Impact Analysis of Pipe Pile Support for Deep Foundation Pits: Postprint

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Abstract

Deep foundation pit engineering constitutes a highly complex geotechnical engineering problem involving soil properties, support structures, groundwater, and surrounding environment, among other factors. The rationality of support scheme selection for deep foundation pits directly influences the safety, economic efficiency, and construction schedule of the support structure. In the design of deep foundation pit support, it is essential to integrate site conditions and characteristics of the surrounding environment to innovatively select support types that can effectively resolve practical engineering challenges while demonstrating superior performance across all comparative aspects. This paper presents a case study of a deep foundation pit support design scheme, conducting comparative analysis from perspectives of design calculations, construction implementation, deformation monitoring, and economic considerations. Through multi-index evaluation, the comprehensive benefits of employing cast-in-place piles and pipe pile support systems are examined and analyzed, which will provide positive guidance and serve as a valuable reference for subsequent similar projects.

Full Text

Preamble

Impact Effect Analysis of Pipe Pile Support in Deep Foundation Pits

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Abstract

Deep foundation pit engineering is a highly complex geotechnical problem involving soil properties, support structures, groundwater, and the surrounding environment. The rationality of support scheme selection directly affects the safety, economy, and construction schedule of the support structure. In deep foundation pit support design, innovative support types should be selected based on site conditions and surrounding environment characteristics to solve practical engineering problems while achieving optimal comprehensive performance. This paper discusses a deep foundation pit support design scheme, comparing and analyzing design calculations, construction processes, deformation monitoring, and economic aspects. Through multi-index evaluation, the comprehensive benefits of using cast-in-place piles versus pipe pile support are examined, providing positive guidance and reference for similar future projects.

Keywords: deep foundation pit; tubular pile supporting; comprehensive benefits
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1. Introduction

With the rapid development of urbanization in China, issues such as scarce construction land, inconvenient transportation, and limited space have become prominent. As development extends both above and below ground, numerous deep foundation pits have emerged. Deep foundation pit engineering is a highly complex geotechnical problem involving soil properties, groundwater, and the surrounding environment. Support structures are generally temporary. In support design, how to fully consider engineering geology, hydrogeological conditions, and surrounding environment to design a support scheme with good stability, small deformation, low investment, guaranteed construction period, and manageable construction difficulty—i.e., a support scheme with optimal comprehensive benefits under multi-index evaluation—presents a challenge for foundation pit designers and a concern for project owners. With current restrictions on anchor cable usage and primary emphasis on engineering quality, large-diameter rotary drilling cast-in-place piles are increasingly applied in foundation pit support projects. This paper uses an actual deep foundation pit support design as an example, comparing and analyzing support effects of rotary drilling cast-in-place piles and steel pipe piles for different sections of the same foundation pit based on deformation monitoring results of surrounding buildings, internal force and deformation calculations, construction schedules, costs, pile construction techniques, and construction quality. The analysis results provide a reference for future similar foundation pit support scheme selection and design.

2. Project Overview

2.1 Foundation Pit and Surrounding Environment Conditions

The proposed main structures consist of three super high-rise residential buildings, with the remainder being low-rise commercial buildings and a basement, all featuring shear wall structures. The project includes an integrated three-level basement. According to the geological survey report provided by the client, surrounding road network and pipeline data, and on-site surveying results, the actual excavation depth of the foundation pit is 14.1 m (including a 300 mm deep drainage ditch inside the pit), with a perimeter of 517.6 m.

The environment outside the foundation pit red line is as follows: on the east side is a boundary wall and 30 m wide Baita Road with heavy vehicle traffic; on the south side is a 20 m wide planned road, opposite which is a residential community; on the west side is a 15 m wide planned road; on the north side is a boundary wall and 24 m wide planned road, opposite which is a 10-story office building of the State Taxation Bureau. The safety level for the Baita Road side of the foundation pit is Grade I, while the remaining sides are Grade II.

2.2 Engineering Hydrogeological Conditions

Based on drilling data, the soil structure and its physical and mechanical properties reveal that the site foundation soils can be divided into five major layers according to genesis types: Quaternary artificial accumulation layer (Qml), alluvial-proluvial layer (Qal+pl), alluvial-lacustrine layer (Qal+l), residual-slope layer (Qel+dl), and Permian Lower Maokou Formation (P1m) bedrock. The site soil exhibits typical multi-rhythmic alternating deposition characteristics, with significant undulation of the bedrock (limestone) surface.

