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Construction Technology of Pile Foundation for Subway Tunnel Crossing Bridge

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Abstract: Urban infrastructure has become more complex with the rapid development of urban transportation networks. In urban environments with limited space, construction of facilities like subways and bridges may mutually influence each other, especially when subway construction requires passing under bridges. In such cases, pile foundation replacement technology is often necessary. However, this technology is highly specialized, with a lengthy and risky construction period, and high costs. Personnel must be proficient in key technical aspects to ensure construction quality. This article discusses the technical principle, construction process, and core technology of pile foundation replacement, along with the application of this technology in subway tunnel crossing bridge projects, supported by engineering examples for reference.

Keywords: Subway tunnel; Bridge pile foundation; Replacement construction

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1. Introduction

With the rapid development of cities and the increase in population, the problem of urban traffic congestion gradually appears. The construction of subways has become the primary solution to urban transportation problems. The growing development and construction of subways can impact existing city buildings, particularly when subway tunnels intersect with bridge pile foundations. In such scenarios, utilizing pile foundation replacement technology becomes essential for smooth construction. Hence, studying the application of this technology is crucial.

2. Pile foundation replacement construction

2.1. Technical principle

Pile foundation replacement involves installing new pile columns alongside the steel bars to be replaced. An enlarged column head is placed on top of the pile, and a steel supporting beam is positioned on the new pile, aligning it with the original column's midpoint. During construction, a jack exerts force on the cap, facilitating the transition to the new pile. Once the structure is stable, concrete, including steel support, is incrementally added to create a new cap, forming a cohesive new bridge structure to maintain structural integrity [1].

2.2. Construction process

Preparation work such as ground support and anchor pile construction should be done before pile foundation replacement. Prefabricated steel support beams are then replaced, and manual hole digging is conducted to excavate the foundation pit for the new cap. Enlarged head construction is carried out on the pile top of the manually excavated pile, and steel plates are affixed to the bottom surface of the original cap [2]. Upon repositioning the steel support beam, it is anchored between the original caps. Jacks and I-beams are placed atop the pile, and jacks are used to lift the pile. Finally, the original pile foundation is cut off in stages, and side planting of the original caps, binding of steel bars, and concrete pouring are executed. The entire process is closely monitored throughout its duration.

2.3. Core technology

Pile foundation replacement construction involves several key technologies. Firstly, pile body reinforcement ensures the original pile body is straightened to ensure full articulation between the pile and the beam. The second technology is jacking operation, which involves structural loading and requires careful placement of jacks between the beam and replacement columns, with steel mat boards set up above and below. During construction, hierarchical loading is used to control the jack within the same beam body, while monitoring deformation, support pile, pier column, and settlement to prevent safety issues. After jacking, the jack is locked [3]. The third technology is node connection. Interface agents are applied in concrete at the beam bottom and column top, reserved steel bars are welded, and then concrete is poured [4].

3. Construction technology of pile foundation replacement for subway tunnel crossing bridge

3.1. Project overview

In this urban subway construction project, an underground tunnel connects two stations in a north-south direction. The foundation is buried at a depth of 14.8 m, and a special-shaped bridge spans 19 m + 19.5 m + 13.5 m above the tunnel. Prestressed concrete materials are utilized, with special-shaped porous plates poured at a thickness of 0.76 m. Enlarged pile construction involves manual digging to form the special-shaped bridge foundation structure, with pile dimensions of 1.2 m in diameter and 7.9m in length. Independent columns support the special-shaped plates, while caps and rectangular pier columns are positioned above the bridge, measuring 6.5 m × 3 m and 1.2 m × 0.9 m, respectively. The distance between the column structure and the tunnel top is 3.9 m, with a 1.5 m distance between the tunnel center and the column side. During construction, foundation parts such as piles require removal to ensure original bridge safety and smooth tunnel construction progress. Therefore, buttressing construction on bridge piles and other foundation parts is necessary to reinforce the structure and maintain safety during construction.

