Original Research Article

Construction Technology of Underpinning and Pre-supporting Pile Foundation of Special-shaped Slab Beam in Urban Interchange

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Abstract: With the rapid development of China's urbanization process, the original transportation plan cannot fail to meet the needs of urban economic development, and the transformation and upgrading of the urban transportation system is imminent. Urban rail engineering has become the only way to solve traffic problems in major core cities. However, conflicts between subway shield tunnels and existing building foundations occur from time to time, especially when some important buildings and public facilities cannot be demolished, underpinning technology is required. This paper relies on the Shijiazhuang Metro Line 2# underpassing the urban overpass special-shaped slab beam construction and bridge project built in 1994, combined with the past pile foundation underpinning and current intelligent construction technology, in the multi-support prestressed concrete special-shaped slab beam substructure pile foundation Intelligent pre-supporting technology is adopted in the underpinning construction process, which solves the problem of synchronous control of multi-supporting special-shaped slab girder under complex environment, and ensures the safety of construction and bridge operation.

Keywords: Urban interchange; Special-shaped slab beam; Underpinning of pile foundation; Intelligent pre-supporting technology.

1. Engineering Overview

The section between Chang 'an Park Station and Lantian Shengmu Station of Shijiazhuang Metro Line 2 is under the urban overpass construction and bridge, and the section is constructed by shield tunneling method. The shield tunnel conflicts with the four pile foundations of the north block 45# and 46# of the Jianhe Bridge and the six pile foundations of the south block 40# and 42#, so it is necessary to replace the pier foundations of 45#~46# and 40#~42# with pile foundations.

Jianhe Bridge was opened to traffic in 1996. The upper structure of the two-storey ring bridge is prestressed concrete multi-point supported special-shaped slab. Jianhe Bridge main bridge range is a ring bridge, divided into east, south, west, north four shaped block bridge, the four blocks are not symmetrical. Special-shaped block beam height 1.3, cantilever 3m, multi-box special-shaped prestressed structure. The pier 40#~42# is a row of fulcrum piers in the middle of the south shaped block, which is a single cylindrical pier with a diameter of 1.2m and a height of 3.6m. Under each column are four pile caps of 6.3×6.3×2.0m, pile foundation diameter of 1.5m, pile length of 20.6m; Piers 45# and 46# are a row of fulcrum piers in the middle of the north shaped block, which are single cylindrical piers with a diameter of 1.2m and a height of 3.6m. Under each column are four piles of 6.3×6.3×2.0m, pile foundation diameter of 1.5m, pile length of 20.6m.

2. Overview of Existing Technologies

According to the different application status and core technical mechanism of the underpinning technology, it is mainly divided into active underpinning and passive underpinning. The former means that loads are applied to the new pile and the underpinning structure before the original pile is unloaded to partially eliminate the time-

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dependent effect of long-term deformation of the underpinning system, and the deformation of the underpinning structure and the superstructure is dynamically regulated by the jacking device during the load transfer process of the upper part. Generally used for bearing loads or structural deformation requirements of high bearing engineering, relatively high reliability; The latter refers to the original pile in the unloading process, the superstructure load with the deformation of the supporting structure, passively transferred to the new pile, generally used in the supporting load is small, relatively low reliability.

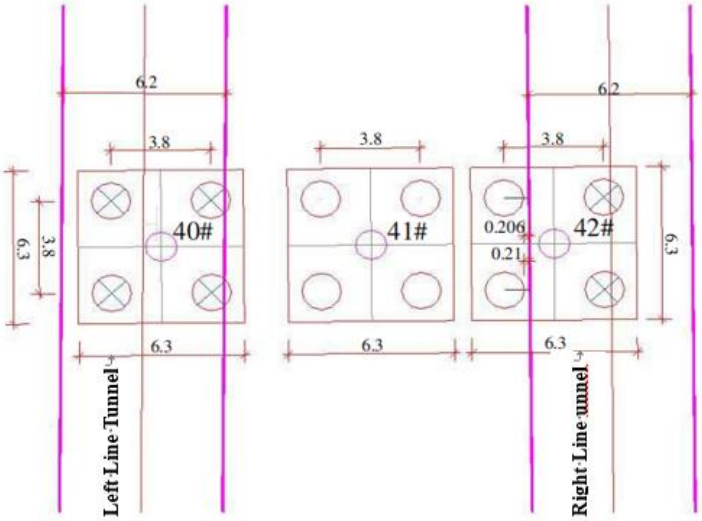

Figure 1 Plan view of the shield tunnel in relation to piers 40# and 42#.