The site groundwater types include Quaternary loose layer pore water and bedrock (limestone) karst water. Based on pumping test results, the groundwater influence radius is 86.1–92.9 m, indicating significant impact on the foundation pit. The loose layer pore water is weakly confined, primarily occurring in the silty sand layer with strong permeability and water richness, followed by the gravel layer with moderate permeability and weak to moderate water richness. The shallow loose layer groundwater has a shallow burial depth, with water level and discharge varying significantly by season, posing considerable impact on foundation pit engineering. The physical and mechanical property indices of each soil layer are shown in Table 1.

Notes:
1. Data marked with “*” in the table are empirical analogy values.
2. According to the geological survey report, except for the shallow artificial fill and organic clay which are under-consolidated soils, the remaining soil layers are normally consolidated. Therefore, direct quick shear indices are used for miscellaneous fill, organic clay, and gravel, while consolidated quick shear indices are used for other layers.

2.3 Foundation Pit Support Design

The division of foundation pit support sections is shown in the support plan layout [Figure 1: see original paper]. To save support costs, recyclable steel pipe piles were used for local support piles on the east side of the foundation pit, specifically Q235 830×12 welded steel pipes. For support sections 1-1, 4a-4a, and 4b-4b, after a 3.5 m bench slope at the top, 830 steel pipe piles at 1.1 m spacing + 4 rows of anchor cables at 2.2 m spacing were adopted. Section 5a-5a (main building 12.2 m from pit edge) used 830 steel pipe piles at 1.1 m spacing + 4 rows of anchor cables at 2.2 m spacing after overall 3.5 m excavation and bench slope. Section 5b-5b used 830 steel pipe piles at 1.2 m spacing + 4 rows of anchor cables at 2.4 m spacing after overall 3.5 m excavation. Section 2-2 used 800 cast-in-place piles at 1.3 m spacing + 4 rows of anchor cables at 2.6 m spacing after a 4 m wide, 3.5 m high bench. Section 3-3 used 800 cast-in-place piles at 1.1 m spacing + 4 rows of anchor cables at 2.2 m spacing after a 1.8 m wide, 3.5 m high bench. The water cutoff curtain piles used 600 long spiral mixing piles at 400 mm spacing, with pile lengths of 18–20 m. All support faces were reinforced with mesh shotcrete, with capping beams installed at pile tops. Detailed support section drawings using steel pipe piles and cast-in-place piles are shown in [Figure 2: see original paper] and [Figure 3: see original paper].

3. Support Effect Analysis

3.1 Force Analysis of Two Support Pile Types

Using the Lizheng Deep Foundation Pit Support Structure Design Software 7.0, comparative analysis was performed on internal force calculation results for C30 reinforced concrete support piles with a diameter of 0.8 m and Q235 830×12.0 seamless steel pipe support piles. For convenient comparison, two support sections with essentially identical conditions were selected for analysis: foundation pit depth of 14.1 m, support pile embedment depth of 7.4 m, pile top elevation at -3.50 m, pile spacing of 1.2 m, capping beam dimensions of 1.2×1.8 m, and similar surrounding additional loads. The calculation results are shown in [Figure 4: see original paper] and [Figure 5: see original paper], respectively. [Figure 4: see original paper] and [Figure 5: see original paper] present the calculation results using steel pipe piles and reinforced concrete piles for support, respectively. Comparative analysis reveals that when using steel pipe piles, the maximum displacement of the pile body is larger than that of reinforced concrete piles, while the maximum bending moment is smaller for reinforced concrete piles, with essentially no influence on the maximum shear force.

3.2 Deformation Analysis

Third-party monitoring results for surrounding buildings, roads, underground pipelines, and retaining wall top displacement were analyzed, with results shown in Table 2. The maximum vertical displacement of the retaining wall top was

-4.17 mm, and the maximum horizontal displacement was 4.3 mm, both relatively small values. The maximum settlement of underground pipelines was 5.51 mm. Vertical displacement of surrounding buildings reached 4.82 mm. Vertical displacement of surrounding roads exceeded horizontal displacement, with a maximum vertical displacement of only 4.99 mm. All deformation values are far smaller than the control values, indicating the support structure is safe and reliable. [Figure 5: see original paper] presents the final deformation monitoring results, showing that deformation monitoring results for steel pipe pile support were slightly larger, with a maximum of 4.3 mm, while reinforced concrete cast-in-place pile support showed a maximum deformation of 3.0 mm. The difference is minimal, and the deformations are very small—only 1/10 of the allowable control value of 30 mm—demonstrating that steel pipe pile support fully meets requirements with a shorter construction period.