3.2. Infrastructure construction

During the foundation structure construction of this project, several key steps are involved, including ground support, replacement of new piles, excavation of bearing platform pit, and pile expansion. Given the pile foundation replacement process, the shaped bridge surface is susceptible to decline. To address this, temporary support is employed at the pile foundation position using steel pipe material (φ609 mm × 14 mm). Temporary support is placed on the bearing platform of replacement piles, with four supporting steel pipes arranged around the pier columns. A 200t jacking weight jack is positioned atop the steel pipes to prevent subsidence issues during pile foundation replacement. Each support position jack is adjusted according to the actual subsidence of the profiled plate and pier column during construction to ensure that the profiled plate deformation remains within a controllable range [5]. During the replacement of new piles for the bridge, two locations require new piles with a length of 23m and a diameter of 1.6m. Piles include a pile expansion head at the top position and are grouted with submerged concrete, type C30, using a pressurized grouting process. A waterproofing layer is installed below the pile top elevation to create an isolation layer with negative friction on the outside of the pile body. Due to the large diameter of the piles and limited clear height under the bridge, hand-dug piles are constructed during the pile-forming stage. Excavation of the bearing platform pit is carried out manually. Layered excavation is carried out with a layered height of 1.5m, [6].

Due to the limitations of the construction site, it is necessary to control the slope ratio of the pit, with 1:0.3 being the best ratio. For the excavation process, the anchors are driven perpendicular to the direction of the slope. The anchors are made of φ20mm rebar, and concrete is sprayed on the surface of the slope after hanging the mesh on it. After the excavation and support construction of the bearing platform pit is completed, the pile foundation is treated with an expanded head, and the embedded steel plate is accurately processed according to the design drawings, with reserved holes for grouting, exhausting, and anchoring reinforcement on the steel plate surface to ensure precise hole placement. Reinforcement bars are then tied. When connecting the expanded head and steel joists for beam anchorage, steel bars are connected using splicers, ensuring they do not touch the steel beam bottom surface. The splicer’s height is controlled lower than the actual rail height after steel beam placement. Micro-expansion concrete (C30) is used in the construction process, ensuring that the material expansion rate is not less than 0.03%, with pouring being continuous and uninterrupted. To control pile foundation deformation during replacement, if the pile foundation and expanded head reach the designed strength gradually, decompression treatment of the pile foundation is required based on site conditions to ensure that the single pile load does not exceed 41000kN [7].

3.3. Pile foundation replacement construction

Ensuring the connection between the original bearing platform and the steel joist is secure is crucial during the pile foundation replacement process. This involves drilling holes in the ground of the bearing platform and then installing steel plates on top. Once the steel joist is in position, it is fixed with bottom anchor bolts for added stability.

3.3.1. Installation of steel joist

Q345D-type steel plates are used for the one-way, double-chamber girder structure. The steel plate dimensions are 9.1m in length, 1.9m in width, and 1.0m in height. Standard steel girders are processed by the manufacturer. Due to the relatively large size and weight of the steel bearing platform, installation requires auxiliary machinery. A 35 t automobile crane is chosen to position around the bearing platform pit. Tracks are laid in advance in the foundation pit, and then the steel beam is placed on top, with the steel cap positioned beneath using equipment such as a truck crane, jack, and hand hoist. Positioning errors may occur, and accuracy is adjusted using a theodolite and level to ensure a tight fit between the steel support beam and the original cap surface. Once precisely positioned, jacking operations are completed using a jack, followed by the installation of I-steel. Subsequently, the steel bracket is replaced and the I-steel is anchored in place [8].

3.3.2. Structure jacking construction

The jacks must be laid out before commencing jacking construction. When the steel beam is in place, two 200t jacks are positioned above the top of the new pile. Following the safety factor standard of twice the load during jack usage, each jack can provide 800t lifting force for the pier column during jacking. The distance between the centerline of the pile column and the replacement pile is 400mm, ensuring a symmetric distribution of jacks along the pier column centerline to ensure equal bearing pressure for each jack. Safety should be paramount during jacking construction. After each jacking operation, the jack screw must be locked. Once the jacking height reaches the design value, I-beams are placed on both sides of the top of each pile, totaling 12. I-steel and jacks form a load-bearing structure, supporting the safe operation of steel beam jacking and preventing jack failure due to uneven discharge.