The disadvantages and shortcomings of the prior art are as follows: (1) It is difficult to determine the pre-supporting force of each fulcrum in the complex stress system of the multi-fulcrum special-shaped prestressed concrete slab beam; (2) Synchronous control of multi-fulcrum special-shaped plate beam support and settlement can not be realized during the transformation of beam structure stress system during the construction of pile foundation substructure replacement.

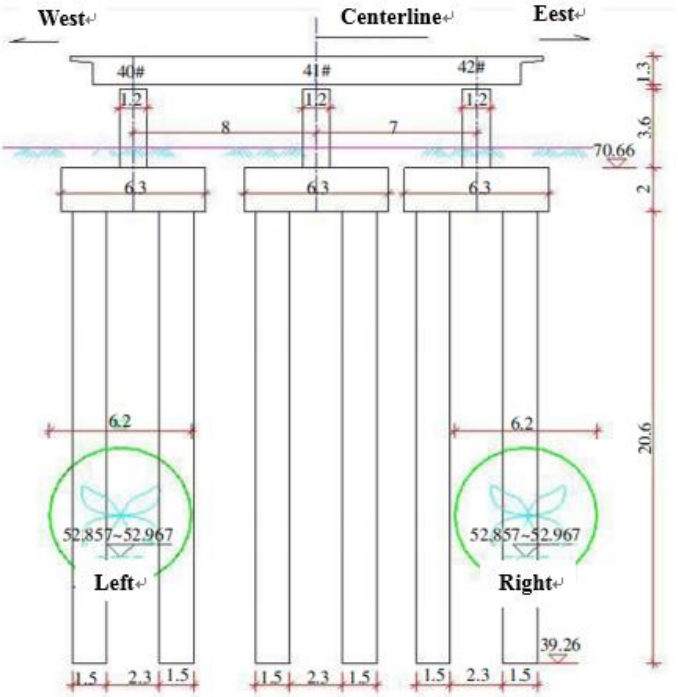

Figure 2 Elevation of shield tunnel in relation to pier 40# and 42#.

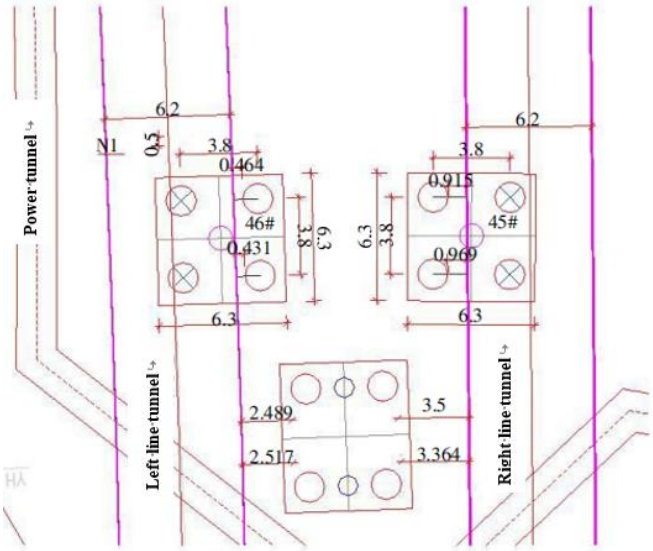

Figure 3 Plan view of the relationship between the shield tunnel and piers 45# and 46#.

3. Problems Faced

(1) Before pile foundation replacement, the supporting force of each fulcrum of the multi-fulcrum special-shaped plate beam is different, so the critical value of uneven settlement and the pre-supporting force of each fulcrum should be determined.

(2) The stress structure of the multi-fulcrum special-shaped plate beam is complex, the structural deformation of the upper and lower parts of the beam body is stable, and the beam body is more sensitive. It is necessary to solve the problem of synchronous settlement of the upper structure during the process of replacement and the transformation of the beam body stress system after construction.

(3) Jianhe Bridge was built in 1994, has been used for many years, its deformation has been completed, and its upper structure is multi-fulcrum prestressed concrete special-shaped slab beam. It is necessary to ensure the safety of construction and bridge operation during the construction process of pile foundation replacement and the secondary deformation and stability of beam structure after construction.

4. Intelligent Pre-Supported Roof Construction Technology

During the excavation of pile foundation pit, the 40#~42#, 45# and 46# piers dug 4m below the bottom of the old cap may weaken the bearing capacity of the original pile foundation, which may lead to the subsidence of the cap pier, and the adjacent piers 22#, 28# and 34# may also be affected by different degrees of subsidence. When the shield passes through the bridge area, the soil in a certain range of the shield tunnel body will rise and fall to a certain extent, so that the pier will change to different degrees. Therefore, it is necessary to preload the above piers. When some or some piers settle, the beam body can be lifted to the initial position through the preload roof system. Avoid the cracking of the beam body and ensure the operation safety of the beam body.

