Original Research Article

Optimal Design and Application of Earthwork Excavation Scheme for Deep Foundation Pit:

Taking the New Construction of the Entrance and Exit of the Underground Passage in the Central area of the Pudong Senlan Block as an Example

LI Ai-hua

Shanghai Pudong New Area Construction（Group）Co.，Ltd.，Shanghai 200120，China

Abstract: In the process of building construction, the optimization of the construction scheme has always played a great role in saving construction costs, reducing construction risks and speeding up the construction progress. This paper studies the optimization of the implementation plan of the deep foundation pit earthwork excavation stagein the actual case, and analyzes the results of the optimization of the plan, so that the optimized new plan can accelerate the construction period and save money while ensuring the project quality and construction safety. The construction cost has played a significant role.

Keywords: Deep foundation pit; Earthwork excavation; Shortcomings of the old scheme; Scheme optimization; Senlan Shangdu.

1. Introduction

At present, with the acceleration of urbanization in China, the sharp increase in population and traffic flow has brought great pressure to urban transportation. As a result, many underground transportation projects are also being constructed more and more. However, the construction environment of underground transportation projects is complex, and the procedures are complex, which also involves the cooperation of various departments, which has a great impact on these construction projects. Therefore, in order to optimize the construction of underground engineering, relevant departments should adopt innovative and scientific construction techniques, continuously optimize the design of technical schemes and technological innovation, in order to improve the quality of underground engineering construction and promote the healthy development of urbanization construction.

The article takes the new construction project of the underground passage entrance and exit in the central area of the Senlan plot as an example to optimize the construction plan, mainly to improve the quality of the project construction, provide safety and technical support for construction. The optimized and innovative construction plan is not only convenient for construction, but also saves costs, shortens the construction period, and achieves the win-win construction goal of economic efficiency and social benefits.

2. Brief Description of Deep Foundation Pit Engineering

Deep foundation pit engineering refers to the engineering of dewatering, support, and earthwork excavation for foundation pits with an excavation depth exceeding 5m (including 5m). Deep foundation pit engineering has complex system engineering characteristics. In carrying out deep foundation pit engineering, the most important ones are deep foundation pit support and earthwork excavation engineering, which need to cooperate and coordinate with each other to ensure the stability and safety of underground engineering structures.

Received: 1 July 2022 Accepted: 21 July 2022 Available online: 19 September 2022
Copyright © 2022 by author(s). *Value, Function, Cost* is published by Academy of Science Pte. Ltd.. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), permitting distribution and reproduction in any medium, provided the original work is cited.

2.1 Deep Foundation Pit Support Technology

The deep foundation pit support technology in the construction process of building engineering refers to the corresponding technology provided by the supporting structure of the building to ensure the safety of actual structural construction and foundation pit construction. The technology is not in place during the construction process, providing technical support for basic construction. At the same time, it also provides guarantees for the overall bearing capacity and strength of the building foundation, which can continuously improve the construction quality. To a certain extent, deep foundation pit support technology will have an impact on the overall construction quality, and even affect the overall construction progress, and it will also have a certain correlation with the economic benefits of construction. The treatment of deep foundation pit support technology in the construction process can effectively combine different tasks, select appropriate technical content, ensure actual technology, and maximize advantages.

2.2 Soil Nail Support Construction

The common deep foundation pit support technology in the construction process of building engineering, including soil nail support construction, uses land for foundation pit support as a common form of support. Its principle is to make the slope soil more stable through the interaction between soil and soil. On the basis of ensuring soil stability and integrity, soil nails are placed inside the soil, It will ensure the stability of the actual soil under the action of bending moment and tension. Before supporting deep foundation pits, it is necessary to first conduct experiments on the soil. During the project, strength experiments should be conducted after the soil nails enter the soil to ensure the stability of the construction process and avoid factors that may affect deep foundation pit support technology, leading to safety accidents. Before the construction of soil nails, it is necessary to measure the depth of the holes in the soil nails. In the technical construction process, grouting should be strictly carried out in accordance with the requirements of the deep foundation pit support construction specifications, and the water cement ratio and admixtures of the cement mortar should be strictly controlled. Until the hole is filled with grouting, attention should be paid to the grouting time to ensure that the specific grouting work is completed before the initial setting of the cement mortar. The grouting ratio should be well prepared during the mixing grouting process, and the actual setting specifications should be strictly followed. The amount of cement per square meter should be controlled.

