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Application of pile underpinning technology on shield machine crossing through pile foundations of road bridge

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ABSTRACT: Shanghai's subway construction has entered a new period of rapid development. A notable characteristic of subway network construction is that the construction environment is increasingly complex. Take Shanghai subway line 10 as an example, in the position of Shajinggang Bridge on Siping Road, the shield machine will have to pass through the bridge's pile foundation. Since the embedded depth of piles has already run through the entire tunnel section, these piles have to be pulled out or cut off. But, as one of the main arteries of Shanghai city, Si Ping Road has big traffic flow, and it does not allow the traffic volume to be affected during the construction period. What's more, there are intensive residential quarters around the bridge and the construction space is limited. Therefore, this paper will mainly introduce how the pile underpinning technology can be used in the subway construction of Shanghai area for the first time.

1 INTRODUCTION

Along with the continuous construction of metro lines in cities and unceasing improvement of metro network, there are more and more cases of new tunnel lines passing through old nearby buildings [1]~[3].

In the past 20 years, Shanghai has been experiencing the unprecedented climax of city infrastructure construction. There are total 17 lines planed in the urban rail transit network, of which 11 lines are subway with length of 385 km, presently, 5 lines have been completed, 5 lines are being constructed. By 2010, total 10 lines will be put into use with length of 250 km.

A notable feature of the new period of metro construction is that the construction environment is increasingly complex, that is, examples of intercrossing between new line and old line, crossing through various existing structures etc., are becoming more and more. Take Shanghai subway line 10 as example, it spans from Hongqiao Airport to New Jiangwan Town with total length of 28.8 km, which forms a convenient channel between the north and the west part of Shanghai city. During its construction process, the main pile foundations that impede the advance of shield machine are located at Shajinggang Bridge, Zoumatang Bridge, Chenjiaqiao Bridge and Huangxin Road Bridge, as shown in Figure 1.

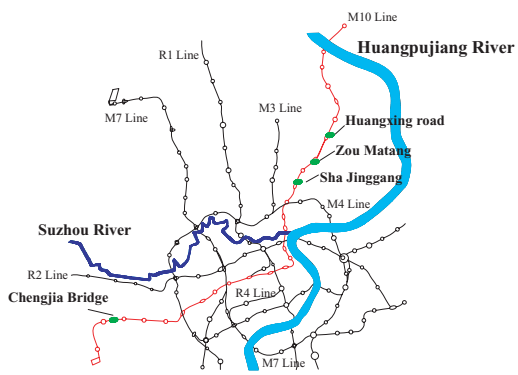

Figure 1. The general picture of subway Line 10.

Regarding to the situation of new line crossing through existing structures, generally speaking, the line should be chosen to avoid existing buildings in the stage of planning. In fact, there are various practical situations often make it difficult to avoid such

structures. As to the examples of tunnel crossing the bridge foundation mentioned in this paper, when the line can not avoid existing pile foundation, the general construction method is: construct temporary alternative bridge → change traffic course, remove the old bridge, extract pile → drive the shield machine forward → construct a new bridge → restore the original traffic → demolish the temporary bridge.

If follow this method, it results in long construction period, high construction cost, and great impact on the society. But if we adopt the pile underpinning technology, that is, based on the premise of keeping the existing structure can be worked normally, while a series of construction technology are used to extract or truncate piles, and finally reach the purpose of driving shield machine forward. This can not only shorten construction period, reduce construction cost, minimize its impact on the community, but also can promote Shanghai's subway construction level.

2 PROJECT OVERVIEW

2.1 *Status of Shajinggang Bridge*

According to the plan of Shanghai subway Line 10, the interval tunnel from Liyang Road to Quyang Road will cross through the piles of Shajinggang Bridge on Siping Road. The bridge is a simple beam structure with three spans; its spans are 6 m, 12 m and 6 m respectively. This bridge includes two piers and two abutments. Each pier uses 23 quadratic reinforced concrete piles as its foundation, with dimension of 400 × 400 × 26000 mm; while each abutment uses 14 quadratic reinforced concrete piles as its foundation, with dimension of 400 × 400 × 27000 mm. Since the elevation of tunnel vault beneath the bridge is about −6 ∼ −7 m, in the process of shield drive, there are about 4 piles at each pier and 3 ∼ 4 piles at each abutment will affect tunneling excavation, as shown in Figure 2 and 3.