Before pile foundation replacement, the settlement is not stable when the new cap is not loaded. Therefore, the jacking system is set up between the new and old caps to complete the system conversion. Before the old pile is cut off, 1.2 times of the design load is applied to the new cap, so that the settlement of the new cap becomes stable quickly. After the settlement is basically stable, the old pile foundation between the new and old caps is cut off, so that the new and old caps are in a free state. If the lifting is not more than 1mm, the supporting reaction is determined, and finally concrete is poured between the new and old caps. Specific construction steps are as follows.

The first step: construction preparation and construction of retaining pile, foundation pit excavation, erection of pre-supporting roof equipment; The second step: construction supporting pile foundation, supporting

cap; Step 3: Install jack and jacking; Step 4: cut pile; Step 5: Underpinning structure sealing; Step 6: Construction of shaft and manual excavation of residual piles in the tunnel area; Step 7: Shield through; Step 8: Remove the prepaid roof facility.

4.1 Jacking Control Unit

4.1.1 Pre-Supported Roof Settlement Control and Buttress Jacking Control Mode

The automatic control program is designed in two modes: overall breaking action and automatic. The manual mode is normal operation mode, and the manual mode is transferred before the operation starts. The automatic model is the safety guarantee mode, and the job is transferred to the automatic mode after completion. In automatic mode, when the system detects that the force and deformation exceed the limit, the SMS notifies the authorized phone, and the system will automatically run according to the set action.

When the manual mode is running, it is adjusted according to the adjustment value provided by the third-party monitoring, and checked by the force situation of itself and the adjacent pier; During automatic operation, 90% of the minimum support reaction force calculated by design is the upper limit, 70% is the lower limit, and the limit of each stroke is 1mm, at this time, the jack is mainly borne by the liquid pressure, and a small part is borne by the thread self-locking. When 70% of the reaction force is analyzed in the finite element analysis model, the stress increase of the beam body does not exceed the design value of anti-cracking.

4.1.2 Principle of Hydraulic Control System for Settlement Control of Preloaded Roof and Jacking of Pallets

In the pumping station system, the pressure retaining valve, accumulator and safety valve are reasonably designed, and the hydraulic pump with rated flow rate of 1.2L/min is selected. Through two kinds of safety valves can control the oil pressure of thousands of pounds, to prevent the use of jack overload; The rated flow rate controls the jacking speed of the jack, the shutdown valve provides convenience for troubleshooting, and the hydraulic components in all pumping stations are jacks of the same specification and model and the same tonnage, and the consistency is obtained when the speed is adjusted by the frequency converter. The negative feedback control ensures the synchronization. The pumping station design schematic diagram is shown in Figure 5.

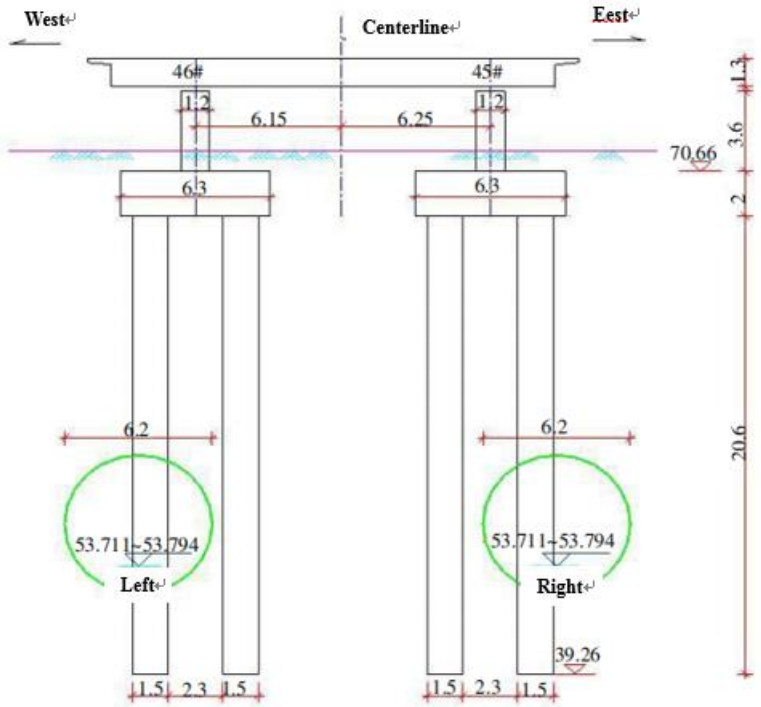

Figure 4 Elevation of shield tunnel in relation to pier 45# and 46#.