2.3 Construction Techniques for Soil Anchor Rods

In the application process of deep foundation pit support technology, soil anchor rods are also an important aspect of the specific construction process, which can be drilled through drilling machines. The specific depth should be established according to the construction plan. Firstly, a comprehensive inspection of the anchor rod is required. During the drilling process, if any obstacles or foreign objects are encountered, the work needs to be stopped in a timely manner. Only after solving the actual problems can the construction be completed normally. During the construction process of soil anchor rods, strict control should be exercised to ensure that the statistical errors are within a certain range. During cold joint treatment and drilling rig installation, the screw should be kept uniformly rotating, and the inclination of the bottom of the borehole should not exceed 3% of the length of the anchor rod. At the same time, the depth of the anchor rod should be designed to not exceed 1% of the design length, and the corresponding ratio should be strictly in accordance with specific design requirements, Grouting should be carried out from top to bottom for the holes.

2.4 Support Technology of Retaining Piles

This technology often uses enclosure structures to support deep foundation pits, in order to prevent quality problems during the construction of deep foundation pit structures. It is particularly helpful for the safety of deep foundation pit construction and can fully leverage the advantages of deep foundation pit support technology.

2.5 Continuous Wall Support Technology

In this type, the underground continuous wall itself has a strong height and performs well in waterproofing and leakage prevention functions. It can be applied to the construction environment of soft clay and sandy soil layers below the groundwater level, and is more suitable for the application system of deep soil foundation pit support construction, ensuring the effective construction of deep soil foundation pit support construction application system.

2.6 Deep Mixing Support Technology

It mainly uses solidifying agents combined with cement to carry out the mechanical equipment mixing process, and combines solidifying agents and soft soil agents for forced mixing. After chemical reactions, it gradually hardens, effectively improving the safety and stability of deep foundation pit support construction.

3. Overview of the New Construction Project for the Entrance and Exit of the Underground Passage in the Central Area of the Senlan Plot in Pudong

The new construction project for the entrance and exit of the underground passage in the central area of Senlan plot is located in Waigaoqiao New Town, Pudong New Area. The entrance and exit of the underground passage in this project is an important passage that connects the entire underground ring road of Senlan plot with surrounding municipal roads. The central plot has planned a transportation loop on the underground second floor to connect the various plots together, making parking spaces complementary and communication convenient, and optimizing regional ground transportation. The entrance and exit of the loop directly reach the city's main roads Zhouhai Road and Zhangyang North Road, and smoothly connect with urban transportation. This project involves four underground tunnel entrances and exits, with specific locations as follows: Tunnel One is an underground vehicle entrance and exit passage located on the east side of Zhangyang North Road and the south side of Qifan Road; Tunnel 2 is an underground entrance and exit passage for vehicles, located on the east side of Zhangyang North Road and the north side of Qifan Road; Tunnel 3 is an underground vehicle entrance and exit passage, located on the south side of Zhouhai Road, connecting to the basement on the north side of D1-4; Tunnel 4 is an underground vehicle entrance and exit passage, located on the south side of Zhouhai Road, crossing Lansong Road and connecting to basement D1-4.

The buried section of the tunnel adopts an integral box frame structure, while the open section adopts a U-shaped groove dock structure. The net height of the buried section is 5.5m, and the net width of tunnels 1, 2, and 3 is 9.0m, with a total width of 10 Yao 11m; The fourth tunnel has a net width of 7.0m and a total structural width of 8m. The underground tunnel has a buried section of 50m in length, an open section of 110m in length, and a total length of 160m; The buried section of Tunnel 2 is 80m long, the open section is 80m long, and the total length is 150m; Tunnel 3 only has a 30m long open section, with a total length of 30m; The buried section of the underground tunnel is 70m long, the open section is 70m long, and the total length is 140m.