Around Shajinggang Bridge, there are intensive buildings and underground pipelines, which should be taken into account during the construction process. The important buildings near the bridge are a high-rise building in the southwest, a single story pump station in the south, a 24-storey building in the southeast, a reinforced concrete and brick building with 4 floors in the northeast, the pit of Quyang Road Station in the north and the Huaxi Stock Exchange Building in the northwest. The important underground pipelines are a group of power cable, a water supply pipe with diameter of 1500 mm and a group of telephone cables to the east of the bridge; while two gas pipes with diameter of 300 mm and 700 mm respectively, a water supply pipe with diameter of 300 mm and two groups of telephone cables to the west of the bridge.

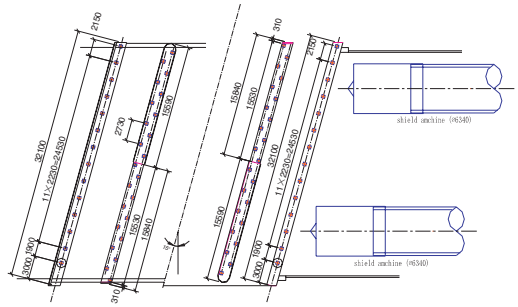

Figure 2. Plan view of tunnel crossing bridge foundation.

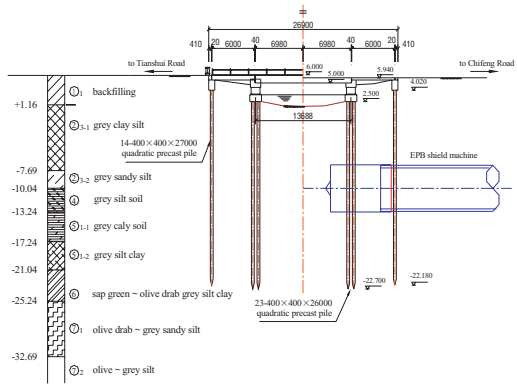

Figure 3. Elevation view of tunnel crossing bridge foundation.

2.2 *The geological conditions of the project*

According to engineering geological survey report, the geological conditions at Shajinggang Bridge can be divided into the following layers. The first layer is miscellaneous backfilling with thickness from 1.9 to 3.7 m, containing cinder, stone, etc. The second layer is grey and yellow clayey mingled with 1.0 m thick black humus in it. The third layer is grey silt soil containing clay in it. It belongs to medium compression soil, about 10 m thick. The fourth layer is grey clay with sand body trapped in it. It is high compression soil, including white stiff block and black humus in it, about 5 ∼ 12 m thick. The fifth layer is dark green hard clayey. It belongs to medium compressed soil, about 2.4 ∼ 2.8 m thick. The sixth layer is olive drab hard clay, which is medium compression soil also. The seventh layer is olive drab silt soil.

2.3 *Existing problems and solutions*

In this project, the uniqueness and difficulties is not only reflected on complicated site topography and more intensive surrounding buildings, but also can be seen from the following aspects.

1. Since Quyang Road subway station is very near to the bridge pile foundation, coupled with the restriction of line slope in longitudinal section, the tunnel can not cross beneath the pile foundation directly.
2. Since the outer diameter of shield machine is approximately 7 m, in the crossing process, 4 piles at each pier and 3 piles at each abutment should be removed.
3. Since Siping Road is one of main roads of Shanghai city, its traffic flow is big at day and night, it is not allowed that the traffic volume to be affected during the construction period.

