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# KEY TECHNOLOGY OF SUPER-LARGE DIAMETER SHIELD PILE FOUNDATION REPLACEMENT CONSTRUCTION

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## ABSTRACT

This study investigates the critical technologies for large-span pile foundation replacement construction under super-large diameter shield tunneling conditions, using the Guangzhou Haizhu Wan Shield Tunnel Project as a case study. A novel "active buttressing-pile truncation" integrated methodology was developed, featuring a 20.8m-span composite buttress system comprising pile groups, pre-stressed double-beam structures, and bearing platforms. The research emphasizes the active buttressing phase, which critically influences superstructure deformation. Maximum settlement of existing buildings reached -6.1mm (negative denotes downward movement) with no differential settlement detected. Structural Performance: Joist stress-strain responses and building inclinations remained within 65% of warning thresholds. The proposed system demonstrated superior settlement control efficacy, reducing superstructure displacements by 42% compared with conventional methods. The findings confirm that this large-span pre-stressed double-beam buttress pile foundation system provides an effective technical solution for urban underground construction involving complex foundation replacement, offering both theoretical and practical references for similar projects.

## KEYWORDS

Super-large diameter shield tunnel, Pile foundation underpinning, Construction monitoring, Monitoring and analysis

## INTRODUCTION

With the rapid development of China's economy and the improvement of residents' living standards, many large and medium-sized cities have experienced a proliferation of vehicles and insufficient road transportation capacity, which in turn leads to the increasingly obvious problem of traffic congestion, and thus the structure of the underground space and transportation system plays an increasingly important role [1-3]. In urban planning and development, it is necessary to avoid the existing underground structures, but for the development of earlier urban underground space is more complex, will inevitably conflict with the existing underground buildings [4-6]. If such conflicts are resolved by demolishing and reconstructing existing buildings, it increases the cost and duration of the project. Therefore, when planning underground space, it is necessary to comprehensively consider the economic and technical feasibility, and the most cost-effective way to solve this problem is generally the pile foundation underpinning technology [7].

Underground space development and utilization has been further developed by the emergence of pile foundation underpinning technology, and the birth of this technology has brought new scientific research directions in the design of the scheme of the required structure, on-site construction, safety monitoring, etc. [8-9]. With the increasing maturity of pile foundation underpinning technology, more and more countries are using pile foundation underpinning in their underground projects. For pile foundation underpinning, it is actually to make the load of the superstructure redistributed on the new structure after the existing pile foundation is cut off during the construction process, for a reinforced concrete structure, it is necessary to try to ensure that the settlement and deformation of the original structure and the replacement structure during the construction of the pile foundation underpinning comply with the specification requirements [10-12]. Frequently, there will be settlement differences between the old and new structures, and settlement differences that exceed a certain value will adversely affect the normal use and safety of the structure [13]. Moreover, load bearing condition and load transfer pattern of the old and new structures in the process of buttress replacement are also important factors to judge whether the buttress replacement is successful or not. Therefore, numerical simulation analysis and real-time monitoring of the old and new structures in pile foundation underpinning are necessary [14-15]. Pile foundation underpinning has been a great help for many complex projects, however, in the past pile foundation underpinning projects, there are more pile and beam underpinning programs of "two to one", and there are fewer projects that use large-span pre-stressed underpinning beams to underpin group pile foundations under super-large diameter shield tunneling conditions, and most of the scholars have only studied the load transfer, foundation settlement, building deformation, etc. before and after the overall underpinning project [16-18]. For this kind of project, most scholars only studied the load transfer, foundation settlement and building deformation before and after the whole replacement. For the case of single-span pile foundation underpinning with multiple existing pile foundations, the different excision order of existing pile foundation means that the system conversion of pile foundation underpinning is carried out in a different way, and the impacts on the replacement structure as well as the pre-stressing tendons of the pile foundation underpinning are also different, so it is very necessary to study and propose a reasonable sequence of pile excision for this kind of project [19-20].

This paper takes Guangzhou Haizhu Wan shield tunneling project as the engineering background, systematically summarizes the key technology of super-large diameter shield large-span pile foundation underpinning construction, establishes the numerical simulation of the underpinning construction process, analyzes and carries out the research on different parameters such as jacking force, prestressing steel beam configuration and the sequence of the removal of the old piles, etc., and puts forward the reasonable pre-stressing steel beam underpinning construction according to the influence on the deformation of the super-structure and the stress and deformation of underpinning girder. According to its influence on the deformation of the superstructure, stress and deformation of the joist, a reasonable pre-stressing beam configuration and pile removal sequence at the bottom of the beam are proposed.

## PROJECT OVERVIEW

Haizhu Wan Tunnel Project is the northern section of Guangzhou South Railway Station Fast Track, connecting the existing Dongxiaonan Elevated Road in the north and Nanpu Avenue in the south. Total length of the project line is 4348 m. Design speed of the main line is 60 km/h. It is mainly constructed by shield tunneling method, open cut method and bridge method. From north to south, the project crosses Nanzhou Road, Metro Line 2 and South Ring Elevated in turn through bridges, and then goes into the ground in the form of tunnels to cross the Pearl River Lijiao Waterway, Luoxi Island, Sanzhixiang Waterway and Nampo Boulevard. Tunneling length is 3463 m, of which the length of the Nam Chau cut section is 541 m, the length of the Nam Po cut section is 845 m. Shield tunneling length is 2093 m in the west line and 2102 m in the east line, and the project schematic diagram is shown in Figure. 1.


*Fig. 1 - Engineering diagram of Haizhu Wan Tunnel shield section*

Design of the shield tunneling section is a 6 lane east-west two-lane tunnel with a single shield tunnel outside diameter is 14.5 m. It is constructed with two mud-water balanced shield machines, with a minimum flat surface radius of 1000 m and a maximum gradient of 4%. Among them, the west line is a Herrenknecht mud-water balanced shield tunneling machine, with a cutter diameter of 15.07 m, a cutter with a pressure change function, a panel type structure, and an opening rate of 30%. East line is a mud-water balanced shield tunneling machine of Iron Construction Heavy Industry, the diameter of the cutter plate is 15.07 m, the structure is star spoke type, and the opening rate is 35%. Figure 2 shows the east-west line shield tunneling cutter plate diagram.