Due to the full opening of the entire Senlan business in mid-2021, the owner has very high requirements for the construction period of the four underground passage entrances and exits. At the same time, the structures of the four entrances and exits are not complex. Therefore, the key processes that have the greatest impact on the progress of the entire project implementation process are the construction of enclosure and earthwork excavation. At the same time, as the four underground passages are implemented simultaneously, there is a high requirement for the connection of the flow operation of each process. Therefore, a suitable excavation plan for the foundation pit is crucial for early project planning.

4. Design Intent and Drawbacks of the Original Earthwork Excavation Plan

4.1 Design Scheme for Enclosure

This project involves four underground passages. Taking the most complex underground passage four as an example, the underground passage is a long strip shaped foundation pit with an arc shape, with a size of approximately 150m × 13.5m, excavation depth 0.7-11.96m, the foundation soil of this project is mainly composed of cohesive soil and sandy soil. The soil layers are as follows: the first layer is plain fill soil; The second layer is silt; The third layer is hydraulic fill soil (clay powder mixed with muddy clay); The fourth layer is composed of silty clay with sand inclusions; The fifth layer is sandy silt; The sixth layer of muddy clay; The seventh layer is silt. The shallow groundwater in the engineering site belongs to the diving type, with an average annual groundwater depth of 0.3-1.5m. The seventh layer within the site is the fourth confined water aquifer. The excavation depth of the proposed foundation pit is relatively deep, and the seventh layer of pressurized water does not surge. According to the survey measurement results, the burial depth of the seventh layer of slightly pressurized water is between 3.0-11.0m.

The depth of the four tribes in the local underpass is 14.26m. Implement different enclosure methods based on the on-site situation. The depth of the foundation pit is between 0.7 and 3.0 meters, and a three-axis gravity retaining wall is used; When the depth of the foundation pit is greater than 3.0m, a drilling and grouting pile with a three-axis mixing pile water stop curtain will be implemented on the north side. The SMW construction method pile form will be used on the south side, and a double axis mixing pile will be implemented at the bottom of the foundation pit for the trial work of adding suction bars to the skirt. In addition, two three-axis mixing pile water stop curtains will be used inside the foundation pit to resist internal water stop, as shown in Figure 3. One to four supports are used according to the depth of the foundation pit (see Table 2), and detailed enclosure parameters are shown in Table 1. (Figures 1 and 2)

Table 1 Structure of the four surrounding walls and water stop curtain in the underground passage.

Surrounding wall	Cast in place pile arrangement	Ø750@950 Ø 850@1050 Ø 950@1150
	SMW	Ø850@600 Triaxial + H700×300×13×24 Tight insertion of steel profiles Ø 850@600 Triaxial + H700×300×13×24 Steel bar insertion two jumps one Ø 850@600 Triaxial + H700×300×13×24 Insert and jump the steel section one by one
	Gravity retaining wall	Ø 850@600
Water stop curtain	Three axis mixing pile	Ø 850@600
	High pressure rotary jet grouting pile (local)	Ø 800@500

Figure 1 Underground passage four plan view.

Figure 2 Four vertical sections of underground passage.