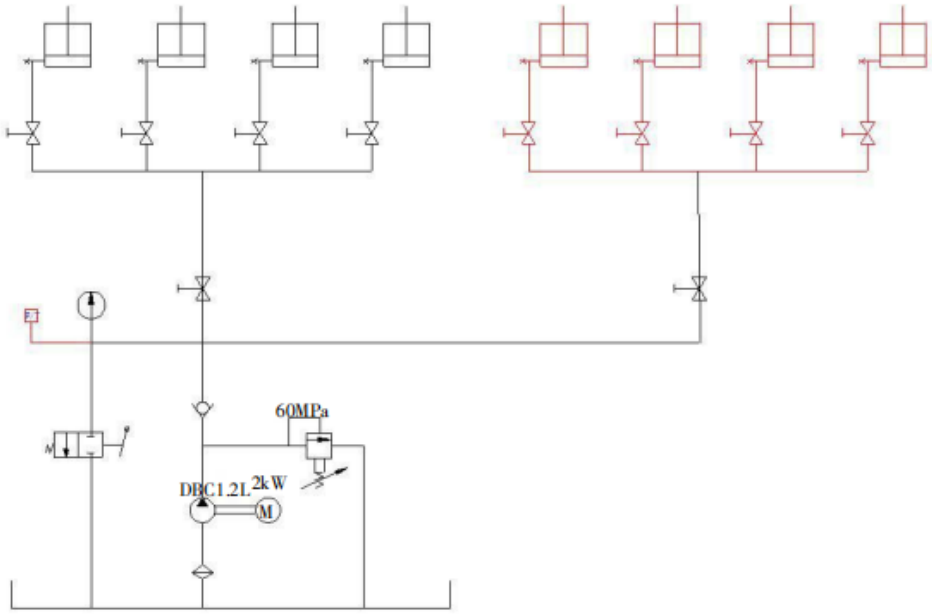

Figure 5 Hydraulic schematic diagram of jacking control equipment.

4.1.3 Principle of the Electrical Control System for Settlement Control of the Pre-Supported Roof and Lifting of the Buttresses

Firstly, the main circuit is designed. According to the main wiring diagram, the central distribution box and central control box are designed to realize the remote central control and synchronous control of the jacking system. Through the design of terminal distribution box and terminal control box, the sub-control of a single pumping station system is realized. At the same time, any sub-control system can stop all the control systems. The operation stations of the central control system and terminal control system are also designed. The jacking process is mainly realized by buttons.

4.1.4 Pre-Supporting Roof Settlement Control and Replacement Jacking Device Composition

The jacking device is mainly composed of jack, pump station and control system. The rated working pressure of the hydraulic system is 63MPa, the power of the electrical system is three-phase 380V, and the control system is DC 24V. Each device works according to the instructions of the operator according to the set logic under the system management.

(1) Jack: There are three main specifications of jack, one is the jacking force of 400t, the stroke of 100mm, the number is 20, and the spare 2 are used for pile foundation to change the jacking. The second type is the top force of 300t, the stroke of 100mm, the number is 44, and the spare 4 are used for the advance top under the shaped block. The third type is the top force of 100t, the stroke of 100mm, the number is 18, and the spare 2 are used for the pre-supported top under the T-shaped beam. A total of 90 hydraulic jacks of various specifications are required. The three specifications of jacks are single-acting jacks with mechanical self-locking. In the process of use, after the top lift to the design position, it is necessary to tighten the nut in time, and the lifting distance should not be too large each time to prevent adverse consequences caused by lax sealing. This type of jack can not be in the full extension state to tighten the nut, otherwise it will not be removed, and it can not be up or down, adding trouble to yourself. The basic structure of the jack is shown in Figure 6.