In view of the above considerations, under the premise of existing traffic not to be affected, the proposed construction strategies include: ① adopting pile foundation underpinning technology at each pier and abutment; ② removing piles affecting shield tunneling. Since Shanghai has not yet had the precedent of pile under-pinning in subway construction, it is necessary to conduct series comprehensive technical studies on this technology and its accessory method, thus provide a common technical guidance for future similar projects.

3 ACCESSORY CONSTRUCTION METHODS IN PILE UNDERPINNING

3.1 *Methods of foundation reinforcement*

The purpose of foundation reinforcement is to ensure the stability of existing structures, such as pier and abutment, and to provide stable foundation.

The main methods of foundation reinforcement can be concluded as:

1. Grouting method: the main role of grouting is to seal water, but it is not applicable to cohesive soil.
2. Deep mixing method: it can ensure foundation intensity and its sealing characteristics. This method includes two categories, that is, vertical construction method and transverse construction method.
3. Freezing method: it can guarantee foundation strength and sealing effect; but it is difficult to resolve the ground deformation when defrosting.

3.2 *Method of removing existing piles*

There are two methods, that is, extracting piles from ground surface and demolishing piles within layers.

(1) Extracting piles from ground surface

Deep excavation method: it is very simple, cheap and the required operation space is small also. The main procedure is shown in Figure 4.

Extracting piles with casing pipe: according to some overseas related experiences, this method includes processes of extracting piles with casing pipe and

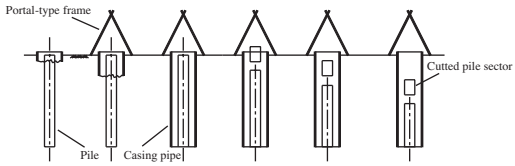

Figure 4. Sketch map of deep excavation.

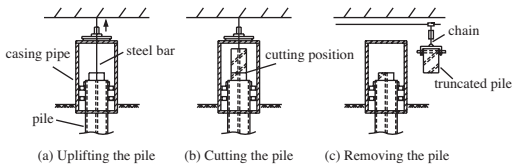

Figure 5. Sketch map of extracting pile with casing pipe.

cutting piles, only needing 5 ~ 6 m construction space in height, as shown in Figure 5.

(2) Demolishing piles within layers

This method can also be divided into two types: demolishing piles manually inside the chamber and cutting piles directly by shield machine. For the first type, it should reinforce the foundation firstly, and then remove piles manually in the chamber. For the sake of safety, compressed air can be used as supplementary measure to stabilize the excavation face. For the second type, piles can be cut directly by the special device installed on the cutter disc of shield machine without human operation. But, the shield machine used here is relatively more expensive.

4 PROPOSAL FOR SHAJINGGANG BRIDGE

Based on overseas experience and some successful instances [4], two feasible schemes are provided here. A scheme is reinforcing foundation and eliminating piles inside the shield chamber, while B scheme is reinforcing foundation, adding new piles and extracting piles with casing pipe.

4.1 *A scheme*

(1) Foundation reinforcement and construction of retaining wall

Foundation reinforcement and construction of retaining wall is to form operation space which is used to reinforce bridge structure, as shown in Figure 6 and 7. Since the river flows perennially under the bridge, cofferdam should be built firstly.

(2) Pit excavation behind the abutment

Since the foundation of pier and abutment can not be reinforced on road surface, so it is necessary to

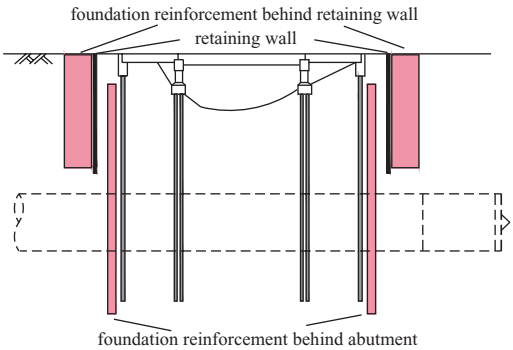

Figure 6. Elevation view of foundation reinforcement.