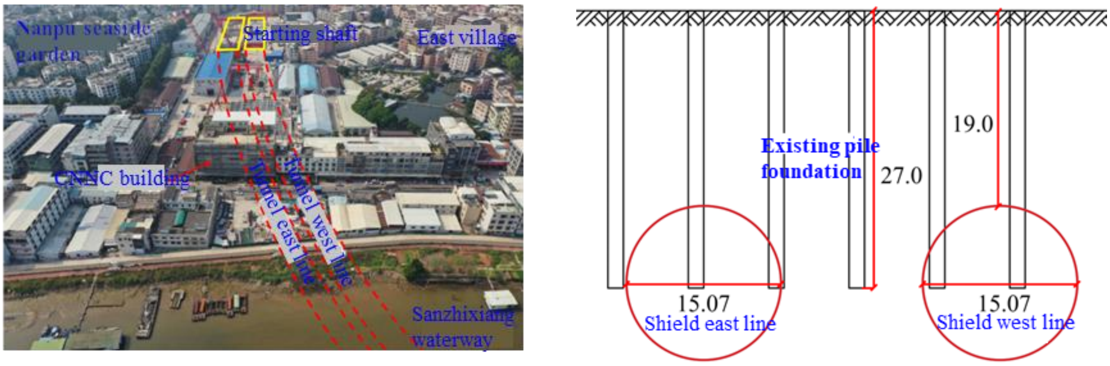

*(a) West line "Avenue Pioneer"*


*(b) East line " Route Pioneer "*

*Fig. 2 - Engineering diagram of Haizhu WanTunnel shield section*

## KEY AND DIFFICULT POINTS of THE PROJECT: SUPER-LARGE DIAMETER SHIELD TUNNELING THROUGH A PILE FOUNDATION

The shield tunneling penetrated the CNNC Business Building after 200 m, as shown in Figure 3. Underground of the building is a poured pile foundation, which is divided into two phases. Above ground is a 6-story reinforced concrete frame structure. Adjacent frame columns of the house have a span of 7.9 m and an average floor height of 3.9 m. The use of the house is for office purposes. A total of 88 piles (49 in the east line and 39 in the west line) were affected within the excavation.




(a) Location map (b) Cross section diagram (unit: m)

*Fig. 3 - General plan of pile foundation of shield crossing building*

A total of 67 grinding piles (30 in the east line and 37 in the west line), which intruded into the tunnel for about 3 m to 9 m, were located within the excavation area. CNNC Phase I is A480 mm cast-in piles with a pile length of 23 m and 6 C16 steel cages in the upper 8 m. CNNC Phase II is A600 mm to A1500 mm cast-in piles with a pile length of 24 m. The steel cages are arranged in a longitudinal arrangement, with the main bars of C16,18 and 20. Below the free-standing foundations of Building 33 are A 300 tubular piles with a length of 23 m and a main reinforcement of C14. See Table 1 for details.

*Tab. 1 - Commercial building pile foundation statistics table*

| Serial number | Diameter (mm) | Pile length (m) | Main reinforcement (mm) | Length of steel cage (m) | Depth of tunnel intrusion (m) | Root | Number of ground piles | Number of Eastern Lines | Number of western lines | Concrete grade |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A480 | 23 | 16 | 8 | 3-4 | 80 | 37 | 10 | 27 | C25 |
| 2 | A600 | 27 | 18 | 27 | 8-9 | 11 | 5 | 5 | 0 | C35 |
| 3 | A800 | 27 | 20 | 27 | 8-9 | 4 | 4 | 2 | 2 | C35 |
| 4 | A1000 | 27 | 20 | 27 | 8-9 | 12 | 6 | 3 | 3 | C35 |
| 5 | A1200 | 27 | 20 | 27 | 8-9 | 2 | 0 | 0 | 0 | C35 |
| 6 | A1500 | 27 | 20 | 27 | 8-9 | 10 | 7 | 2 | 5 | C35 |
| 7 | A300 | 23 | 14 | 23 | 3-4 | 20 | 8 | 5 | 0 | C25 |

## DESIGN of PILE FOUNDATION UNDERPINNING

Underpinning structure consists of two parts, underpinning pile and underpinning beam, underpinning beam includes underpinning main beam and underpinning secondary beam. Micro steel pipe slurry pile is used for underpinning, the diameter of the hole is 250 mm, the steel pipe is made of Q235B steel with diameter of 220 mm, and the pile diameter is filled with pure cement slurry with strength class M30.Main girder span of underpinning are more than 18 m, is about 20.8 m, underpinning main girder cross-section width × height: 0.6 m ~ 0.8 m × 2.2 m, underpinning secondary girder cross-section width × height: 0.6 m × 2.2 m, underpinning girder and underpinning bearing platform adopt C40 grade concrete, reinforcement adopts HRB400 grade reinforcement and HRB300 grade reinforcing steel. Overall underpinning structure plan is shown in Figure 4 (expansion on the existing bearing platform to get a new bearing platform is called extension bearing platform).

