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Research on Spacing Effect of The Construction of Shield Tunnels undercrossed Existing Tunnels at Close Distance

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Abstract. With the increasingly dense distribution of urban subway network, line crossing will inevitably occur. The phenomenon of new tunnels passing through existing tunnels is becoming more and more common. Shield tunneling will inevitably disturb the surrounding soil and redistribute the stress and displacement fields, resulting in the deformation and additional stress of existing subway tunnels. The new tunnel should have strict requirements for the deformation control of existing tunnels and surrounding rocks. The spacing effect of new tunnels under existing tunnels can ensure the safety of new tunnels and the operation safety of existing shield tunnels, which has become an important problem to be solved urgently. On the basis of theoretical analysis, this paper takes a new shield tunnel under the existing tunnel in Xuzhou City as the backing, carries out numerical simulation of the new and old tunnel under different clearance by finite element software, and studies the influence of the new tunnel on the existing tunnel when the tunnel is constructed with different spacing of 1.5m, 0.5D, 1D, 1.5D, 2D and 3D. It is concluded that the reasonable distance between the new tunnel and the existing tunnel should be controlled between 1D and 1.5D under the circumstance of the surrounding environment, the permission of the new tunnel line and the economical and reasonable conditions.

1. Introduction

With the continuous development of underground works in cities, new tunnel underneath existing tunnel projects are constantly emerging. The construction of tunnel passing through existing tunnel has the characteristics of small spacing, great difficulty, great interaction and great construction risk. Due to more and more engineering problems caused by short-distance crossing, it is more and more difficult to construct. It is of great significance to adopt reasonable tunnel clearance to reduce the adverse effects of new shield tunnels on existing shield tunnels, to ensure the safety of construction of new shield tunnels and the safe operation of existing shield tunnels.

In recent years, domestic scholars have carried out a series of valuable research on the spacing effect between new tunnels and existing tunnels, and achieved certain results. Through the study of parallel, overlapping and staggered tunnels with a spacing of 0.2-1D in metro of Shenzhen, Qiu Wenge[1] obtained a standard of unified field distribution for the area of near-distance construction. Liang Jianbo [2] calculates and analyzes the different net spacing of the two tunnels by numerical simulation. It is concluded that controlling the net spacing between the new tunnel and the existing tunnel is of great significance to the protection of the existing tunnel. Li Jiwei [3] simulated the underpass construction under different net spacing conditions, and considered that the reasonable net spacing between the new tunnel and the existing tunnel ranged from 6m to 12m (1D to 1.5D). Chen Junlin [4] thinks that under the premise of grouting measures, the minimum safe distance between overlapped tunnels is 4m. Based on the numerical simulation and field measurement, Huang Shizheng[2] concluded that the distance and relative position between the two tunnels were the main factors causing the deformation when the vertical distance between the two tunnels was close.

Therefore, because of the secondary disturbance to soil, the new tunnel has become the risk source of the first-class project. If too large net spacing is adopted, the depth of the new tunnel will be increased and the construction cost will be increased by [6]. Under the background of the rapid development of rail transit, how to take into account the safety and economy of the underpass project at the same time, and how to choose a reasonable spacing are the problems that need to be solved in the project.

2. Spacing effect of existing tunnel

The new shield construction will cause the two disturbance of the stratum at the close distance from the existing tunnel. Unlike the shield tunnel construction under natural free stratum, the excavation of the existing tunnel has caused a disturbance to the surrounding natural rock and soil before the construction of the new shield tunnel under close distance, and the stress and displacement fields of the soil have changed correspondingly and then re-stabilized. During the construction of new tunnels, the ground will be disturbed twice under the influence of soil excavation, shield tunneling, lining segment assembling and grouting behind the wall, resulting in displacement and stress redistribution.

The essence of the construction of new shield tunnels under existing tunnels lies in the interaction among surrounding rock, shield and existing tunnels. Shield construction disturbs surrounding rock mass [7], resulting in stress redistribution and displacement of surrounding rock mass and deformation and stress addition of existing tunnels in surrounding rock; while reinforced concrete structure tunnels, compared with surrounding rock, have greater stiffness, which will further adjust the strong adaptability of surrounding displacement, and the construction of new shield tunnels. The interaction between the three factors is shown in Figure 1.

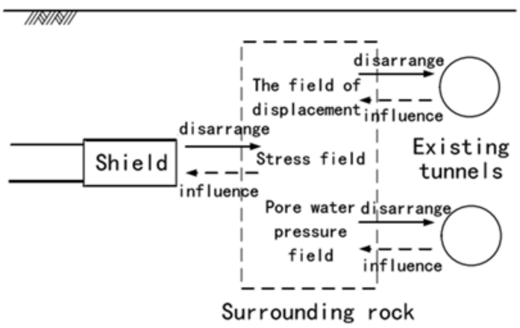


Figure 1. Schematic of mechanism of interaction between new tunnel and existing tunnel.

However, when the underpass distance is large, the influence between the three is weakened or even disappeared, but this distance is related to the surrounding rock grade, geological and hydrological conditions, tunnel excavation section size and other factors. In order to quantify the influence distance, this paper simulates the different spacing S = 1.5m, 0.5D, 1D, 1.5D, 2D, 3D of the two tunnels to explore the influence degree with the change of the distance.

3. Engineering overview

According to the latest planning of Xuzhou urban rail transit network, the long-term planning of Metro Line 5 tunnel will be at the eastern end of Heping Road Station (Metro Line 5) through Line 3 tunnel.