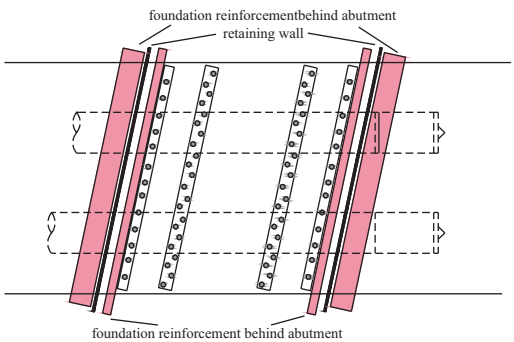

Figure 7. Plan view of foundation reinforcement.

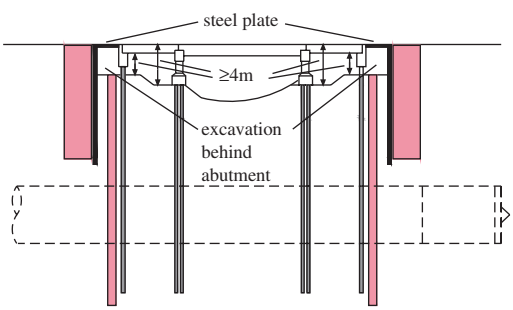

Figure 8. Elevation view of pit excavation behind abutment.

dig pit between the abutment and retaining wall. It is noteworthy that the excavated depth below the road surface should be no less than 4 meters so as to reinforce the foundation smoothly. After excavation, the pit top should be covered with steel plate to ensure that the ground traffic will not be affected, as shown in Figure 8.

(3) Foundation reinforcement of pier and abutment

Once the foundation of pier and abutment had been reinforced, as shown in Figure 9 to 11, it can not

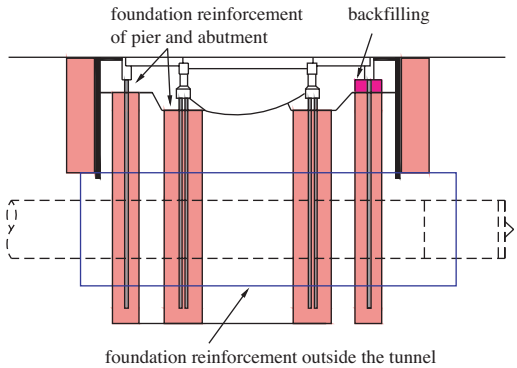

Figure 9. Elevation view of structure foundation reinforcement.

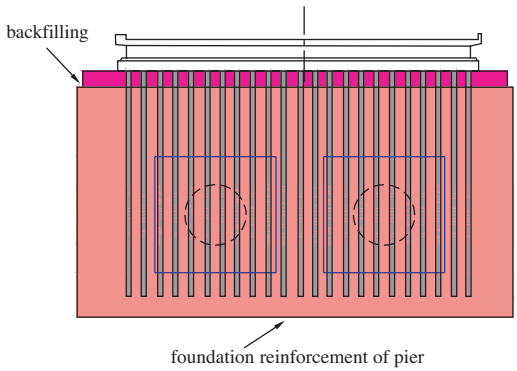

Figure 10. Foundation reinforcement of pier.

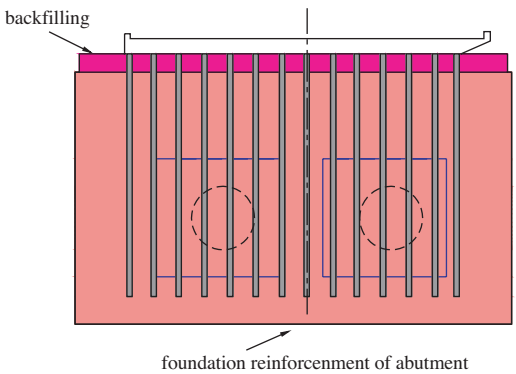

Figure 11. Foundation reinforcement of abutment.

only transfer the load borne by the removed piles to the new added piles and the remaining piles, but also integrate the foundation and piles as a whole body. In addition, the tunnel lining located here should be redesigned as high stiffness segment to withstand the

