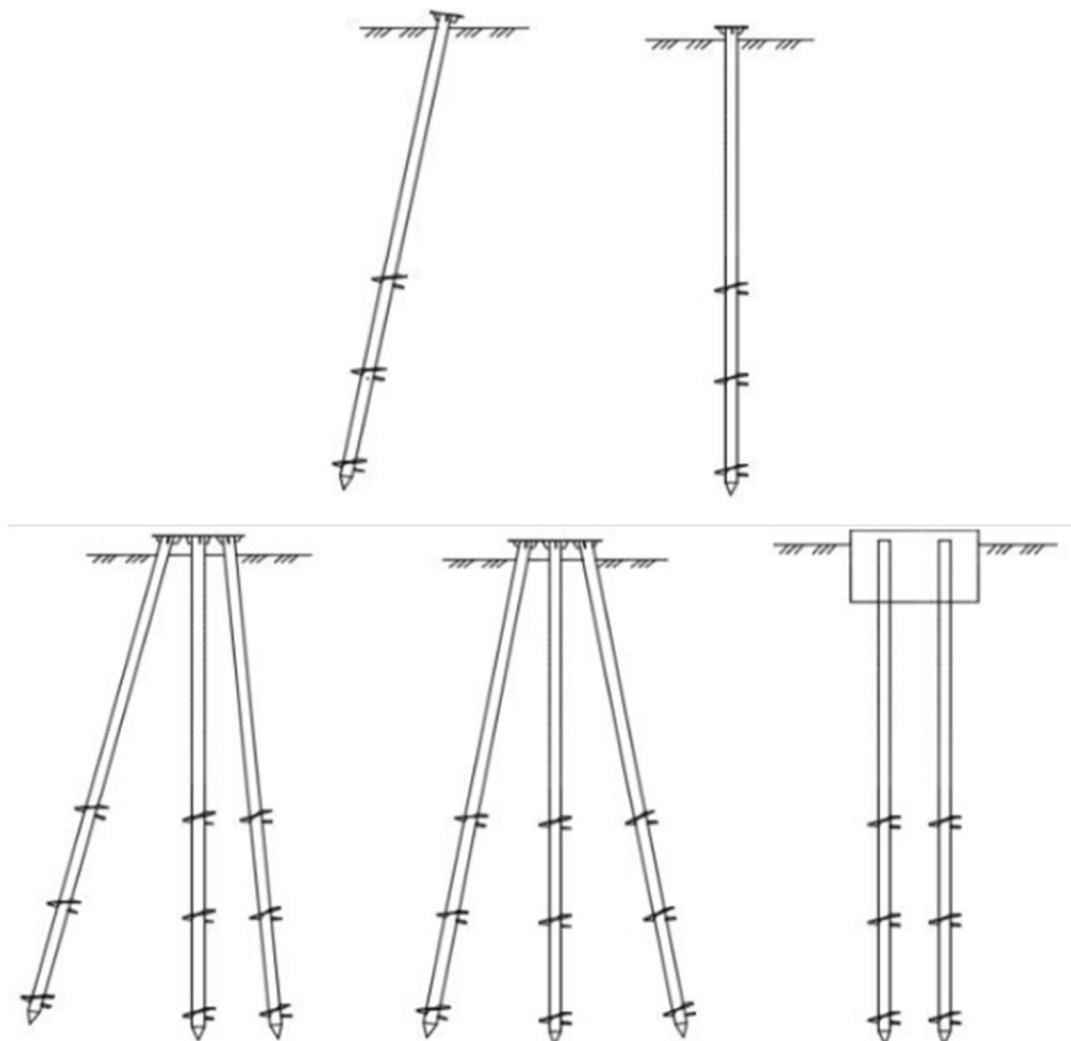


Figure 1. Classification Forms of Helical Anchor Foundations

Helical anchor foundations are classified into single-anchor foundations and group-anchor foundations according to the number of anchor shafts. Single-anchor foundations are further divided into inclined single helical anchor foundations and vertical single helical anchor foundations based on the included angle between anchor shafts and vertical direction. Group-anchor foundations consist of inclined group helical anchor foundations and vertical group helical anchor foundations; inclined group helical anchor foundations can be subdivided into variable-inclination group inclined helical anchor foundations and equal-inclination group inclined helical anchor foundations, as shown in Figure 1.

