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Effect of double track tunnel with small distance on existing tunnel deformation

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***Abstract*—MIDSA/ GTS software is used to simulate the double track parallel shield construction. The influence of double track shield construction on the existing tunnel under different small clear distance is studied, and the displacement and plastic zone development law of the existing tunnel are summarized. The analysis shows that the subsequent shield excavation will cause the clearance expansion and vault subsidence of the existing tunnel, and the uplift deformation of the inverted arch and the plastic zone of the surrounding rock of the tunnel will further become larger. When the clear distance is only 0.8 times the tunnel diameter, reinforcement measures need to be taken.**

Keywords-small clear distance tunnel; shallow buried and concealed excavation; shield; deformation effect

I. INTRODUCTION

With the improvement of the requirements for the development of urban underground space, double line or even multi line parallel small clear distance tunnel engineering is becoming more and more common. The following problems of great construction difficulty and high engineering risk put forward higher requirements for tunnel design technology. It is required that the current design code specifies the minimum clear distance between parallel construction tunnels [1-6]. However, in practical engineering, the objective conditions may lead to the tunnel spacing far less than the specification value [7-11]. Moreover, the construction of small clear distance tunnel will produce superposition effect on the displacement and stratum deformation of the existing tunnel, resulting in the superposition of stress and strain of surrounding rock around the tunnel, reducing the stability of rock mass and increasing the construction risk. It is of great practical significance to analyze the impact of double track parallel tunnel construction on existing tunnels and explore the minimum clear distance between tunnels requiring reinforcement measures.

Taking the double line parallel shield construction of Jinan Metro Line R3 as the engineering background, this paper uses MIDSA / GTS software to simulate the impact of double line parallel shield construction on the existing tunnel, focuses on the impact of different small clear distance on the deformation, summarizes the deformation action rules of the subsequent tunnel on the existing tunnel, and obtains the minimum clear distance that needs to take reinforcement measures during parallel tunnel construction. The specific reinforcement methods are put forward to provide technical support and practical reference for multi-line parallel tunnel engineering in the future.

II. PROJECT OVERVIEW

The construction of Jinan Metro Line R3 adopts the combination of shallow buried excavation method and shield method. Among them, the concealed excavation area is a single tunnel double track horseshoe tunnel (divided into two pilot tunnels A and B), which shall be constructed first; During the shield construction in the open excavation area, the left line goes first and the right line goes later. At the junction of open excavation and concealed excavation areas, the double track shield tunnel and shallow buried concealed excavation tunnel are horizontal. With the progress of construction, the horizontal clear distance between tunnels is gradually smaller, and the minimum is only 2.55m, which is much smaller than the tunnel diameter. The section at the junction of open excavation and concealed excavation of the tunnel is shown in Figure 1.

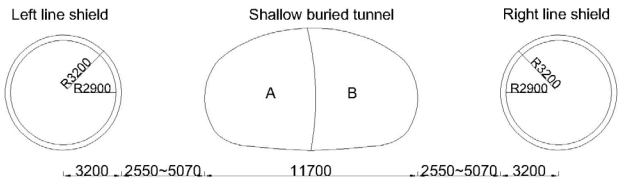

Figure 1. The junction of open excavation and concealed excavation of tunnel

The clearance dimension of the section of the shallow buried tunnel is 11.7m × 8.59m (width ×height), the secondary

lining composed of advance small conduit pre support, grid steel arch hanging reinforcement mesh, shotcrete primary protection and formwork concrete is adopted. The tunnel diameter of double track shield tunnel is 6.4m and the segment thickness is 0.3m.

III. Finite Element Simulation

A. Model Establishment

This paper mainly studies the change of clear distance between tunnels. Taking the tunnel section as the calculation surface, it is simplified as plane strain. The influence range of tunnel excavation is generally 3~5 times of tunnel diameter, so the model size is 100m×60m (width × height).

B. Parameter Determination

The soil model is Mohr Coulomb elastic-plastic model. The distribution of soil layers below the surface and the calculation parameters of the model are shown in Table I.