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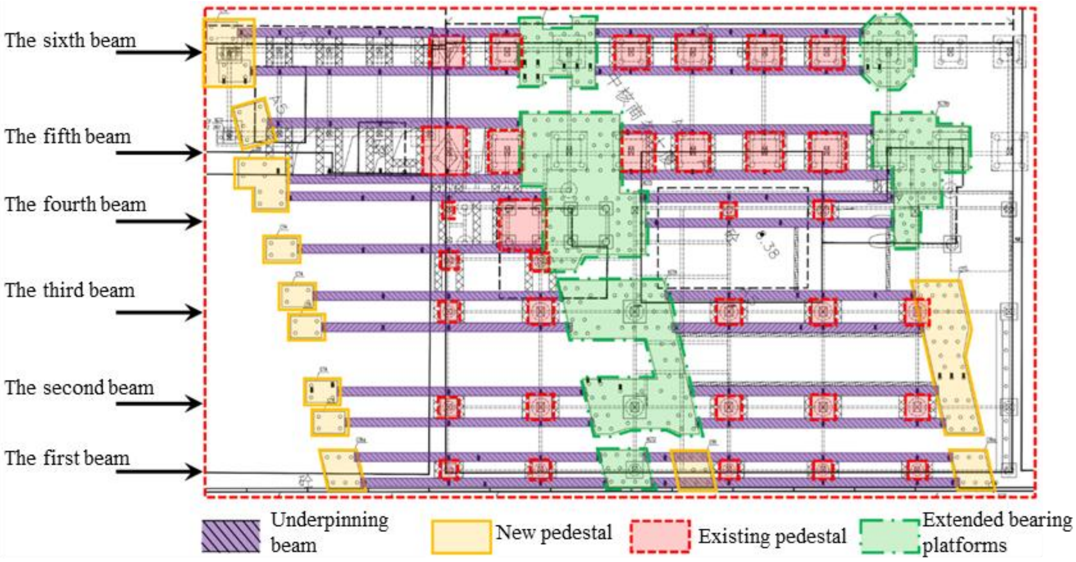


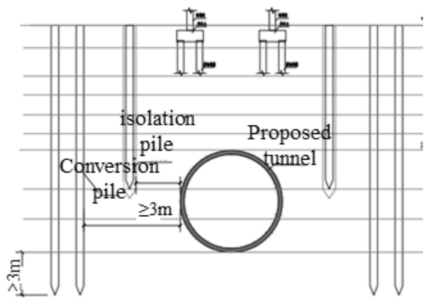

*Fig. 4 - Building replacement structure plan*

Between the underpinning structure and the underpinned structure is mainly designed for shear resistance: with the help of occlusion between the underpinning beam and the old bearing platform, interface treatment and reinforcement planting, the surface of the original bearing platform is chiselled to within the height of the underpinning beam, the diameter of the drilled holes is 14~42 mm, and the holes are cleaned up of dust and dirt using high compressed air or high-pressure water gun, and the processed rebar is inserted after putting in reinforcement adhesive, and then the reinforcing adhesive is cured. Pour the concrete of the solid section.

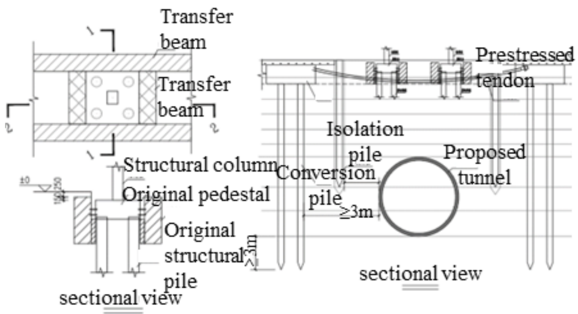
## PILE FOUNDATION UNDERPINNING CONSTRUCTION

### Underpinning Construction Points

This project is a super-large diameter shield tunneling conditions, the use of large-span prestressed double girder buttress buttressing method buttressing the pile foundation of the building group, different from the usual "two drag a" pile and girder structure buttressing, this project single-span buttress buttressing at least buttressing two existing pile foundation, buttressing a maximum of 16 existing pile foundation, the buttressing process of structural stability put forward higher requirements for the whole buttressing process. The maximum number of existing piles to be replaced is 16. Foundation underpinning construction process is shown in Figure 5.




*(a) Surrounding soil reinforcement, construction of conversion pile and isolation pile*




*(b) Construction of beam replacement and new cap, tensile prestress*

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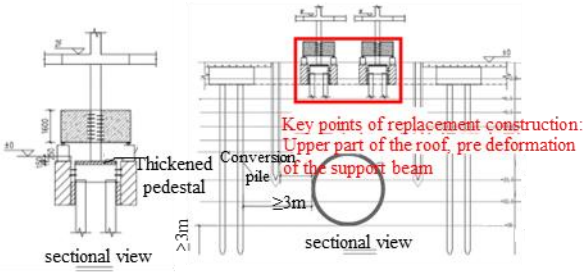
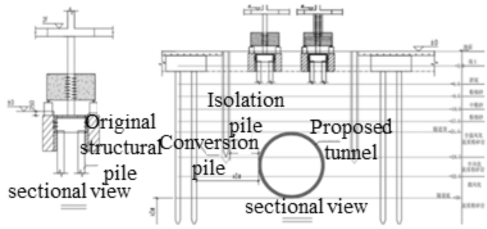
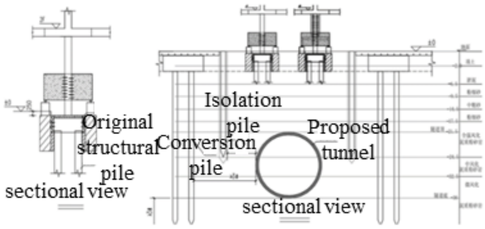



*(c) Back to the top of the supporting beam pre-deformation, thickening the original cap*




*(d) The cap and the bearing beam are sealed twice*




*(e) Remove bracket*

*Fig. 5 - Foundation replacement construction process*

## Implementation of Underpinning Project

In this project, the active underpinning method is adopted, which needs to set up temporary reaction frame under the first floor columns before connecting the underpinning beams with the old bearing platforms, and use the underpinning beams to go back to the top of the upper part of the main body, so as to make the deformation of the underpinning beams stabilized, and then carry out the construction of the connection between the underpinning beams and the old bearing platforms, in which the most important construction process is to go back to the top of the upper part of the body by means of the following methods:

(1) In this building underpinning reconstruction construction, the jacking synchronization can control the insufficient bending deformation hazard of the superstructure in the building underpinning reconstruction construction. After the reinforced concrete pre-roof crossbeam reaches the design strength, four jacks with load-bearing capacity not less than 150 T are arranged between the corners of the pre-roof crossbeam and the joist beams, and temporary steel supports are to be installed on both sides of the jacks, as shown in Figure 6.