(2) Pumping station: the main motor function of each pumping station is 2kW, and the total power of 21 pumping stations is about 40kW, considering that it is unlikely to start at the same time, the standby 50kW three-phase power supply can meet the requirements. Each pier of 28#, 34#, 40#~42#, 45#~46# is prebuttoned with 4 300t jacks, which are a group sharing a pump station. Among them, 40#~42#, 45#~46# pier each pier also has a lifting, each pier lifting is equipped with four 400t jacks, these four are a group of shared a pumping station, taking into account that the presupport top and the lifting of the lifting do not work at the same time, so the

presupport top and the lifting of the lifting share a pumping station. 4 sets of 300t jacks are set at each end of the special-shaped plate of the 22# pier, which are divided into 3 groups, 1 group for each of the 2 sides, 1 group for the middle 2, and 1 pump station for each group; 9 sets of 100t jacks are set at each end of the T beam of 22# pier, which are divided into 3 groups, 3 on each side are 1 group, 3 in the middle are 1 group, and each group has 1 pumping station; A total of 21 pumping stations are required.

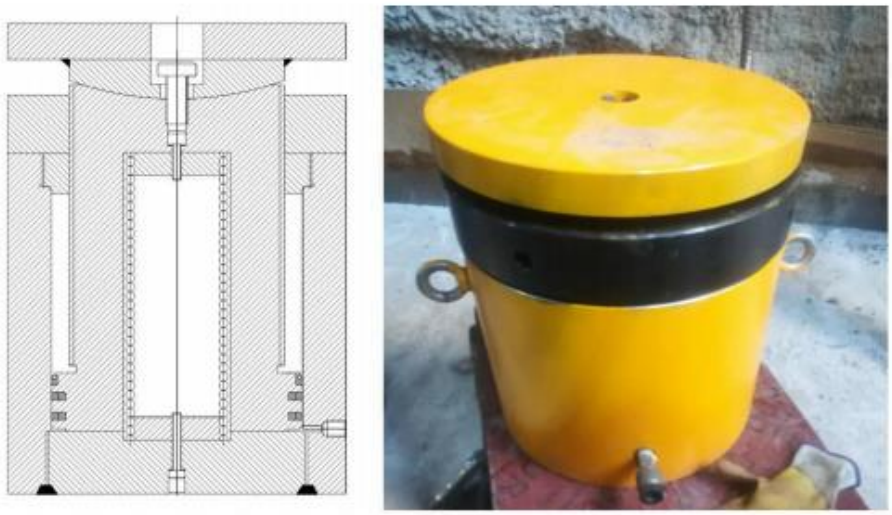

Figure 6 Jack basic structure and physical drawings.

4.2 Advance Roof Settlement Control Device

4.2.1 Overall Layout of the Settlement Control Device of the Prepaid Roof

A temporary pier is installed next to each pier that needs to be pre-supported, and a hydraulic jack is installed on the pier top, which is equipped with a pressure sensor and a displacement sensor. The jack is driven by a hydraulic pump station. The T beam side of the 22# pier is divided into 3 groups according to the left, middle and right, each group has 3 tops, and each group is driven by a pump station. 22# pier shaped plate is divided into 3 groups according to the left, middle and right side, 1 top on the left and 1 top in the middle, and each group is driven by a pump station. 4 tops are installed around each pillar of the remaining piers, which is a group, and each group is driven by a pump station, as shown in Figure 7.

4.2.2 Prepaid Roof Settlement Control Device Temporary Support

The temporary support under the special-shaped beam plate is made of 600mm diameter steel pipe with 14mmQ235 wall thickness as the column, and the steel plate with 20mm thickness is welded into the main beam of the box beam. The column is connected by 219mm diameter steel pipe with 10mm wall thickness, and the weld height is 8mm~10mm. The steel pipe and the old cap are connected by M30 chemical bolt flange, the chemical bolt length is 38cm. The anchoring depth is 30cm, and the filling material is used to level and adjust the height between the flange and the old cap. After installation, the distance between the top surface of the temporary support beam and the bottom surface of the shaped plate is 54cm~56cm, which is easy to install 300t with self-locking jacks.

The temporary support under T beam is made of 400mm diameter and 10mmQ235 steel pipe with wall thickness as the column, and the column is connected with 219mm diameter and 10mm wall thickness. The weld height is 8mm~10mm. The top and bottom of the steel pipe are welded with flanges, and the old cap is connected with M30 chemical bolts with a length of 380mm. The anchoring depth is 300mm. The filling material is used to level and adjust the height between the flange and the old cap. After installation, the spacing between the top surface of the temporary support beam and the bottom surface of the shaped plate is 320mm~340mm to ensure the installation of 100 tons with self-locking jacks, as shown in Figure 12.