TABLE I. Equivalent Parameters of Soils

Soil-layer	Height (m)	Bulk Density (kN • m^{-3})	C (kPa)	ϕ (°)	K_0	E (MPa)	v
plain fill	0.8	18.9	20.0	15.0	0.38	47.48	0.40
Silty clay	8.6	18.9	20.3	13.1	0.41	45.46	0.29
gravels	7.6	21.0	10.0	38.0	0.25	73.63	0.20
Moderately weathered limestone	43.0	26.9	700.0	39.0	0.18	32300	0.18

The scheme of improving the mechanical parameters of surrounding rock is adopted to simulate the advance reinforcement of shallow buried tunnel; The equivalent method is adopted, that is, the steel arch, reinforcement mesh and concrete are regarded as a whole to simulate the initial support of double track shield. The mechanical parameters of the support structure determined by the equivalent method are shown in Table II.

TABLE II. Mechanical Parameters of Support Structure

Structure	Height (m)	Bulk Density (kN • m^{-3})	C (kPa)	ϕ (°)	K_0	E (MPa)	v
Advance small conduit reinforcement area	0.80	21.0	100	38	0.28	100	0.22
Shield segment	0.30	25.0	/	/	/	22300	0.20
Isochronous layer	0.15	25.0	/	/	/	1.2	0.20
Primary branch	0.35	22.0	/	/	/	15000	0.20
Primary branch hardening	0.35	22.0	/	/	/	30000	0.40

C. Construction Procedure

Considering the release coefficient of load, the initial support is divided into two stages: initial support and initial support hardening [12]-[13]. Condition 1 is shallow buried tunnel excavation; Working condition 2 is shield left line excavation; Working condition 3 is shield right line excavation. The simulation steps of construction process are shown in Table III. The control variables are the spacing between tunnels, which are 1.2D, 1.0D, 0.8D, 0.6D and 0.4D respectively (D is the inner diameter of shield tunnel).

TABLE III. Project Overview

Working condition	Name of construction stage
Condition 1	Initial balance of in-situ stress Excavation, initial support and harden of shallow buried tunnel A Excavation, initial support and harden of shallow buried tunnel B
Condition 2	Shield left line excavation and segment installation
Condition 3	Shield right line excavation and segment installation

IV. Result Analysis

A. Horizontal and vertical displacement and obtains the minimum clear distance that needs to take reinforcement measures during parallel tunnel construction

Figure 2 shows the horizontal displacement of the tunnel after the completion of condition 1. The maximum horizontal displacement of shallow buried and concealed tunnels occurs near the arch waist, where the clearance convergence of tunnels A and B is 6.46mm and -5.72mm respectively.

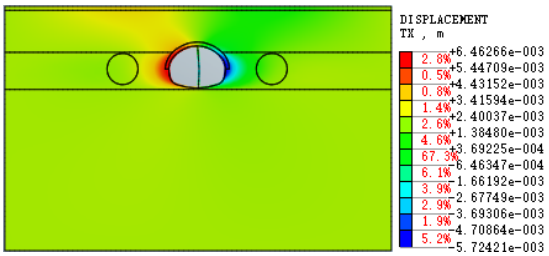

Figure 2. Horizontal displacement of tunnel after completion of condition 1

The headroom convergence of tunnel A and B is shown in Table IV and V. It can be seen that with the construction of shield tunnel, the horizontal displacement at the arch waist of the existing tunnel decreases continuously, that is, the headroom expansion occurs. The smaller the clear distance between tunnels, the more obvious the clearance expansion. This is because the shield tunnels on the left and right sides

produce stress release in the horizontal direction, resulting in the displacement in the opposite direction in the horizontal direction of the middle leading tunnel that originally contracted.