(2) Sequence of back jacking: All topping operations were carried out after the prestressing was tensioned and the design strength was reached. Topping back is done according to the location of prestressing beams from south to north, in batches of 6 sub-synchronized topping back. As shown in Figure 7.

(3) Back jacking process: construction preparation → pre-placement of jack position → installation of temporary steel support → installation of monitoring equipment → test jacking → formal jacking → completion of the first jacking → graded loading jacking to the design pressure (simultaneous monitoring).

(4) Points to back jacking: ① Before jacking, calculate the weight of each jacking point; calculate the amount of arching oil at each point; test the top before jacking. Pay attention to the top of the test top and the speed of each top, not enough to raise more oil can be divided. Rise too fast to tighten the oil valve. Trial top, before synchronized jacking. ② Synchronized pressurized jacking, jacking back to the bracket, underpinning back to the top of the load using the principle of graded loading, a total of ten levels of loading, each level of load increase of 10% of the upper limit value of the jack, cannot be loaded to the maximum value at a time. Each level of loading needs to be

maintained for 10 min, such as structural stability before adding secondary loads. ③ Closely monitor the generation and development of cracks in the underpinning in the process of roof return, and stop loading immediately when the maximum crack width is more than 0.1 mm. ④ Underpinning back jacking force requirements, that is, the maximum back jacking force at each original structural column cannot exceed the column underpinning force, the column underpinning force measurements provided by the design institute are shown in Figure 8.⑤ Observe that the change in settlement of the pile foundation and the deformation of the superstructure remain unchanged before proceeding with the second pouring of the conversion beam to connect the original structure at the bearing platform.


*Fig. 6 - Top return diagram*

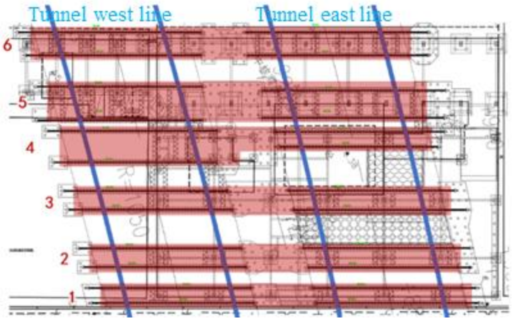



*Fig. 7 - Topping sequence*

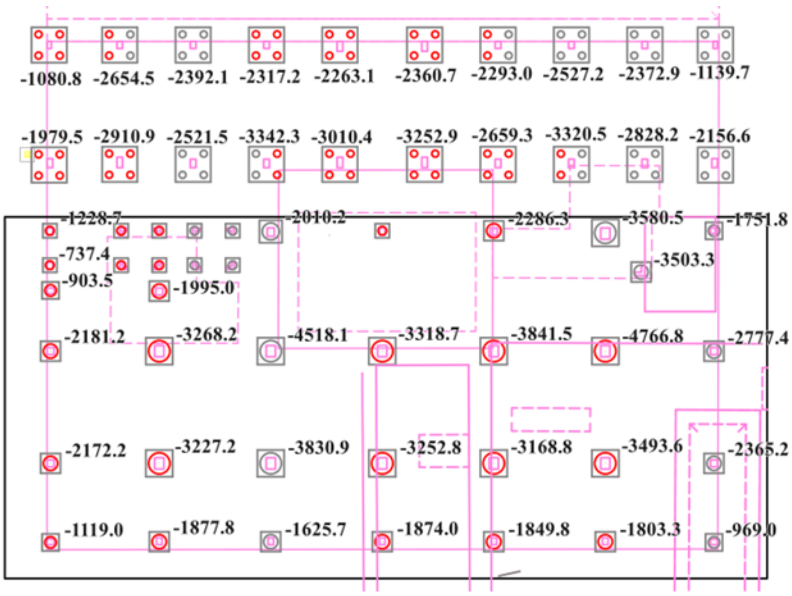



*Fig. 8 - Building column base force (unit: kN)*

## Demolition of Existing Pile Foundations

Original pile removal adopts static cutting method to break the pile, and the removal should be done symmetrically on both sides of the tunnel at the same time. During the demolition process, the original structural columns, underpinning beams, and bearing platform settlement and crack monitoring must be strictly monitored. Once the structure produces cracks or there are any signs of instability, immediately stop construction and organize the evacuation of site personnel. After feedback to the design unit to analyze the causes and forces, new measures will be formulated before entering the construction site.

**(1) Demolition process**

①On-site review of construction plan data: Measurement and determination of cutting position, calculation of deformation settlement; ② Control settlement observation points: Calculate and discipline the arrangement of settlement observation points; ③ Calculate cutting data; calculate data such as cutting position and cutting depth; ④ Installation of cutting machinery: Installation of cutting machinery in accordance with drawings or programs; ⑤ Cutting and real-time monitoring of deformation data: Start the cutting operation, gradually release the structural load of the column, and monitor the deformation data in real time; ⑥ Lifting and removing concrete test blocks; ⑦ Structural settlement observation: an important monitoring measure to ensure structural safety.

**(2) Existing pile removal sequence**

In the original pile excision, although through the jacking back jacking the upper part of the prestressing beam and new pile foundation pre-stressing, so that the original bearing column force system converted to the new underpinning system, theoretically from any position to start excision of the original pile will not have an impact on the existing building itself, but the reality is often do not jacking up the existing pile foundation after the "zero internal force" in order to further ensure the safety of the original pile excision, this project in accordance with the principle of "first dense area then non-dense area, first the middle and then both sides, jump pile excision". In order to further ensure the safety of original pile removal, this project is carried out in accordance with the principle of "first dense area then non-dense area, first the middle and then both sides, jump pile removal". The sequence diagram is shown in Figure 9.