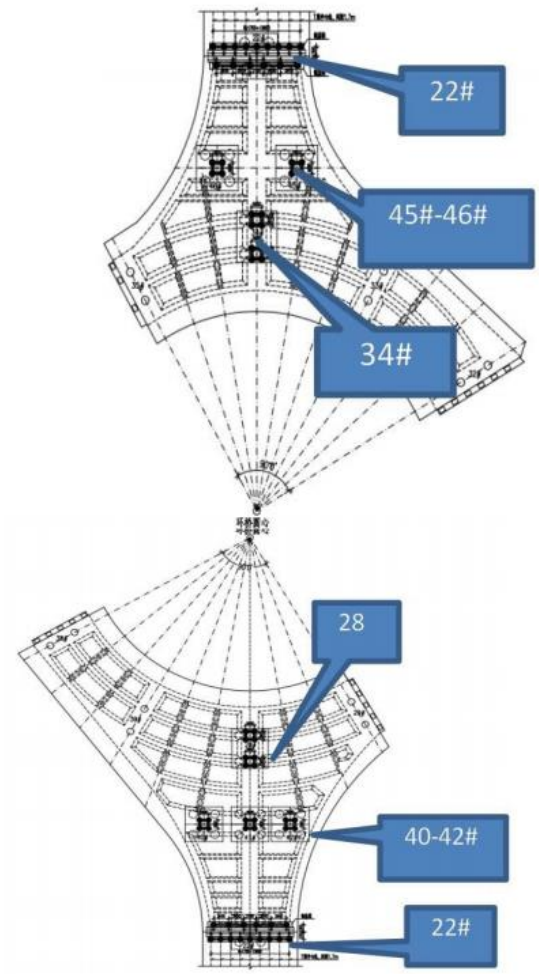

Figure 7 Special shape plate beam support roof layout.

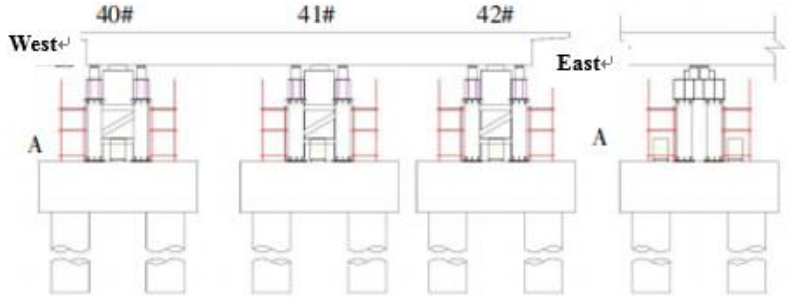

Figure 8 40#~42# pier prebuttal roof layout

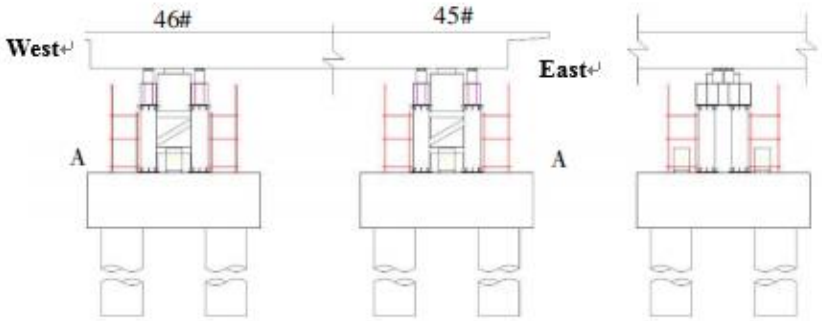

Figure 9 45#-46# pier prebuttal roof layout.

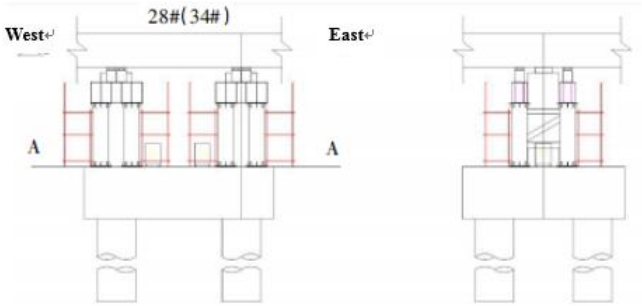

Figure 10 28#, 34# pier prebuttal roof layout.

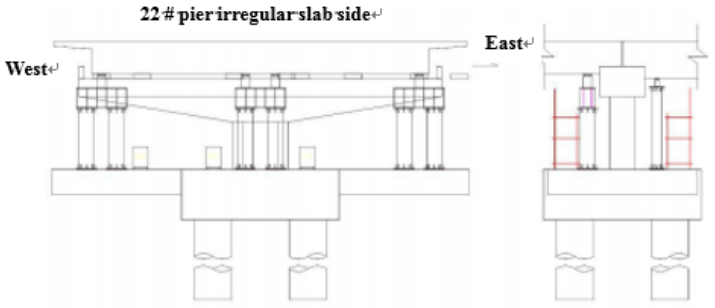

Figure 11 Prebuttressed roof layout of pier 22#.

