Construction optimization of PBA of Subway station tunnel excavation and its cross section in loess area

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Abstract. This paper takes the project of Hejiaying Station of Xi’an Subway Line 2 as the background for the study. The dynamic numerical simulation of the construction process of the station by the PBA method is carried out using the 3D finite element method. The changes of surface settlement, vault settlement, headroom convergence and structural stresses are studied up to the intersection of the guide tunnel and large section duct. The research results show that: the construction of the upper guide hole of the station has a small effect on the deformation and internal force of the initial support structure of the duct. The construction of the lower pilot hole will increase the deformation and internal force of the initial support structure of the duct, especially the construction of the lower 2 pilot holes and the lower 3 pilot holes will lead to a significant increase in the deformation and internal force of the initial support structure of the duct. Therefore, it is necessary to make a 10m reservation for the lower guide hole of the main line, and to grout the cross section of the lower guide hole to ensure the safe construction of the cross section.

1. Introduction
In recent years, due to the geological conditions, ground traffic, underground pipelines, and surrounding buildings and other aspects of the impact, it brings many obstacles to the construction of the metro. The PBA method construction of concealed excavation stations has been more and more widely used in domestic and international metro construction because of the advantages of not affecting traffic and no pipeline relocation [1-4].

In order to ensure the safety during the operation of the subway, air ducts are set at both ends of the station from the consideration of ventilation, fire prevention and rescue. The structural forces at the intersection of the subway concealed excavation station and the duct are complex, and the stresses at the intersection are more concentrated, which is the weak link of the structure and also the key part of the construction [5]. Therefore, only by fully understanding the force characteristics and spatial construction mechanics of this part of the structure, and by understanding the location of the maximum surface settlement point and the trend of surface settlement changes during construction, can we choose reasonable construction methods and effective strengthening measures to ensure construction quality and safety, while reducing costs and improving work efficiency.

In this paper, a three-dimensional finite element analysis method is used to simulate dynamically the construction process of Hejiaying station in the first bid section of Xi’an Metro Line 2 Phase II
construction general contracting, analyze the changes of surface displacement and structural principal stress in the cross section, and propose corresponding construction suggestions to provide reference for similar projects and corresponding inverse analysis studies.

2. Project Overview
Hejiaying station is a 230m-long island station with No. 1 and No. 2 ducts at the north and south ends of the station, and a total of three construction shafts on the east side of the station main line, No. 1, No. 2 and No. 3 construction shafts from north to south respectively. From the construction shafts, the cross passage is excavated to provide the working surface for the construction of the main line guide tunnel. The main line guide tunnel is divided into four upper and two lower, the upper guide tunnel is constructed by step method and the lower guide tunnel is constructed by CD method. The location of the station construction shaft and duct plan is shown in Figure 1.

The span of the upper guide hole of the main line of the station is 4.0m and the height of the hole is 5.0m, while the span of the lower guide hole is 11.4m and the height of the hole is 6.0m, as shown in Figure 2.

3. Build numerical simulation model
Midas/GTS software was used to carry out the construction phase analysis of this project. The project established a 3D model boundary size X*Y*Z=80m*180m*75m (X direction is the station mainline direction, Y direction is perpendicular to the station mainline direction, Z direction is the gravity direction), and the established model is shown in Figure 3 and Figure 4.

4. Model Verification
In order to verify the reliability of the numerical simulation, the surface settlement of the intersection section of the upper and lower guide holes from construction to the interface stage was selected as the
index for comparative analysis, as shown in Figure 5 and Figure 6.

![Comparison of simulated and measured values during the construction phase of the upper guide hole](image1)

![Comparison of simulated and measured values during the construction phase of the lower pilot hole](image2)

From Figure 5 and Figure 6, the simulated values of the surface settlement model are slightly larger than the measured values in the field, and although the two values do not exactly match, the errors are within the acceptable range and have the same trend, thus verifying the reliability of the numerical simulation.

5. Analysis of results

The calculation is mainly based on the simulation of the construction process of the shaft, the western air duct and the mainline guide hole of the station, focusing on the comparative study of the mechanical effect of the construction of the cross section of the mainline guide hole of the station on the initial support structure of air duct No. 1.

5.1. Construction of the upper pilot hole cross section to the interface

The upper guide hole excavation to adjacent to the initial support structure of No. 1 air duct stage, air duct initial support structure maximum settlement value in the top of the arch, about 8.93mm, bulge in the bottom of the air duct, about 17.56mm (see Figure 7a). horizontal displacement maximum occurs in the 9th part of the air duct, about 3.56mm (see Figure 7b).

![Vertical displacement of the initial support of the air duct](image3)

![Horizontal displacement of the initial support of the air duct](image4)

The upper guide hole excavation to adjacent to the initial support structure of No. 1 air duct stage, air duct primary support structure almost all in a state of pressure, the bottom bulge area in the next door axial force is large (see Figure 8a). air duct primary support structure only peripheral closed into a ring
grille steel frame moment is large, the next door and the elevation arch moment is very small (see Figure 8b).

5.2. Construction of the cross section of the lower pilot hole to the interface

5.2.1. Construction of the lower No.1 pilot hole to the interface.

The lower No.1 guide hole excavation to adjacent to the initial support structure of No. 1 air duct stage, air duct initial support structure maximum settlement value in the top of the arch, about 9.21mm, bulge in the bottom of the air duct, about 18.95mm (see Figure 9a). The horizontal displacement maximum occurs in the 9th part of the air duct, about 4.62mm (see Figure 9b).

The lower No.1 guide hole excavation to adjacent to the initial support structure of No. 1 air duct stage, air duct primary support structure almost all in a state of pressure, the bottom bulge area in the next door axial force is large (see Figure 10a). The air duct primary support structure only peripheral closed into a ring grille steel frame moment is large, the next door and elevation arch moment is very small (see Figure 10b).
5.2.2. Construction of the lower No. 3 pilot hole to the interface. The lower No. 3 guide hole excavation to the initial support structure stage at the interface of No. 1 air duct, the maximum settlement value of the initial support structure of the air duct at the top of the arch, about 9.06mm, bulge at the bottom of the air duct, about 19.68mm (see Figure 11a). The vertical displacement increase is not obvious, the maximum horizontal displacement occurs in the 9th part of the air duct, about 4.72mm (see Figure 11b).

The lower No. 3 guide hole excavation to the initial support structure stage at the interface of No. 1 air duct, air duct primary support structure almost all in a state of pressure, the bottom bulge area in the next door axial force is large (see Figure 12a). The air duct primary support structure only peripheral closure into a ring grille steel frame bending moment is large, the next door and elevation arch bending moment is very small (see Figure 12b).
6. Conclusions

- The construction of the upper guide cavern on the main line of the station has a small impact on the deformation and internal force of the initial support structure of the duct.
- The construction of the lower guide tunnel of the station main line will have a greater impact on the deformation and internal force of the initial support structure of the duct, and attention should be paid to the construction safety of the cross section during construction.
- The construction of the lower No.1 and lower No.4 guide holes will increase the deformation and internal force of the initial support structure of the duct, especially the deformation and internal force of the initial support structure of the duct will increase significantly due to the construction of the lower No.2 and lower No.3 guide holes.
- There is obvious stress concentration at the intersection of the duct and the station, so the vault and the intersection should be reinforced with grout during the construction process, and a safe construction distance of 10m should be reserved.

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