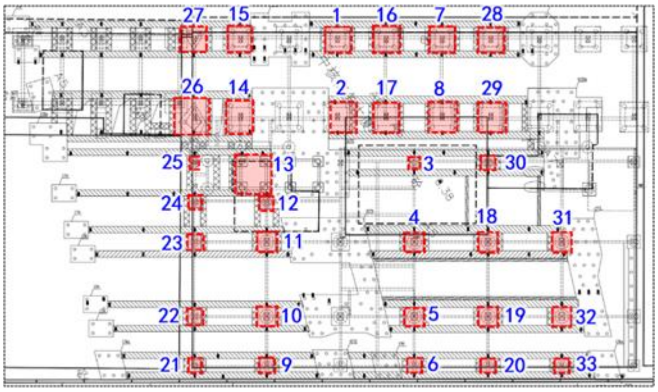



*Fig. 9 - Old pile removal sequence diagram*

**(3) Construction without support and replacement**

1. Excavate 1.5 m downwards at the original bearing platform and install the rope saw cutting equipment.
2. The first knife from left to right cutting to pile cross-section of about 75%, due to the structure of the pile by the cutting machine cutting surface gradually increased, pile force area gradually reduced, when the pile force surface is less than 25% or so, the pile vertical force eccentricity, this time, the pile and the conversion beam superstructure will be released tiny downward deflection of the force, resulting in the corded saw jammed locks, and then converted to cut the second knife;
3. Second cut is made at an interval of 150 mm between the top and bottom of the pile, and the second cut is made from right to left to about 95% of the pile cross-section, and the saw is locked to convert the cutting seam. The third cut is made at an interval of 150 mm between the top and bottom, and the third cut is made from right to left to cut through the whole pile section. Underpinning pile and superstructure stripping, cut off the pile in pieces 1 m. Pile foundation underpinning is basically completed.

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## Monitoring Arrangement

### 1. Settlement monitoring arrangement for existing buildings

Ninety-one settlement monitoring points were deployed for this project. Settlement observation layout is shown in Figure 10.

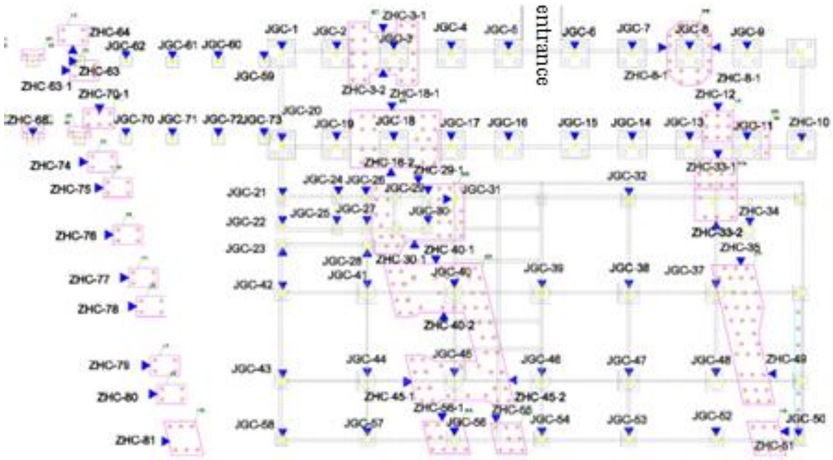


*Fig. 10 - Settlement observation point layout*

Construction monitoring activities commence from the initiation of pile foundation work. During the construction phase, observations of underpinning beam construction and underground tunnel work are conducted twice daily. For the remainder of the construction period, these observations are reduced to once per day. Special monitoring is required for the following events: once each during the suspension and resumption of construction activities, once monthly during periods of work stoppage, three times per month during the first two months of the operational phase, once per month from the third to the sixth month, once every two months from the sixth to the twelfth month, two to three times per year in the second year, and once per year from the third year onward until the construction reaches a stable state.

### 2. Stress monitoring of underpinning beams

There are 135 stress observation points laid out for this project. Stress monitoring layout is shown in Figure 11.

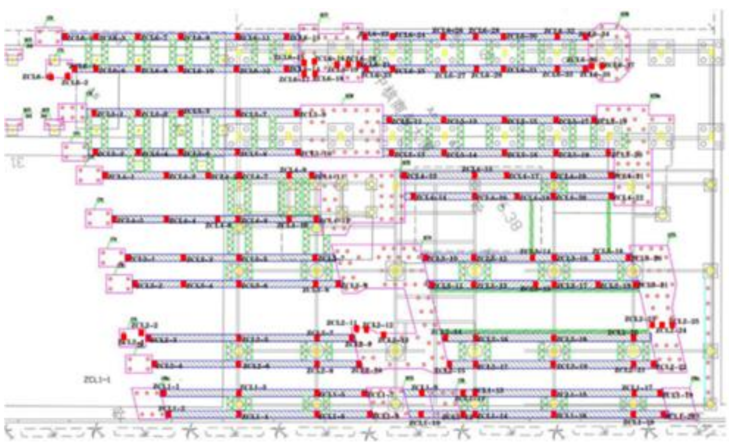

*Fig. 11 - Layout of stress monitoring points*

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## 3. Tilt monitoring of existing buildings

There are 18 building tilt points laid out for this project. Building tilt point layout is shown in Figure 12.