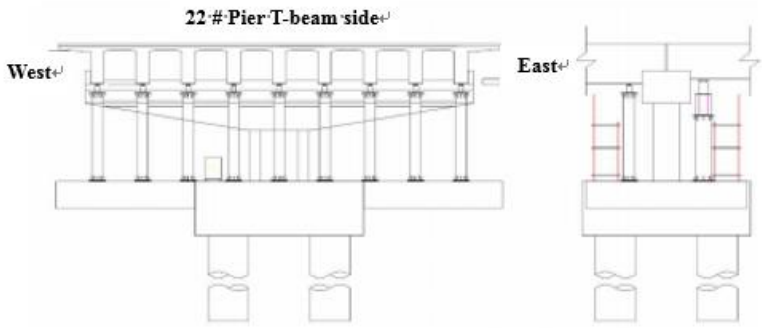

Figure 12 Prebuttressed roof layout of pier 22#.

4.3 Underpinning the Top Lift

4.3.1 Support Jack Arrangement

40#~42#, 45#46# pier install 4 tops between each old and new cap, in 1 group, each group is driven by its corresponding pre-supported top pump station, the pre-supported top and the lifting of the support do not work at the same time, only need to operate the corresponding control valve can be converted.

4.3.2 Control and Layout of Pump Station for Pre-Supporting and Lifting Jack

Considering the large difference in the support reaction of each pier, in order to ensure that each is in an ideal working state, each pump station is driven by a frequency converter to adjust the respective jacking speed, so that the speed is consistent during synchronous work and can be negative feedback closed-loop control. Each frequency converter is controlled by a PLC to achieve logical control between different piers, and each pump station constitutes a sub-station.

The south block has 11 sub-stations, controlled by one main station; The North block has 10 sub-stations, controlled by one main station. The main sub-stations are connected by wireless network. The operator is a tablet computer equipped with a control program. The main station is equipped with a 4G communication module, which can communicate with the project department and the monitoring room. In the monitoring room, the lifting system can be viewed, recorded and controlled.

In the process of cutting off the original bridge pile foundation, the internal force and displacement of the support and replacement cap should be monitored. If there is a large displacement or the monitoring value changes abruptly, the pile cutting should be stopped immediately, and the owner, design and supervision should be notified in time to negotiate and deal with it. When the original bridge foundation is truncated, the load at the bottom of the old cap is completely transferred to the replacement cap, and the jack on the replacement cap bears all the load at the bottom of the old cap.

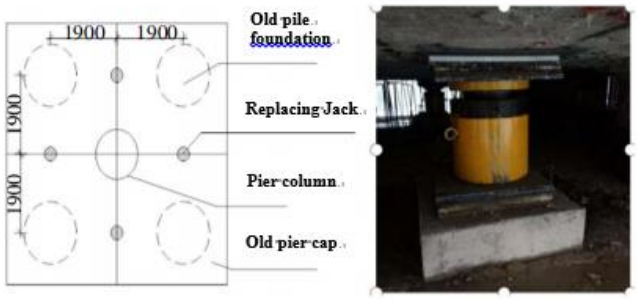

Figure 13 Support jack layout.

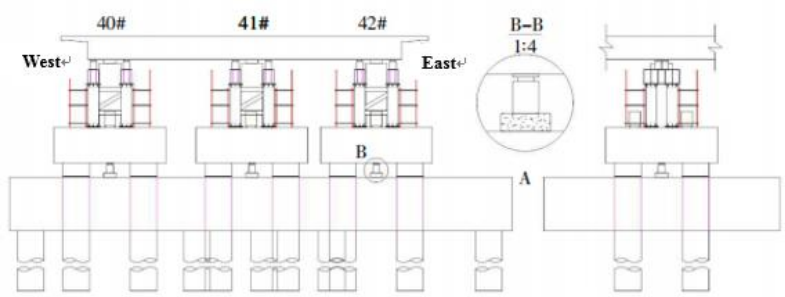

Figure 14 40#-42# pier support jack elevation layout.