A single helical anchor consists of anchor tip, helical plates, anchor shaft and connecting fittings, as shown in Figure 2.



Figure 2. Composition of Single Helical Anchor

Field photos of completed helical anchor foundations are shown in Figure 3.



Figure 3. On-site Photo of Completed Helical Anchor Foundation Connection Node

The construction process of helical anchor foundations includes nine key working procedures: foundation layout survey, rotary drilling rig positioning, helical anchor screwing penetration, top surface trimming of group anchors, positioning of steel bearing cap angle steel, steel bearing cap welding (factory welding for single anchors, field welding for group anchors), ultrasonic

flaw detection for group anchors, anti-corrosion paint coating, and final foundation acceptance[5,6]. In accordance with relevant specifications, full-scale bearing capacity tests shall be conducted before construction, and corresponding test costs shall be included in project investment.

3. Billing Principles for Expenses of Helical Anchor Foundations

According to the content of the Supplementary Quota for Helical Anchor Foundation Engineering (Trial) (State Grid Electric Construction [220] No. 28), the main construction of helical anchor foundations requires the inclusion of helical anchor installation and steel pile cap installation. Among them, helical anchor installation is into single anchor and group anchor, calculated by the number of anchors according to the design, with "piece" as the unit of measurement; steel pile cap installation is divided into single anchor group anchor, calculated by the number of steel pile caps according to the design, with "unit" as the unit of measurement. The work content of helical anchor installation includes construction preparation surveying, setting out pile positions, on-site transportation, screwing in guide piles and extension piles, pile-to-pile connection, cutting and grinding of pile ends, site cleaning and movement of tools and equipment; the work content of steel pile cap installation includes construction preparation, excavation and backfilling of welding working surfaces, lifting and positioning of steel pile caps, steel cap welding, reinforcement plate welding, non-destructive testing, application of anti-corrosion coating, site cleaning, and movement of tools and equipment.

If transmission line projects adopt helical foundations, a full-scale prototype test is generally conducted before the main construction to verify the bearing capacity of the foundation.

According to the requirements of the "Technical Code for Testing Building Piles" JGJ106-2014, helical anchor foundations require single pile vertical compression static load tests, single pile vertical uplift static load tests, and pile horizontal static load tests after construction. The "Guiding Opinions on the Inclusion of Foundation and Pile Testing Fees for Power Transmission and Transformation Projects" (State Grid Corporation of China Construction Quota Station Standard (GDFY-2023-04)) provides corresponding prices based on different load levels F (unit: kN) for testing and different pile D (unit: mm) of helical anchors. Therefore, the total cost of helical anchor foundations, in addition to the main construction costs, includes the materials and installation costs of the test anchors and steel accessories for testing equipment, the materials and installation costs of the reaction pile foundations, as well as the vertical and horizontal static load testing costs of the pile bodies⁴ Cost Comparison with Conventional Foundation Types.

4. Comparison with Traditional Base Costs

Helical anchor foundations are suitable for ordinary soil, sand and other soft soil layers with high mechanization level. Considering the mobilization cost of anchor rotary rigs and loading test devices, helical anchor foundations are mainly promoted on flat terrain and desert areas. Thus plate foundations and manually excavated foundations are selected as comparative conventional foundation types in this analysis.

Taking a 750 kV transmission line project in Xinjiang as the research object, technical and economic indicators including concrete consumption, steel consumption, earthwork volume and total foundation cost are compared between inclined single helical anchor foundations, plate foundations and manually excavated foundations under identical geological and environmental conditions, as shown in Table 1.

