Study on Effect of Late Tunnels on Deformation of Early Tunnel in Three Small Net Distance Tunnels

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Abstract. This paper is based on the tunnels construction in small net distance in Jinan Rail Transit Line R3. The deformation of early mining tunnel when double-line shield tunneling under different net distance conditions is simulated. The results show that the late shield tunneling will cause the clearance convergence, vault settlement and inverted arch uplift of the early mining tunnel to further deformation. When the distance is 0.8 times of the tunnel diameter, reinforcement measures are needed.

1. Introduction

In order to meet the needs of different engineering conditions, the parallel construction of shield tunnels and mining tunnels with small net distance is increasing recently[1]. Because shield tunneling method and mining method have different disturbance forms and influence ranges on surrounding rock, it is more and more difficult and risky to construct shield tunnels and mining tunnels with small clear distance[2]-[3]. The existing design specifications only stipulate the minimum net distance between parallel tunnels, but in practical engineering, the net distance between two tunnels is restricted by objective conditions, which may be much smaller than the specifications[4]. Therefore, it is of great practical significance to analyze the effect of late tunnels on deformation of early tunnel in three small clear distance tunnels.¹

This paper is based on the tunnel construction in small net distance in Jinan Rail Transit Line R3. In order to reveal the law of the influence of the later tunnels construction on the deformation of the early tunnel, and provide technical support and practical reference for similar engineering construction, the deformation of early mining tunnel (CD method) when double-line shield tunneling under different net distance conditions is simulated by using Midas GTS software.
2. Engineering situation
The entrance/exit line of Jinan Metro Line R3 is laid south along Longding Avenue from the small mileage end of Mengjiazhuang Station. It is divided into open-cut section and underground excavation section, in which the underground excavation section is constructed by mining method (CD method, divided into cave A and cave B). The section between Longdongzhuang Station and Mengjiazhuang Station is constructed by shield method. Two shield machines start from the long-distance end of Longdongzhuang Station successively, the left line goes first and the right line goes later. When shield tunnels are tunneled to the underground excavation section of the entrance/exit line, the left-right symmetry is at the same level as that of the mining tunnel, and the horizontal net distance decreases gradually. The minimum horizontal net distance is only 2.55m, which is much smaller than the shield tunnel diameter. The tunnel section layout is shown in Figure 1.

![Figure 1 Sectional view of the tunnels.](image)

Among them, the early mining tunnel is horseshoe-shaped tunnel with a cross-section size of 11.70 m × 8.59m. It adopts advance small pipe pre-supporting. The grid steel arch frame with steel mesh and shotcrete are used in the initial support of the tunnel. The diameter of the shield tunnels is 6.4m and the thickness of the segment is 0.3m.

3. Model Establishment

3.1 Finite Element Model
The Midas GTS software is used to establish the two-dimensional finite element model of the tunnels. The problem of three tunnels construction under different tunnel clearance conditions (1.2D, 1.0D, 0.8D, 0.6D, 0.4D, D is the shield tunnel diameter) is analyzed. Because the influence range of tunnel excavation is generally 3-5 times of tunnel diameter, the model size is selected to be 100m wide and 60m high.

3.2 Material model and parameters
According to the actual situation and characteristics of the project, the following considerations are taken into account in the finite element model’s establishment:

The material parameters are extracted from the detailed survey report provided by geological exploration units. The soils which is simplified into a horizontally layered are modeled as elastic-plastic material. The soil layer consists of plain fill, silty clay, gravelly soil, and moderately weathered limestone, and soil parameters are shown in table 1. The soils are modeled using the Mole-Coulomb model.

For the mining tunnel, the mechanical parameters of surrounding rock are improved to simulate the advance grouting of small pipe. Because the individual simulation of steel arch and concrete in the initial support are more complicated, the steel arch, steel mesh and concrete were modeled by the equivalent method as a whole. The equivalent physical and mechanical parameters are shown in Table 1. Considering the release coefficient of load, the initial lining is divided into two stages: initial supporting and initial supporting hardening [5-7].
Table 1. Parameters of rock mass and supporting structure.

| Material name                  | Mass density $\rho$(kN/m$^3$) | Internal friction angle $\varphi$(o) | Cohesion $c$(kPa) | Lateral pressure coefficient $K_0$ | Thickness $h$(m) | Modulus of elasticity $E$(MPa) | Poisson ratio $v$ |
|-------------------------------|-------------------------------|-------------------------------------|------------------|-----------------------------------|-----------------|---------------------------|-----------------|
| 1-1 Plain fill                | 18.9                          | 15.0                                | 20.0             | 0.38                              | 0.8             | 47.481                    | 0.4             |
| 10-1 Silty clay               | 18.9                          | 13.1                                | 20.3             | 0.41                              | 8.6             | 45.455                    | 0.29            |
| 17-1 Gravelly soil            | 21.0                          | 38.0                                | 10.0             | 0.25                              | 7.6             | 73.632                    | 0.20            |
| 21-2 Moderately weathered limestone | 26.9                      | 39.0                                | 700.0            | 0.18                              | 43.0            | 3.227×10$^4$             | 0.18            |
| Advanced small pipe reinforcing area | 21.0                        | 38.0                                | 100.0            | 0.28                              | 8.0             | 100.0                     | 0.22            |
| Shield segment                | 25.0                          | /                                   | /                | 0.3                               | /               | 2.23×10$^4$              | 0.20            |
| Initial supporting            | 22.0                          | /                                   | /                | 0.35                              | /               | 1.5×10$^4$              | 0.20            |
| Initial supporting hardening  | 22.0                          | /                                   | /                | 0.35                              | /               | 3.0×10$^4$              | 0.40            |