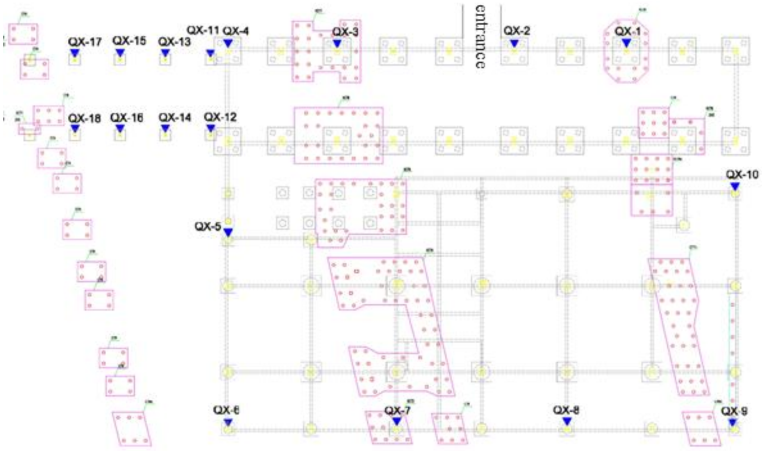


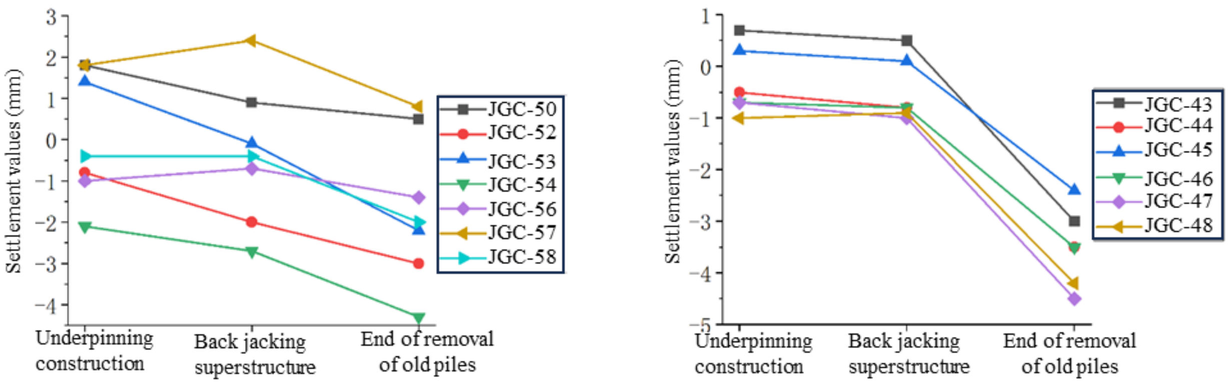

*Fig. 12 - Building tilt monitoring layout*

## 4. Surface crack monitoring

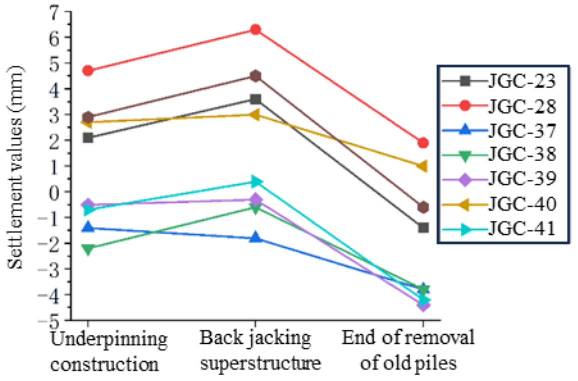
There are several crack monitoring points for this project, and crack monitoring shall include crack location, orientation, length, width, and changes. For crack width monitoring, steel nails can be embedded on both sides of the crack, and the distance of the nails can be used to observe whether the crack is further developed. It is also important to focus on the areas where cracks are likely to occur. Timely detection of new cracks, good records and observation marking tracking observation, through the existing cracks on the surface or due to engineering construction cracks to carry out width monitoring, to assess the degree of impact of engineering construction on the surrounding safety and normal use.

## Analysis of Settlement Monitoring Data for Existing Buildings

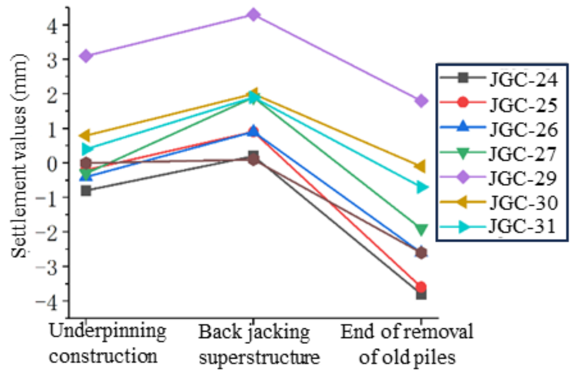
Monitoring point settlement values were selected for key nodes at the end of the joist construction, the end of the back jacking upper construction, and the end of the old pile removal construction during the entire underpinning construction process, as shown in Figure 13.



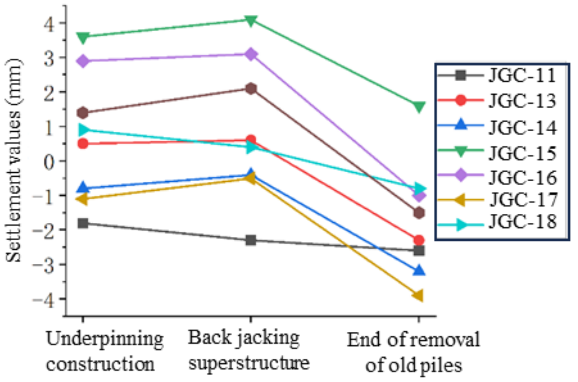

*(a)The first beam* *(b)The second beam*



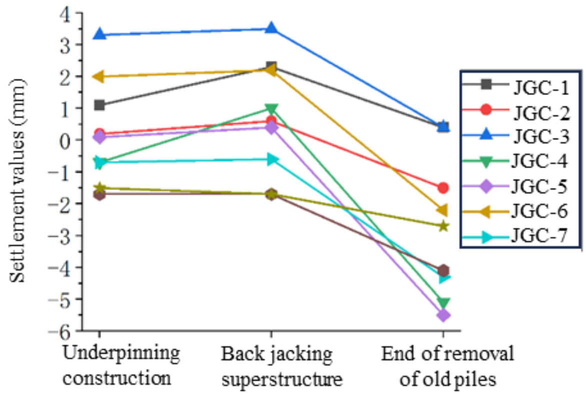

*(c)The third beam*




*(d)The fourth beam*




*(e)The fifth beam*




*(f)The sixth beam*

*Fig. 13 - Settlement value of building monitoring point*

Maximum deformation values of the six underpinning beams at the critical nodes of construction and maximum cumulative deformation values are shown in Table 2.