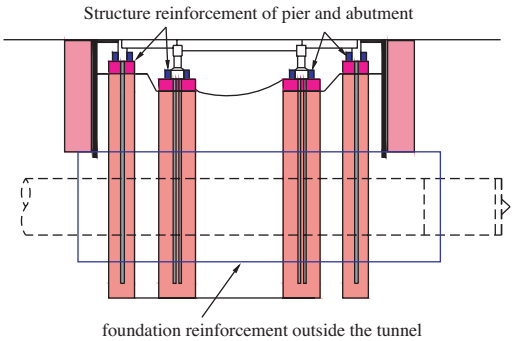

Figure 12. Elevation view of reinforcing pier and abutment.

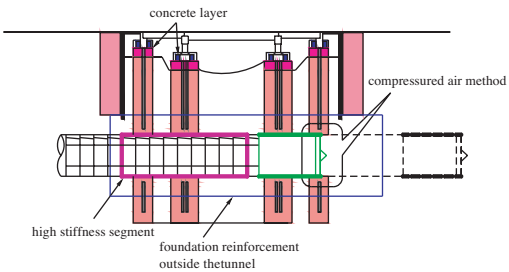

Figure 13. Demolishing piles and propelling shield machine.

load transferred from the removed piles. Considering the security of manually operation and stability of tunneling face, the foundation outside the tunnel should also be reinforced firstly, and the reinforced scope is indicated by the blue line in following figures.

(4) Structure reinforcement of pier and abutment

The purposes of reinforcing pier and abutment structure is to transfer the load borne by the removed piles to the reinforced foundation and remainder piles, and improve the capacity to resist shear force and moment perpendicular to the axial of pier and abutment. During reinforcement, steel beam can be used to support the structure, as shown in Figure 12.

(5) Demolishing piles and propelling forward the shield machine

After all the reinforcement work had been done, it will be able to demolish piles, propel forward shield machine and assemble segments subsequently. Since the work of demolishing piles is done inside the chamber, the excavated soil in it should be discharged firstly. Thereafter, tunneling face is in the unsupported status, so compressed air can be used to stabilize the face. The whole sketch map is shown in Figure 13. If necessary, high stiffness segment may be used within the whole

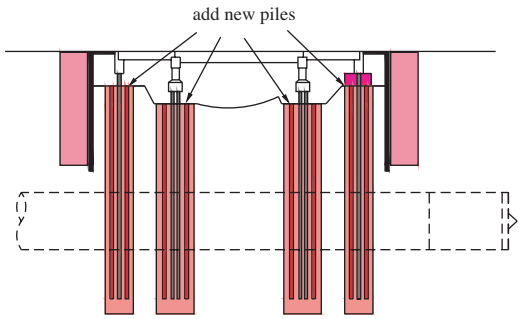

Figure 14. Elevation view of foundation reinforcement.

length below the bridge, which is indicated by the purple line in the figures. Meanwhile, the deformation of pier and abutment should be monitored strictly.

(6) Maintaince of steel beam and restoration of road surface

To prevent the corrosion of steel beam, it should be coated with a layer of concrete. After the obstacle piles had been removed and the shield machine had passed by, in order to guarantee regular transportation running, it is necessary to demolish the retaining wall, backfill the pit and restore the road surface. But, during these processes, more attention should be paid to monitor the deformation of structure.

4.2 *B scheme*

(1) Foundation reinforcement and the construction of retaining wall

Foundation reinforcement and the construction of retaining wall are the same as that in A scheme, as shown in Figure 6 and 7.

(2) Pit excavation behind the abutment

This process is also identical with that in A scheme, as shown in Figure 8.

(3) Foundation reinforcement of pier and abutment and the construction of adding new piles

Compare with that in A scheme, there are two differences in this process altogether, first is the reinforced scope, second is adding new piles, as shown in Figure 14 to 17. After the foundation reinforcement, the foundation at the topside around the piles should be excavated to form working space for adding new piles. Therefore, the required vertical clearance under pier and abutment should be not less than 3.5 meters.