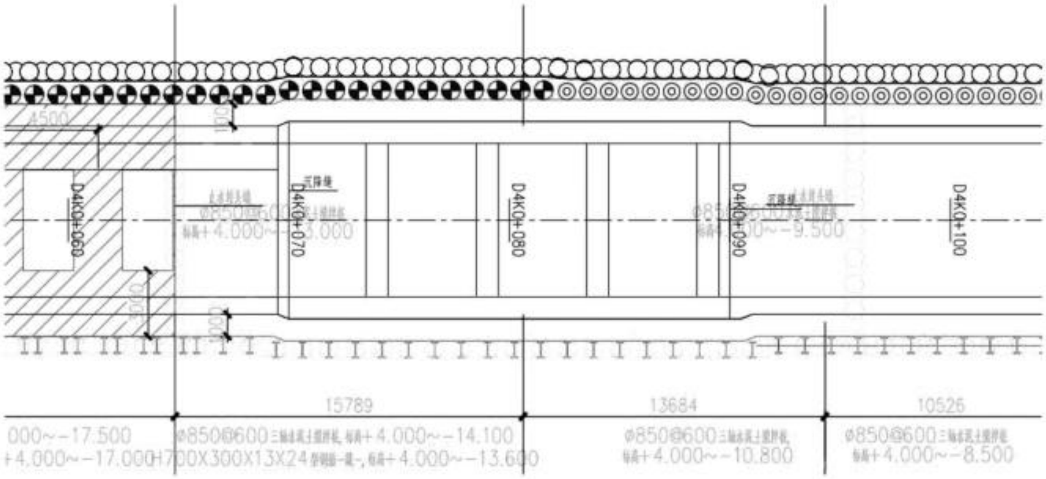

Figure 3 Location map of water stop curtains in the four pits of the underground passage.

Table 2 Relevant information on the four supports of the underground passage and the Yuanwei purlin of the crown beam.

First support	Center elevation (m)	3.10
	Crown beam (mm)	1200×800
	Main support (mm)	800×800
Second support	Center elevation (m)	0.26
	Surrounding purlin (mm)	2h700×300×13×14double
	Main support (mm)	Ø609×16@4500steel pipe
Third support	Center elevation (m)	-2.58
	Surrounding purlin (mm)	2h700×300×13×14double
	Main support (mm)	Ø609×16@4500steel pipe
Fourth support	Center elevation (m)	-5.42
	Surrounding purlin (mm)	2h700×300×13×14double
	Main support (mm)	Ø609×16@4500steel pipe

4.2 Excavation Plan for Original Foundation Pit

According to the enclosure design, the bottom reinforcement form used in the deep pit did not seal the pit bottom, and the two three-axis waterproof curtains inside the pit divided the entire foundation pit into three parts. In order to ensure the effectiveness of dewatering in the pit, the original plan divided the pit into three sections with two waterproof curtains as the boundary (see Figure 4 for details), with a sequence of ①→②→③. In the ① section, four supports and three supports were set up according to different depths. Following the principle of "support before excavation, and no over excavation", the surface soil was excavated and the first reinforced concrete support was carried out (see Figure 4). The excavation work of the ① section began. When the first layer was excavated into the deep pit, the first steel was used for bottom support, ensuring that over excavation was learned, Do not excavate the first steel support in the shallow area (see Figure 5). After the first steel support is completed, excavate the second layer of soil until the deep pit area, and then perform the second steel support. In addition, excavate the soil under the first steel support in the shallow soil area, and then perform the second steel support until the first steel support in the shallow area is implemented, as shown in Figure 6. Repeat the steel support construction and soil excavation in a sequential flow until the bottom of the pit, Pour the cushion layer and construct the tunnel structure.

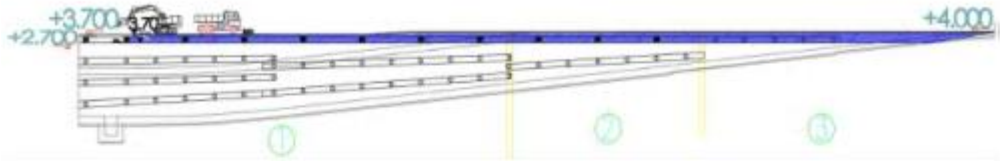

Figure 4 Schematic diagram of surface soil cleaning for underground passage four (Original plan).

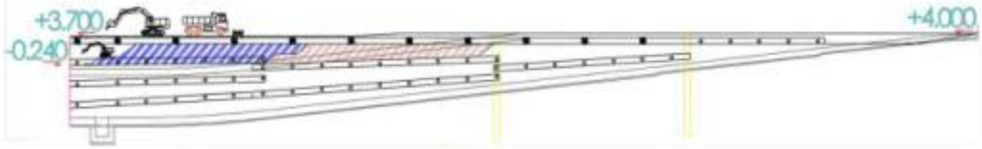

Figure 5 Schematic diagram of earthwork excavation for the first layer of section ① of underground passage 4.

Figure 6 Schematic diagram of earthwork excavation for the second layer of section ① of underground passage 4.