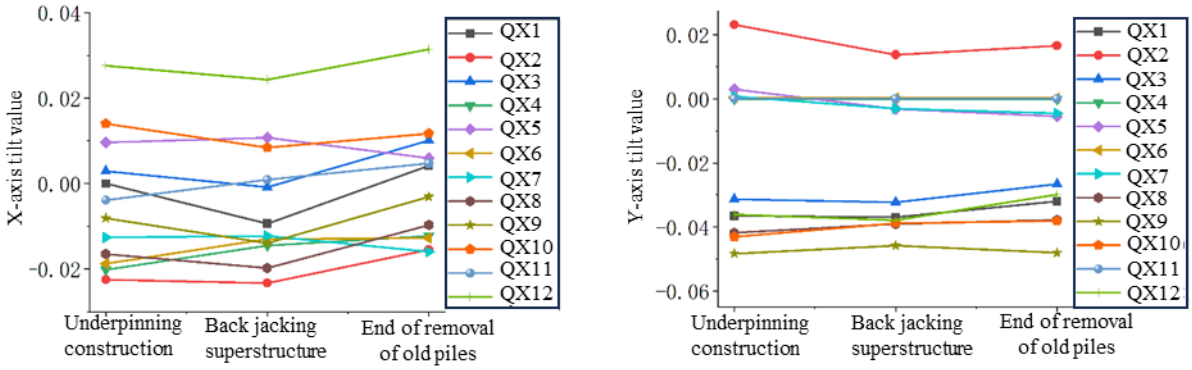
*Tab. 2 - Maximum change value of settlement and maximum cumulative change value*

| Deformation value | Maximum deformation value | | Maximum cumulative deformation value | |
|---|---|---|---|---|
| | Point number | Deformation value（mm） | Point number | Deformation value（mm） |
| The first beam | JGC-53 | -2.1 | JGC-54 | -4.3 |
| The second beam | JGC-44 | -3.5 | JGC-46 | -3.8 |
| The third beam | JGC-42 | -5.1 | JGC-28 | 6.3 |
| The fourth beam | JGC-25 | -4.5 | JGC-37 | 4.3 |
| The fifth beam | JGC-19 | -3.6 | JGC-15 | 4.1 |
| The sixth beam | JGC-4 | -6.1 | JGC-4 | -6.1 |

From the figure, it can be seen that after back jacking the upper part and making the predeformation construction of the underpinning beams finished, most of the measuring point elevations were basically unchanged or had a change of about 1 mm; after removing the old piles, all the measuring point elevations decreased, but the changes of the measuring points on each beam were roughly the same, and most of the remaining measuring points were between 2~4 mm except for some measuring points, and there was no uneven settlement of the CNA Building underpinning the whole period. All the deformation values are less than the warning value ±10 mm warning value.

## Tilt Monitoring of Existing Buildings

Monitoring point tilt values were selected for key nodes during the entire underpinning construction process, the end of the joist construction, the end of the back jacking upper construction, and the end of the old pile removal construction, as shown in Figure 14.




*(a) X-axis* *(b) Y-axis*

*Fig. 14 - Inclination value of building monitoring site*

Maximum change in tilt and maximum cumulative change in tilt at the nuclear building measurement points in the critical nodes of construction are shown in Table 3.

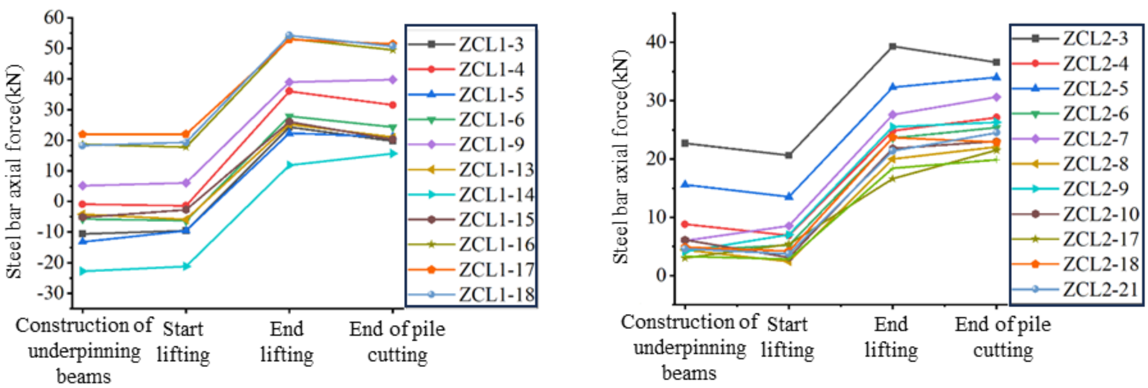
*Tab. 3 - Maximum change value of tilt and maximum cumulative change value*

| Deformation value | Maximum change value | | Maximum cumulative change value | |
|---|---|---|---|---|
| | Point number | Change value (°) | Point number | Change value (°) |
| X-axis | QX-1 | 0.0136 | QX-12 | 0.0314 |
| Y-axis | QX-17 | 0.0256 | QX-9 | -0.0481 |

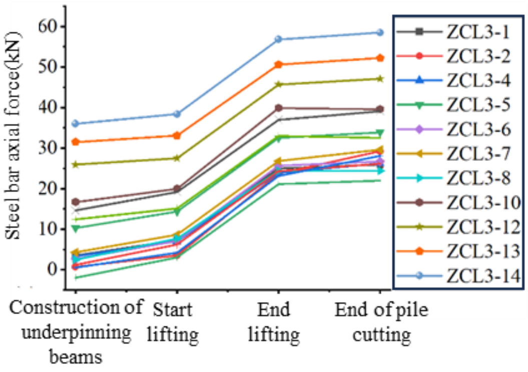
Maximum change in X-axis and maximum cumulative change in all measurement points is less than ±0.2292° warning value, maximum change in Y-axis and maximum cumulative change in Y-axis is less than ±0.2865° warning value.