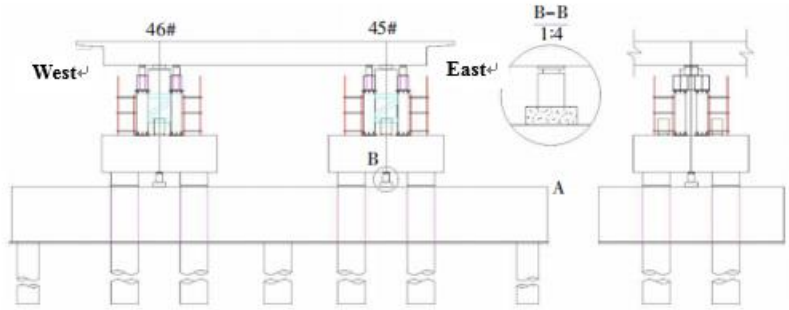

Figure 15 45#-46# pier replacer jack elevation layout

4.3.3 Jacking control area division and hydraulic system layout

The control area is divided into four groups. The principle of control point division is safety and reliability, synchronization and attitude control of bridge during jacking.

The control area is set with grating ruler to control the synchronization of displacement, and the displacement synchronization accuracy is controlled at 0.1mm. The displacement sensor is connected with the central controller to form a closed loop displacement control, so as to achieve accurate displacement control during the jacking process.

5. Jacking Control Effect

(1) The actual bearing capacity of pile foundation can be accurately determined by weighing the pre-supporting roof system with automatic control for different piers and columns in different stages and batches.

(2) Combined with the current intelligent control technology, the synchronous jacking and settlement control of multi-fulcrum prestressed concrete special-shaped slab beams under complex working conditions is realized to ensure the safety of the beam structure.

(3) With the application of the pre-buttoned roof system, when individual or part of piers settle during the pile foundation replacement or shield crossing construction process, the beam body can be jacked up to the initial position through the pre-buttoned roof system to avoid beam cracking and ensure the safety of bridge operation.

(4) The jacking system is set between the new and old caps to complete the system conversion. The new cap is not loaded and the settlement is not stable. Before the old pile is cut off, 1.2 times of the designed load is applied to the new cap by the jacking system, so that the new cap quickly becomes stable and the bridge operation safety is ensured in the process of pile cutting.

(5) For the large special-shaped plate structure with a long history of construction and bridge construction, a set of automatic settlement compensation equipment with automatic monitoring and automatic control is creatively designed to ensure that the beam body is not affected by the slight settlement of pile foundation; The automatic control jacking system can ensure both synchronous jacking and batch jacking to ensure the jacking effect, which ensures the safety of multi-fulcrated prestressed concrete special-shaped slab and beam structure under complex working conditions and provides a guarantee for the safety of construction and bridge operation.

(6) Through in-depth research on the settlement mechanism of pile foundation and the sensitivity of large special-shaped plate girder bridge to settlement, automatic monitoring and manual monitoring are adopted to ensure the stability and safety of special-shaped plate girder body.

6. Conclusion

The key points of pile foundation replacement construction are: first, the settlement monitoring and timely settlement compensation of beam and plate; Second, the timing of lifting and the control of jacking force; The third is to accurately determine the support and reaction force of each support of the large special-shaped plate beam, and guide the lifting operation of the lifting; Fourthly, with the help of a series of guarantee measures such as the pre-supported roof settlement control device, the shield successfully passes through the pile foundation replacement area of the construction and bridge.

References

1. Wang Liping. Design and optimization of pile buttress replacement for large span tunnels through high-rise buildings [J]. Journal of Underground Space and Engineering, 2012(5):1070-1075.
2. Liu Xiaozhong. Research on risk assessment and control measures of bridge pile foundation replacement construction [J]. Guangdong Civil Engineering and Construction, 2013.
3. Meng Qingjun. Construction technology of bridge pile foundation replacement in Chengdu Metro River [J]. Tunnel Construction, 2011.
4. Zhou Fengmin. Construction Technology of Pile Base Replacement under Pile Base in Shield Interval of Guangzhou Metro Line 5 [A]. Shanghai Civil Engineering Society, Shanghai Tunnel Engineering Co., Ltd, Underground Engineering Construction and Risk Prevention Technology-2007 Third Shanghai International Tunneling Symposium Proceedings [C]. Shanghai Civil Engineering Society, Shanghai Tunnel Engineering Co.
5. Zhou Guannan, Zhou Shunhua, Hou Gang, et al. Study on the effect of pile buttress replacement in neighboring shield construction [J]. Journal of Underground Space and Engineering, 2010.
6. Yan Jilong. Discussion on the design scheme of a subway station with underpassing river and bridge foundation [J]. Railway Standard Design, 2016(5):116-120.