(4) Reinforcement of pier and abutment structure

Reinforcement of pier and abutment can better improve its capability to resist exterior loads. Therefore, steel beam can be used to support the structure;

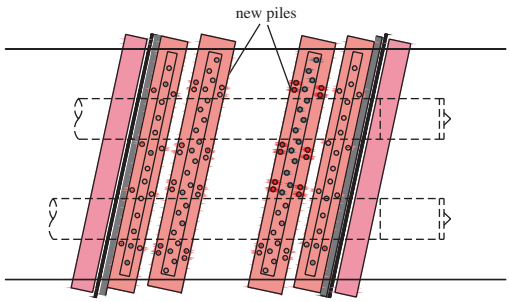

Figure 15. Plan view of foundation reinforcement.

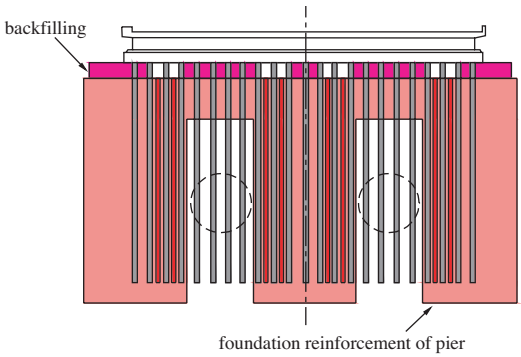

Figure 16. Foundation reinforcement of pier.

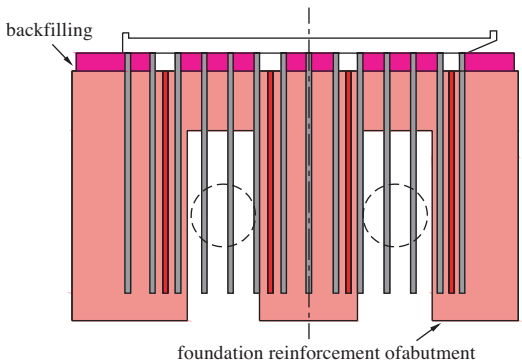

Figure 17. Foundation reinforcement of abutment.

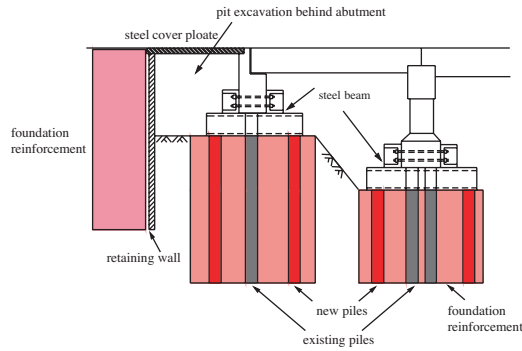

Figure 18. Reinforcing bridge structure and adding new piles.

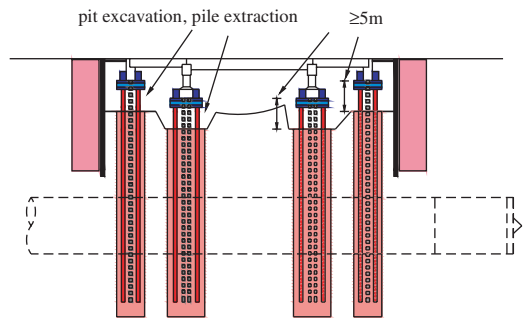

Figure 19. Further excavation of foundation.

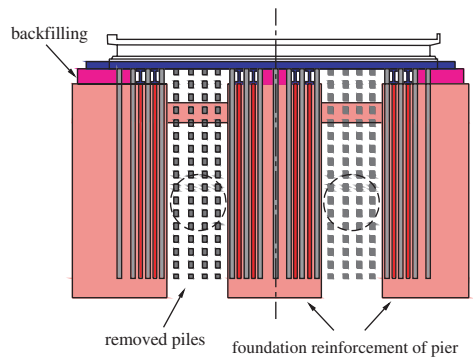

Figure 20. Extracting pile with casing pipe at pier.

the main process is identical to that in A scheme, as shown in Figure 18.