TABLE IV. CLEARANCE CONVERGENCE OF TUNNEL A

Working condition	Clear distance between tunnels				
	1.2D	1.0D	0.8D	0.6D	0.4D
Condition 1	6.46mm	6.46mm	6.46mm	6.46mm	6.46mm
Condition 2	5.92mm	5.39mm	4.97mm	4.25mm	3.41mm
Condition 3	5.87mm	5.32mm	4.80mm	4.10mm	3.07mm

TABLE V. CLEARANCE CONVERGENCE OF TUNNEL B

Working condition	Clear distance between tunnels				
	1.2D	1.0D	0.8D	0.6D	0.4D
Condition 1	-5.27mm	-5.27mm	-5.27mm	-5.27mm	-5.27mm
Condition 2	-5.23mm	-5.20mm	-5.12mm	-5.03mm	-4.72mm
Condition 3	-4.86mm	-4.31mm	-4.03mm	-3.34mm	-2.29mm

B. *Vertical Displacement*

Figure 3 shows the vertical displacement of the tunnel after the completion of condition 1. The vertical displacement of arch crown and invert of tunnel A is the largest, and the maximum values of arch crown settlement and invert uplift are -6.17mm and 4.98mm respectively.

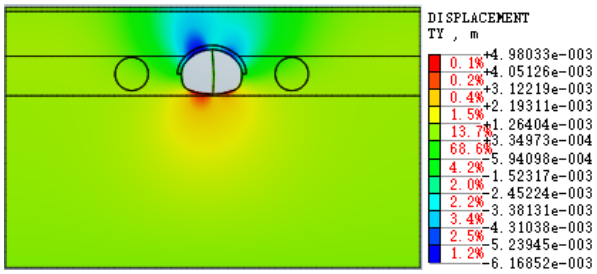

Figure 3. Vertical displacement of tunnel after completion of condition 1

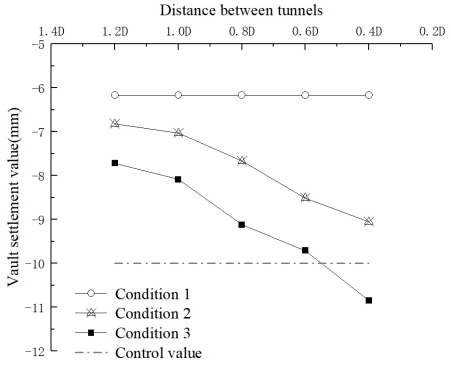

Figure.4 Vault settlement of the early shallow buried tunnel

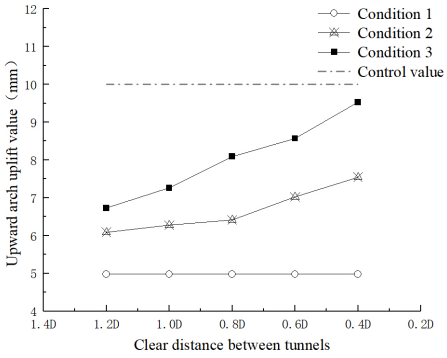

Figure.5 Upward arch uplift of the early shallow buried tunnel

The relationship between arch crown settlement, invert uplift and clear distance between tunnels is shown in Figures 4 and 5. The control value in the figure is 10mm specified in the technical code for inspection of urban rail transit engineering. It can be seen from the figure that the construction of shield tunnel aggravates the arch crown settlement and inverted arch uplift, and the smaller the tunnel clear distance, the more obvious the effect, making the deformation close to or even exceed the control value. Taking 0.8D as the dividing line, there is a great difference in displacement. When the distance between tunnels is greater than 0.8D, the displacement under condition 2 is relatively small, and the displacement values under different clear distances are relatively close. When the spacing is less than 0.8d, the displacement under condition 2 increases rapidly with the decrease of spacing. Taking 0.8D as the limit, when it is greater than this limit, the displacement generated by condition 3 is small and the displacement values at different intervals are similar; When it is less than the limit, the displacement generated by condition 3 is large and the displacement values of different spacing are similar.