4. Results Analysis

4.1 Control Value of the Mining Tunnel

The current 《Technical Specifications for Urban Rail Transit Engineering Inspection》 has made the following provisions for the deformation control value of the mining tunnel:

| Project                    | Control value (mm) |
|----------------------------|--------------------|
| Clearance convergence      | 10                 |
| Vault settlement           | 10                 |
| Inverted arch uplift       | 10                 |

4.2 Horizontal displacement

The horizontal displacement after the initial lining construction of the early mining tunnel is shown in Figure 2. It can be seen that for the mining tunnel with the initial lining, the maximum horizontal displacement appears near the arch waist, the maximum horizontal displacement of the left arch waist (the clearance convergence of the mining tunnel cave A) is 6.46 mm, and the maximum horizontal displacement of the right arch waist (the clearance convergence of the mining tunnel cave B) is -5.72mm. (The same direction as the coordinate axis is positive, and the opposite direction to the coordinate axis is negative, the same as behind).

Figure 2. Horizontal displacement cloud map of the early mining tunnel
Table 3 shows the clearance convergence value of the early mining tunnel when the shield tunneling. It is shown that in the case of the net distance remains unchanged and when the left shield tunneling, the horizontal displacement of the left arch waist and the right arch waist of the mining tunnel increases, the clearance convergence increases, and the change value of the left side of the arch waist is greater than that of the right side. When the right shield tunneling, the horizontal displacement further increased, and the change value of the right arched waist is greater than that of the left. This indicates that the shield tunneling weakened the surrounding rock of the mining tunnel, increased the clearance convergence of the mining tunnel, and the closer to the shield tunnels, the greater horizontal displacement of the arch waist. The right and left shield tunneling caused multiple disturbances of the rock pillars and affected the stability of the middle rock pillars. It is needed to take measures to maintain the stability of the middle rock pillars.

| Condition                        | Clearance convergence (mm) |
|----------------------------------|-----------------------------|
|                                  | Position 1.2D 1.0D 0.8D 0.6D 0.4D |
| Construction of Mining Tunnel    |                             |
| Mining tunnel cave A             | 6.46 6.46 6.46 6.46 6.46     |
| Mining tunnel cave B             | -5.72 -5.72 -5.72 -5.72 -5.72 |
| Left shield tunneling            |                             |
| Mining tunnel cave A             | 7.49 8.27 9.31 9.91 11.61    |
| Mining tunnel cave B             | -5.75 -5.79 -5.84 -5.93 -6.01|
| Right shield tunneling           |                             |
| Mining tunnel cave A             | 7.53 8.28 9.47 10.12 11.30   |
| Mining tunnel cave B             | -6.81 -7.57 -8.55 -9.33 -10.57|

It can also be seen from Table 3 that when shield tunneling, the smaller the net distance of the tunnels is, the greater the original mining tunnel horizontal displacement will be, and the clearance convergence will increase accordingly. When the tunnel net distance decreases to 0.8D, the clearance convergence of the mining tunnel cave A is 9.47mm and the clearance convergence of the mining tunnel cave B is -8.55mm, which are both approaching the control value of 10mm. When the tunnel net distance decreases to 0.6D, the clearance convergence of the mining tunnel cave A is 10.12mm, which has exceeded the control value.

4.3 Vertical Displacement
The vertical displacement after the initial lining construction of the early mining tunnel is shown in Figure 3. It is shown that the maximum vertical displacement occurs at the vault and inverted arch positions of cave A after completion of initial lining construction of the mining tunnel. The maximum vault settlement is -6.17 mm and the maximum inverted arch rising is 4.98 mm.

Figure 3. Vertical displacement cloud map of the early mining tunnel.

4.4 Vault settlement
Figure 4 shows the vault settlement of the mining tunnel cave A after shield tunnels excavation when the net distance is different. It can be seen from the figure that when the net distance remains unchanged, the vault settlement of the vault of cave A increases after the left shield tunneling, and when the right shield tunneling, the vault further subsides. When the shields tunneling, the smaller the
net distance between tunnels is, the greater the variation of the vault settlement of cave A will be. When the tunnel net distance decreases to 0.6D, the vault settlement of the mining tunnel cave A is -9.71mm, which is approaching the control value. When the tunnel net distance decreases to 0.4D, the vault settlement of the mining tunnel cave A is -10.85mm, which has exceeded the control value.

4.5 Inverted arch uplift
Figure 5 shows the inverted arch uplift of the mining tunnel cave A after shield tunnels excavation when the net distance is different. It can be seen from the figure that when the net distance remains unchanged, the inverted arch uplift of cave A is increases after the left shield tunneling, and when the right shield tunneling, the inverted arch further uplift. When the shields tunneling, the smaller the net distance between tunnels is, the greater the variation of the inverted arch of cave A will be. When the tunnel net distance decreases to 0.4D, the inverted arch uplift of the mining method cave A is 9.55mm, which is approaching the control value of 10mm.

5. Conclusions
When the later shields tunneling after the initial lining construction of the first mining tunnel, the clearance convergence, vault settlement and inverted arch uplift of the early mining tunnel are further increased, which reduces the stability of the surrounding rock of the tunnel and increases the risk of surrounding rock instability.

With the decrease of the net distance between tunnels, the influence of shield tunnel on the early mining tunnel increases gradually. When the tunnel net distance decreases to 0.8D, the clearance convergence of the mining tunnel approaches the control value. When the tunnel net distance decreases to 0.6D, the clearance convergence and the vault settlement of the mining tunnel have exceeded or approached their control values. It is necessary to take some reinforcement measures to increase the stability of surrounding rock and reduce the deformation of surrounding rock.

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