4.3 Disadvantages of Original Foundation Pit Excavation

According to this excavation plan, although feasible, there will be significant drawbacks during the construction process:

(1) Due to the need to retain the waterproof curtain inside the pit to seal it, multi-stage sloping needs to be added during phased construction (see Figure 8 for details); Multi level sloping will increase the risk of bottom construction, especially in the Shanghai area where geological conditions are poor and rainfall is frequent, which has a significant impact on the slope. (2) The construction of the ② section needs to be carried out after the completion of the structural bottom plate and the closure of the pit bottom. Although the ③ section is relatively shallow and only has one support that can be implemented together with the ② section, the construction team of earthwork machinery and steel support will repeatedly enter the site, which will not only increase costs but also lead to an increase in construction period. (3) Segmented construction operations can easily lead to structural team idleness, and due to segmentation, the bottom plate cannot be continuously poured. Increasing joint treatment has a significant impact on the waterproof performance of underground structures.

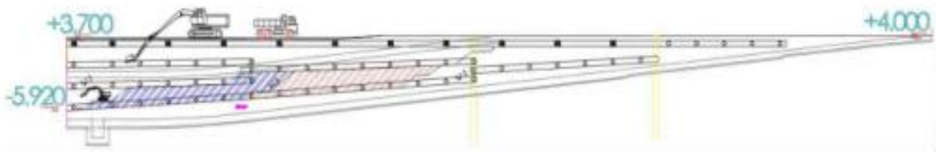

Figure 7 Schematic diagram of earthwork excavation for the third layer of section ① of underground passage 4.

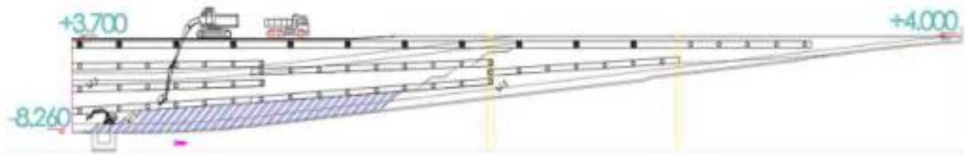

Figure 8 Schematic diagram of earthwork excavation for the fourth layer of section ① of underground passage 4.

5. Optimized Excavation Plan and Advantages for Deep Foundation Pit Earthwork

5.1 Optimization of Enclosure Design Scheme

In order to ensure the progress and safety of the project, the project department actively communicated with the design and owner, and changed the original skirt reinforcement of the deep pit to full reinforcement (see Figure 9). At the same time, a vacuum deep well was added to the unclosed area at the bottom of the shallow pit to reduce the water level in the shallow pit area (see Figure 10), weakening the importance of the three-axis water stop curtain inside the pit.

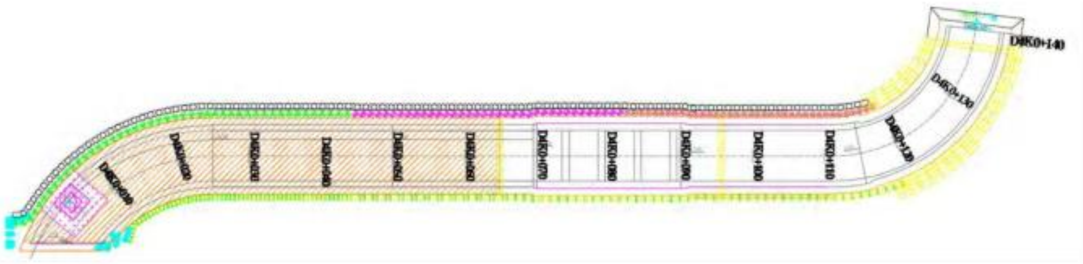

Figure 9 Full reinforcement of the four deep pit sections of the underground passage.

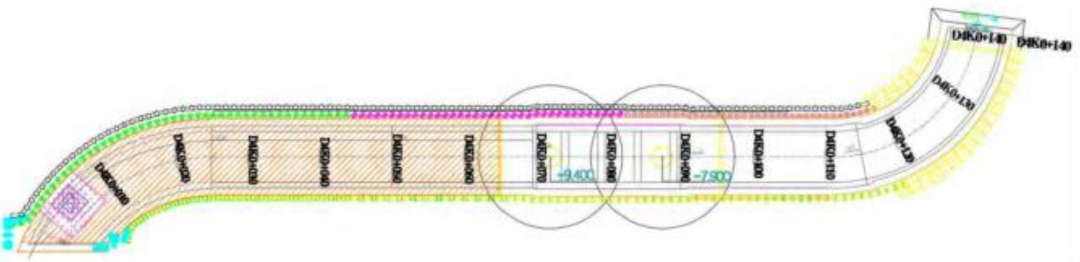

Figure 10 Layout of four deep wells for dewatering in underground passage.