C. *Analysis Of Plastic Zone*

Figure 6 is the diagram of plastic deformation of tunnel surrounding rock during parallel tunnel construction. The plastic strain of the surrounding rock of the existing tunnel in the middle mainly occurs at the bottom and arch waist. The plastic strain of surrounding rock of shield tunnel on both sides is evenly distributed along the portal. With the decrease of tunnel clear distance, the plastic deformation of surrounding rock of each tunnel is further developed and the plastic zone is gradually expanded. When the spacing between tunnels is reduced to 0.8D, the plastic zone of surrounding rock of existing tunnel and shield tunnel overlaps, and the main strain in plastic increases by about 2%. With the further decrease of spacing, the expansion of plastic zone slows down, and the increase value of main strain in plastic zone decreases, which is about 0.7%.

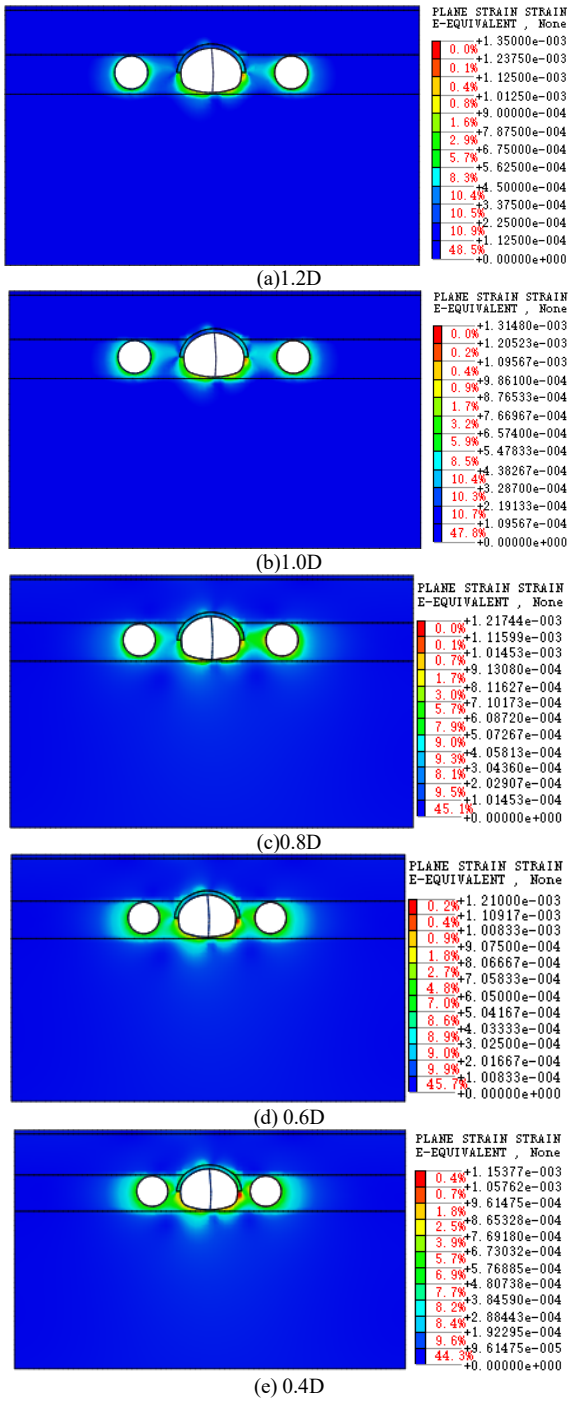

Figure 6. Plastic strain of tunnel under different clearance conditions

V. CONCLUSION

In order to study the influence of double track parallel shield construction on the existing tunnel, the influence of different small clear distance on the deformation of the existing tunnel is mainly studied through numerical simulation. The main conclusions are as follows:

- Shield construction will release the stress of the surrounding rock of the existing tunnel, resulting in the clearance expansion of the existing tunnel; Moreover, the superposition of vertical displacement caused by shield will further aggravate the vault settlement and invert uplift of the existing tunnel;
- The smaller the clear distance between tunnels, the greater the plastic strain and plastic range of tunnel surrounding rock, and the strain value of main plastic zone also increases obviously;
- Considering the comprehensive displacement and plastic strain, when the distance between parallel tunnels is less than or equal to 0.8D, reinforcement measures shall be taken to ensure the safety of the project.

ACKNOWLEDGMENT

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