## Stress-Strain Monitoring of Underpinning Beams

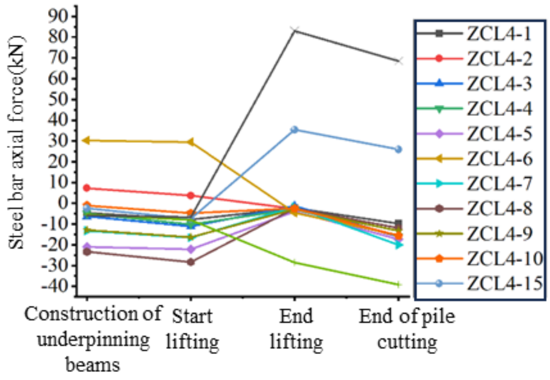
Underpinning beam construction was completed to the end of the old pile removal construction, and the measurement points are shown in Figure 15.



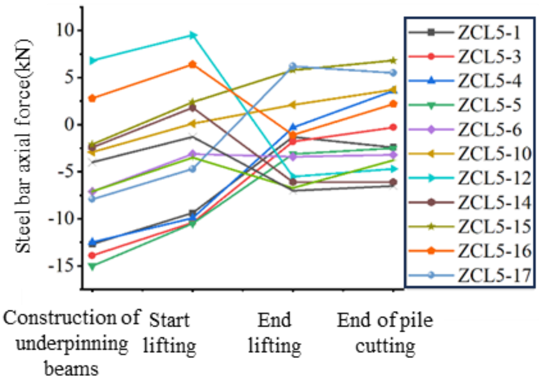

*(a)The first beam* *(b)The second beam*



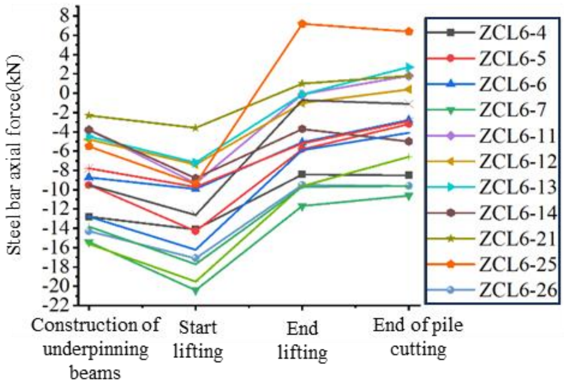

*(c)The third beam*




*(d)The fourth beam*




*(e)The fifth beam*




*(f)The sixth beam*

*Fig. 15 - The monitoring value of stress and strain measuring point of underpinning beam*

For each beam, the support axial force calculated from the measured values of the stress-strain monitoring points of the beams remained basically unchanged from the end of the construction of the beams to the end of underpinning jacking. During the jacking process, the deformation of the beams caused the measured values to undergo a large change, and after the end of jacking to the end of the pile cut-off, there was basically no change in the support axial force calculated from the measured values. The maximum values of cumulative changes in axial force of each beam are shown in Table 4.

*Tab. 4 - Change in tension/pressure of the underpinning beam*

| Underpinning beam | Cumulative maximum change value | |
|---|---|---|
| | Point number | Change value（kN） |
| The first beam | ZCL1-18 | 65.3 |
| The second beam | ZCL2-3 | 39.3 |
| The third beam | ZCL3-14 | 59.1 |
| The fourth beam | ZCL4-20 | 83.2 |
| The fifth beam | ZCL5-20 | -16.5 |
| The sixth beam | ZCL6-7 | -20.4 |

Maximum value of cumulative change was measured at the fourth beam, ZCL4-20, with a maximum value of 83.2 kN. Cumulative change of tension/pressure at all stress-strain measurement points was much less than the ±687 kN warning value.

From the results of settlement monitoring, tilt monitoring, and stress-strain monitoring of the beams underpinning, the construction results of the pile foundation underpinning of CNNC Building by the double beam underpinning method are good.

## CONCLUSIONS

In this paper, for the super-large diameter shield tunneling conditions, large-span prestressed double-beam buttress replacement of pile foundations underpinning buildings, unlike the usual "two-tow-one" pile-beam structural buttressing, the single-span buttress beam of this project is at least buttressing two existing pile foundations, and at most buttressing 16 existing pile foundations, which puts forward a higher requirement for the structural stability in the whole process of buttressing.

(1) Settlement monitoring data, tilt monitoring data, and stress-strain monitoring data of the underpinning beams for the existing building were carried out and collected on site during the underpinning construction. Subsidence of the CNNC building did not show large settlement before and after several construction phases, and the maximum deformation value was 6.3 mm.

(2) Maximum change in X-axis and maximum cumulative change in all measurement points is less than ±0.2292° warning value, maximum change in Y-axis and maximum cumulative change in Y-axis is less than ±0.2865° warning value. There is no overall uneven settlement, and all deformation values are less than the warning value ±10 mm warning value. For the tilt monitoring data, the tilt values of X-axis and Y-axis are less than the warning value.

(3) Maximum value of cumulative change was measured at the fourth beam, ZCL4-20, with a maximum value of 83.2 kN. Cumulative change of tension/pressure at all stress-strain measurement points was much less than the ±687 kN warning value. Underpinning beam stress-strain monitoring, the cumulative change of tension/pressure calculated from all stress-strain measurement points is much smaller than the warning value. From the results of settlement monitoring, tilt monitoring, and stress-strain monitoring of the beams, the construction result of using double-beam underpinning method to underpin the pile foundation of CNNC Building is good.

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