At the same time, the entire long foundation pit will be implemented as a whole, and each layer of soil will be divided into three flow sections based on the number of support channels (see Figure 11 for details).

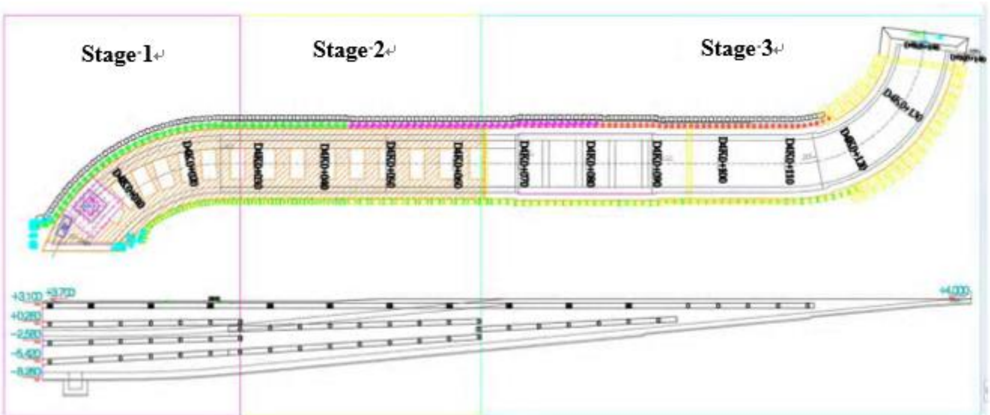

Figure 11 Schematic diagram of earthwork block division for each floor of underground passage four.

After the surface earthwork excavation of the deep foundation pit is completed, the first layer of steel concrete support should be consistent with the original construction plan. Then, the first layer of earthwork should be excavated until the first section of the first steel support is completed. After the construction is completed, the first layer of steel support should be carried out. In addition, when the excavation depth does not exceed the first section, the earthwork of the second and third sections should be excavated (see Figure 13 for details).

The second layer adopts a similar assembly line operation method, sequentially excavating and constructing the second steel support of the first section and the first steel support of the second section, because the depth of the entire foundation pit gradually becomes shallower, and the spacing between each support is about 3 meters, so only one level of slope can be placed.

During the excavation process, do the following:

(1) The excavation process follows the construction philosophy of “layered excavation, no over excavation” and “large foundation pit, small excavation”, and full-time inspectors are arranged to comprehensively supervise and evaluate the entire excavation process. In the construction plan, each excavation must be effectively coordinated and coordinated with the supporting construction party.

(2) After excavating the soil to the height of the first foundation pit bottom, repair the soil and pour the concrete cushion layer in a timely manner. The cushion layer should extend to the edge of the enclosure structure and lay underground drainage ditches on all sides of the foundation to prevent groundwater from entering the pit.

(3) Protective railings are installed around the deep foundation pit, with safety railings installed at a height of 1250m above the ground. The horizontal railing below is 500mm above the ground, and a 120 high toe board is installed near the ground. Two fixed ladders are installed at both ends of the excavation pit for personnel going up and down.

(4) Strictly carry out deep foundation pit drainage. There should be a specialized scheme design for deep foundation pit drainage to ensure the scientific, reasonable, and effective engineering design. The waterproofing and drainage of the top position of the foundation pit slope are usually achieved through road surface hardening, interception and drainage ditches, etc. During the construction process, excavation of the foundation pit can easily lead to slope deformation, which can form cracks on the ground and hardening of the slope top position. The road surface often serves as a construction diversion, causing frequent construction vehicles on the bottom surface of the slope, which is prone to corresponding crack problems. Effective waterproofing measures cannot be taken properly, resulting in insufficient waterproof facilities and insufficient drainage. After surface water infiltrates through cracks, it can cause slope deformation, ultimately leading to the failure of the entire foundation pit. Therefore, in the process of setting up foundation pit drainage engineering, strict design requirements and plans need to be followed. During the excavation process, specific measures for reducing the water level during excavation must be strictly implemented. During precipitation, monitoring of the surrounding environment should be strengthened to prevent local subsidence, which may affect the construction safety of the actual foundation pit engineering.