As this was an experimental study, most of the support used 800 long spiral drilling cast-in-place piles. The project quantity for 800 rotary drilling C30 concrete cast-in-place piles was 5,173 m, with a unit price of 697.8 yuan per meter, totaling 3,609,709.05 yuan. The project quantity for 830 steel pipe piles was 630 m, with a comprehensive unit price of 525 yuan, totaling 330,750 yuan. The water cutoff used 600 deep mixing piles, with a total cost of 897,582 yuan. Comparing the two, the unit price per meter for 800 long spiral drilling cast-in-place piles is 172.8 yuan higher than that for 830 steel pipe piles. If all long spiral drilling cast-in-place piles were replaced with steel pipe pile support, the total cost could be reduced by 893,894.4 yuan.

4. Steel Pipe Pile Construction and Recycling

Steel pipe piles were constructed using alternate pile construction, with joints connected by lap welding using an ICE hydraulic vibratory hammer. Given the project’ s downtown location and thick gravel layer, steel pipe piles above the gravel layer were pre-drilled, with an average pre-drilling depth of 2.5 m (specific depth determined based on actual site conditions). The upper part of the foundation pit exposed a thick loose gravel layer. According to rotary drilling cast-in-place pile trial drilling conditions, if mud wall protection experienced severe collapse, steel casing wall protection was used in the upper gravel layer section.

For convenient construction and recycling, pile tops were alternately exposed 0.5 m and 1.0 m above the capping beam. For recyclable steel pipe piles, a film was installed between the mesh and steel pipe pile to ensure shotcrete would not bond to the steel pipe pile.

Key points for steel pipe pile recycling: (1) Recycle in sections, with section lengths within 20 m; (2) Within the same recycling section, piles constructed earlier are recycled later, and piles constructed later are recycled earlier (i.e., remove the higher pile heads first, then the lower ones); (3) Backfill soil in layers to the designed anchor cable elevation, release anchor cable tension, then backfill to the upper anchor cable elevation and release tension—repeat this cycle until reaching the capping beam top before recycling; (4) Use an ICE hydraulic vibratory hammer suspended from a crawler crane, vibrating the steel pipe pile before extraction to liquefy surrounding soil for easier recycling; (5) For anchor cables connected to steel pipe piles, tension must be released for recycling, so anchor head steel strand reserved length should be >70 cm, with strand ends wrapped with binding wire to prevent damage.

[Figure 6: see original paper] shows the schematic diagram of 830 steel pipe pile support, and [Figure 7: see original paper] shows the connection position between 830 steel pipe piles and 800 cast-in-place piles. Pile tops are alternately exposed 0.5 m and 1.0 m to connect with the capping beam, while cast-in-place pile tops expose reinforcement bars extending into the capping beam. [Figure 8: see original paper] and [Figure 9: see original paper] show the welded steel pipe piles and construction diagram, respectively. In terms of construction speed, steel pipe pile construction is much faster than cast-in-place pile construction. Cast-in-place piles require hole drilling, reinforcement cage placement, and concrete pouring, which needs time to reach sufficient strength, whereas steel pipe piles can be driven immediately. Therefore, steel pipe pile construction periods are shorter, and steel pipe piles can be recycled and reused, unlike cast-in-place piles.

5. Conclusions

1) For complex site and surrounding environment conditions, multiple support schemes should be analyzed and compared to select the optimal design.

2) Through comparative analysis of steel pipe piles and reinforced concrete cast-in-place piles for the same foundation pit, steel pipe pile support demonstrates good effectiveness, short construction period, recyclability, resource savings, and cost reduction. Vertical and maximum horizontal displacements of the support structure, as well as deformation of surrounding roads and pipelines, are all within the allowable ranges specified in relevant codes. The steel pipe pile support design scheme is highly effective and safe, providing excellent protection for the surrounding environment while conserving resources and reducing costs.

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Note: Figure translations are in progress. See original paper for figures.