The supporting project is located in Ruoqiang County, Xinjiang Uygur Autonomous Region, with a total route length of 119 km and 257 newly-built tower foundations, among which 20

foundations adopt helical anchor structures. The steel weight of test anchors is 9 tons; steel and accessories for test equipment weigh 3.2 tons; reaction pile foundations for tests consume 220 m³ concrete and 19.98 tons steel. Cost calculation is based on the winning bid contract price of helical anchor steel materials and the latest local construction material market price of the project.

Table 1. Technical & Economic Comparison: Helical Anchor Foundation vs. Conventional Foundations

Fundamental type	Helical anchor foundation	Raft foundation	Bored pile foundation	Note
Concrete (m3)	/	737.6	440	12-base ZB1, 8-base ZB2 foundations, raft foundations, and openings use C40 concrete, with the surface coated 500-micron thick epoxy asphalt anti-corrosion coating.
steel(kg)	60928	86754	40560	The winning bid price for steel in helical anchor foundations is 8,700 yuan/ton including tax, while traditional foundation steel uses the current information price
Earthwork(m3)	/	11492	531.2	
cost(10,000 yuan)	71.38	221.15	183.16	
Unit construction cost (10,000 yuan)	3.57	11.06	9.158	

Supplementary Notes:

- 1) The listed cost of helical anchor foundations excludes full-scale test fees.
- 2) Steel consumption does not include anchor bolts.
- 3) Geological condition: silty fine sand mixed with round gravel.

Test fees of helical anchor foundations are affected by the steel weight of test anchors, dimension of reaction pile foundations and quantity of test anchors. Generally, test costs rise with higher voltage grades. Test cost data of helical anchor foundations for the supporting project are listed in Table 2.

Table 2. Test Expenses of Helical Anchor Foundations

Voltage(kV)	Quantity of work or cost
Test anchor steel quantity (tons)	11.2
Concrete volume of reaction pile	220.304
Steel reinforcement quantity of reaction pile	19.98
Basic cost (10,000 yuan)	86.42

It can be concluded from Table 1 and Table 2 that if only main construction costs are considered, helical anchor foundations have obvious advantages over traditional plate foundations in construction cost, safety performance, environmental protection and material conservation. However, full-scale test fees must be incorporated into total project investment, so helical anchor foundations can only realize economic superiority when the construction scale reaches

a specific threshold. Based on geological and cost data of the Xinjiang project, the economic thresholds are calculated as follows:

Threshold compared with plate foundations: $(86.42 \div (11.06 - 3.57) = 11.54)$ tower foundations.

Threshold compared with manually excavated foundations: $(86.42 \div (9.158 - 3.57) = 15.47)$ tower foundations.

A total of 20 helical anchor foundations are arranged along the whole line of this project. After including test expenses, the total investment is reduced by approximately 640,000 RMB compared with plate foundations, and about 250,000 RMB compared with manually excavated foundations.

5. Conclusion

This paper analyzes the full cost composition of helical anchor foundations and puts forward standardized billing principles. Through cost comparison with conventional foundation types, the main conclusions are summarized as follows:

- 1) Compared with traditional foundations, helical anchor foundations have multiple advantages including shorter on-site construction period, zero earth excavation, reduced material consumption, convenient and efficient construction, high mechanization degree and lower main structure cost.
- 2) Based on research on construction procedures and review of relevant national & industrial specifications, the total investment of helical anchor foundations covers not only installation fees of helical anchors and steel bearing caps, but also static load test fees for vertical and horizontal bearing performance verification.
- 3) When full-cycle costs (including test fees) are taken into consideration, helical anchor foundations have a definite economic threshold against conventional foundations. The threshold value varies with different site and geological conditions of individual projects, and shall be calculated after geological survey and before foundation design.
- 4) Helical anchor foundations shall be widely promoted in ultra-high voltage (UHV) and extra-high voltage (EHV) transmission line projects to improve overall project economic efficiency and reduce total construction investment.

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