(5) Relevant construction workers should cooperate with regulatory requirements in a timely manner, strictly monitor slopes according to requirements, promptly identify existing safety hazards, and report to higher-level departments to handle safety risks in a timely manner.

While doing the above work well, then excavate each layer of soil in sequence until the bottom plate structure is constructed. (Figures 12-16)

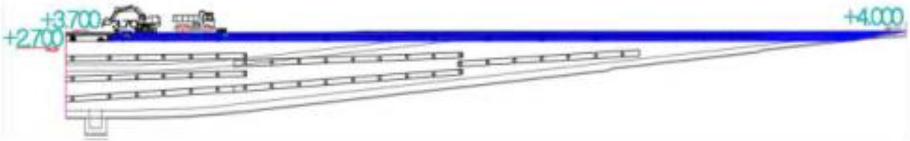

Figure 12 Schematic diagram of surface soil cleaning for underground passage four.

Figure 13 Schematic diagram of earthwork excavation on the first floor of underground passage four.

Figure 14 Schematic diagram of earthwork excavation for the second floor of underground passage four.

Figure 15 Schematic diagram of earthwork excavation for the third floor of underground passage four.

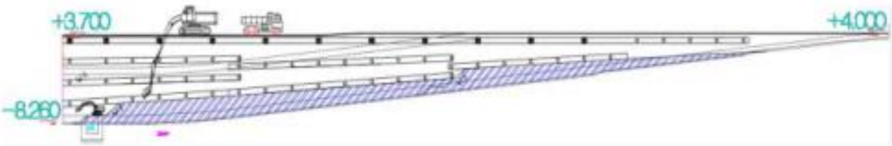

Figure 16 Schematic diagram of earthwork excavation on the fourth floor of underground passage four.

5.2 Advantages of Optimized Earthwork Excavation Plan

The main advantages of optimizing and adjusting the plan include the following aspects:

(1) Solved the safety hazards of multi-level sloping, as the spacing between supports is about 3 meters, and the thickness of each layer of excavated soil is smaller in shallow buried sections. Therefore, only one cross slope needs to be placed during the construction process, greatly reducing the danger of construction.

(2) The connection between each process is more smooth, as each layer of soil is excavated in stages at once, reducing repetitive entry operations. Taking into account the four underground passage entrances and exits, the construction efficiency is further improved.

(3) To ensure the quality of continuous pouring of the bottom plate, the optimized plan reduces the number of bottom plate segments, making it easier to implement continuous pouring of the bottom plate, reducing joint treatment, and ensuring structural quality.

(4) The working face is more convenient for construction. Compared with the original plan, the construction work surface of each process is larger, and the impact of interspersed construction is smaller. At the same time, the shallow buried section is opened up, making on-site material transportation more convenient and reducing the frequency of lifting materials more economical.

6. Conclusion

In summary, the optimization of on-site construction plans has always played a significant role in saving construction costs, reducing construction risks, and accelerating construction progress. In the early planning process of actual on-site construction, project management personnel should consider the feasibility of various conventional construction plans based on the actual situation of the construction project, in order to select a more suitable construction plan for the project. The optimized construction plan has passed the evaluation of the Shanghai Municipal Science and Technology Commission and has also been recognized by experts. It has also demonstrated specific aspects such as cost savings, reduction of construction risks, and acceleration of construction progress during the construction process.

References

1. DG/TJ08-61-2018，Technical standards for foundation pit engineering [S].
2. Huang Jianzhang. Optimization and on-site management of excavation plans for ultra deep foundation pits [J]. Construction, 2008 (5).
3. Wang Hongsheng. Optimization and Effect Analysis of Earthwork Excavation Route [J]. Industrial Architecture, 2013 (1).