(5) Foundation excavation and pile extraction

The purpose of further excavation of foundation below the bridge is to ensure that the working space for extracting pile can be satisfied. But, only those places, where the piles need to be extracted, should be excavated down. Since casing pipe method is used to extract piles, the required vertical clearance under the bearing platform should be no less than 5 m, as shown in Figure 19 to 21. During the construction of extracting pile, more attention should be paid on the monitoring of pier and abutment, especially for structure deformation.

(6) Propelling shield machine and installing segments

After the impeded piles had been removed, the shield machine can then move forward and pass

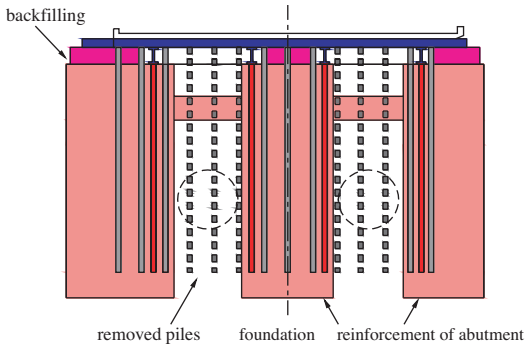

Figure 21. Extracting pile with casing pipe at abutment.

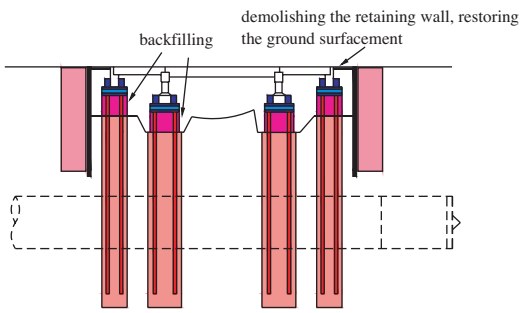

Figure 22. Backfilling and restoration of road surface.

through bridge foundation, followed by installation of segments. During the crossing process, deformation of pier and abutment structure should be monitored primarily.

(7) Backfilling and restoration of road surface

Once the shield machine had passed through the pile foundation, it is necessary to demolish the retaining wall, backfill the pit and restore the road surface to guarantee the regular traffic running, as shown in Figure 22. During such process, it is important to put emphasis on the deformation monitor of bridge structure.

5 CONCLUSIONS

Combined with the practical situations of in Shanghai area and the example of shield machine crossing through the pile foundations of Shajinggang Bridge, this paper mainly study how the underpinning technology can be used in subway construction. Based on concrete analytical studies, two main construction schemes are presented here. One is 'reinforcing foundation and eliminating piles inside the chamber'; the other is 'reinforcing foundation, adding new piles and extracting piles with casing pipe'. Since the pile underpinning technology has never been used in the subway construction of Shanghai area, the two schemes provided in this paper can not only be used as reference of design and construction, also as precious experience for future similar projects.

REFERENCES

Ishimura, T., Metoki, M. & Shimizu, M. 2006. Development of removed pile method with cutting. *Tunnelling and Underground Space Technology* 21: 411–412.

Iwasaki, Y., Watanabe, H., Fukuda, M., Hirata, A. & Hori, Y. 1994. Construction control for underpinning piles and their behavior during excavation. *Geotechnique* 44(4): 681–689.

Sharma, J.S., Hefny, A.M., Zhao, J. & Chan, C.W. 2001. Effect of large excavation on deformation of adjacent MRT tunnels. *Tunnelling and Underground Space Technology* 16: 93–98.

Yamaguchi, I., Yamazaki, I. & Kiritani, Y. 1998. Study of ground-tunnel interactions of four shield tunnels drive in close proximity, in relation to design and construction of parallel tunnels. *Tunnelling and Underground Space Technology* Vol.13, No.3: 289–304.