It is important to ensure the structural safety of the shaped plate during jacking construction. Therefore, the equipment must be carefully debugged in advance to prevent horizontal displacement of the steel beam during jacking operations. Following equipment debugging, the steel beam is firmly connected to the original cap using self-cutting anchor bolts. Subsequently, anchorage steel bars above the expanded head of the pile foundation are inserted into the steel beam using connectors. Precise control of the jacking process is vital, and a hydraulic lifting synchronization control system, coupled with comprehensive monitoring through information technology, can be employed. Control of the replacement construction strength is critical, achieved through accurate control of structural displacement during jacking operations. The initial jacking force is set at 500kN, incrementally increased layer by layer with each lifting level also set at 500kN. The support load is continuously monitored during jacking, and if pre-roofing force loss is excessive, supplementation is required promptly. Pre-roofing force should be sustained until joist deformation stabilizes. If jack elevation stabilizes and the relative displacement of the jack and joist span center remains stable at 5.0mm, then the jacking force increase operation can be stopped. The next construction operation is decided based on the monitoring data and site displacement. After applying external jacking force in each construction phase, a steel pad must be added between the I-beam and steel beam to ensure structural stability.

During the jacking construction, it is crucial to focus on controlling the drag replacement steel beam and monitoring the force situation of the new pile foundation to ensure operations stay within safety limits. All jacks should increase their jacking volume synchronously. Specific control points during the jacking operation include stress monitoring, using detectors to keep track of jacking force and stress in the steel beam span [10]. It is also important to monitor the new pile foundation and steel beam for any anomalies during hydraulic jacking to address them promptly and avoid safety risks. Displacement monitoring is crucial, with monitoring points set up at the hydraulic top of all jack sections to track displacement generated by the steel beam during jacking operations at all levels. Applying monitoring measures ensures all hydraulic jacking operations are carried out simultaneously, with limit control instruments installed at the jacking place of the steel beam and new pile foundation to control jacking height and speed. Stress generation and redistribution during the jacking of the new pile foundation can impact construction quality if jacking values are high. Therefore, strict adherence to the construction program is necessary, controlling the overall jacking height within design values. After each jacking operation level, the actual jacking volumes of all hydraulic jacks should be checked to ensure consistency. If inconsistencies arise, adjustments must be made before proceeding with the next jacking operation.

3.3.3. Pile cutting construction

Secondly, it’s essential to pay attention to displacement monitoring during the jacking process. Monitoring points are placed at the hydraulic top of all jack sections to promptly track displacement generated by the steel beam at all jacking levels. Considering the actual construction needs, the jacking operation of the project comprises six levels. The steel base furthest from the subway building is chosen, and it is operated level by level truncation. The first truncation is set at 1/3, followed by the second at 1/2, the third at 2/3, and finally, all levels are truncated. When each level of the pile foundation is cut off, steel shims are used to wedge the foundation position tightly to ensure that the steel beam is laterally stabilized. All levels of pile links are cut off, and changes in the steel beam are closely monitored. If necessary, the jacking force is adjusted to ensure that the relative displacement of the dislodged steel beam remains unchanged, the elevation value between the pier and the shaped plate remains unchanged, and so is the elevation of the top of the original abutment.

3.3.4. Bearing platform construction

After the pier pile foundation is cut off, the pier top elevation is adjusted, and any settlement before construction is supplemented. The structure is observed, and once the area is stabilized, the screw device of the jack is locked, and the shell and cylinder are tightly welded. Once all the reinforcement planting operations of the original bearing platform are completed, the bearing platform reinforcement is retied according to the construction plan to ensure the firmness of the structural connection of the reserved reinforcement at the position of the expanded head of the pile foundation, the reinforcement of the new bearing platform, and the steel beams. Once the reinforcement of the new bearing platform position is tied, the supporting operation is carried out, and then concrete is poured. The pouring process is carried out in layers to ensure that the vibration operation is reasonable and the structural compactness is up to standard.

4. Conclusion

Pile foundation replacement technology is required during the construction of the subway tunnel crossing bridge. The construction plan is designed based on the site conditions. It is crucial to prioritize the key points of foundation construction and pile foundation replacement construction to ensure construction safety and quality. This approach ensures the smooth progress of the subway tunnel crossing the bridge construction project.

Disclosure statement

The author declares no conflict of interest

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