The construction of new No. 5 line tunnel will inevitably affect the deformation of existing No. 3 line tunnel, and the existing tunnel has a very strict control index of deformation, which increases the difficulty of construction.

The site belongs to alluvial plateau: that is, the high floodplain of the abandoned Yellow River, formed by silt and clay accumulated by the Yellow River. Groundwater mainly consists of shallow pore phreatic water, silty aquifer confined water and bedrock fissure water. The positional relationship and geological conditions of the tunnels of Lines 3 and 5 are shown in Figures 2 and 3.

Shield tunnel construction is adopted for line 3 tunnel and planning line 5 tunnel. Line 3 and 5 shield tunnels adopt single-layer assembled flat-plate reinforced concrete lining segments, and the concrete strength grade is C50. The outer diameter of the segment lining ring is 6200mm, the inner diameter is 5500mm, the thickness of the segment is 350mm, and the width of the ring is 1200mm.

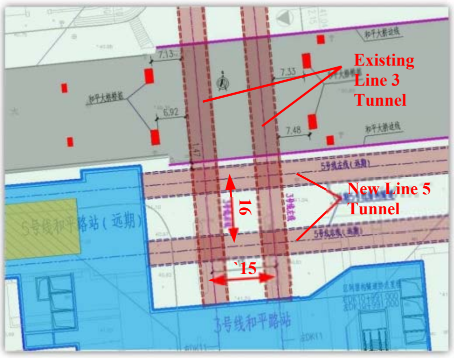


Fig 2. Relationship between Metro Line 3 and Planning Line 5.

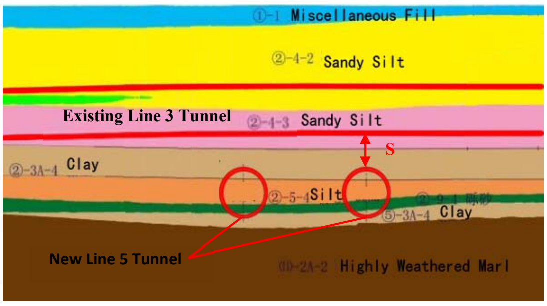


Fig 3. Relationship between Metro Line 3 and Planning 5 Line profile and geological section map.

4. Finite element calculation

4.1. Model establishment

In this paper, 3D geotechnical finite element analysis software MIDAS GTS/NX is used for numerical analysis and calculation. According to the relevant literature, when the ratio of soil calculation model to actual structure plane size is more than 3-5 times, the influence of boundary effect on the static and dynamic response of the structure is very small and can be neglected. Details are shown in Figures 4 and 5. Calculating boundary: the boundary on both sides of the model restricts horizontal displacement; the bottom restricts vertical displacement; the surface is a free surface. In this calculation, the surrounding rock and soil layers with similar mechanical properties are merged, so that the soil between the new tunnel and the two tunnels is in the same layer of soil, and the rock and soil layers are assumed to be homogeneous and horizontally stratified. The physical and mechanical parameters of the surrounding rock soil and material are shown in Table 1.

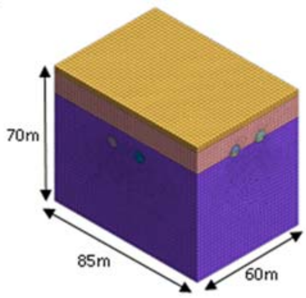


Fig 4. Model elevation.

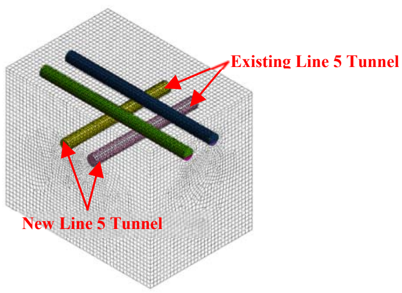


Fig 5. Model perspective.

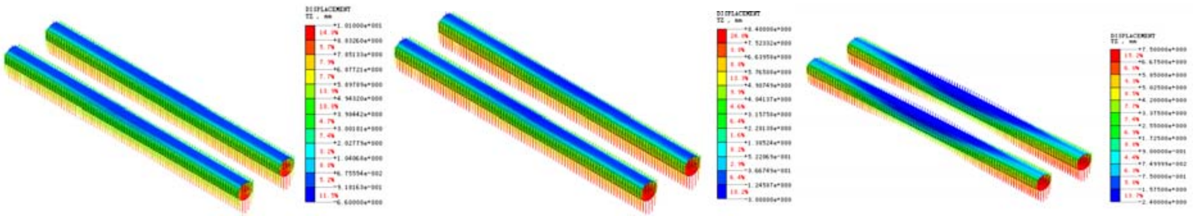
4.2. Simulation condition
Before the new tunnel is excavated, the initial ground stress and the existing shield tunnel excavation are simulated firstly, and the displacement clearing function is used to keep the stress state produced by the existing tunnel excavation and remove the surrounding rock deformation caused by the existing tunnel excavation. Then the excavation of the new left and right line tunnels and the assembling of the segments are carried out. In order to better simulate the stress release process of the unit during construction, the stress release of surrounding rock in excavation stage is 20%, and the stress release of surrounding rock in segment assembly stage is 80%.

Table 1. Mechanical parameters of surrounding rock soil and material.

Protect	Thickness (m)	γ (N·m^{-1})	Es (MPa)	c(KPa)	φ （°）	υ	Unit attribute	Constitutive model
Miscellan-eous fill	3	18		10#	8#	0.4	Entity unit	Mohr-Coulomb
Sandy soil	11	19.4	8.0#	11.5	28	0.3	Entity unit	Mohr-Coulomb
Clay	56	19.6	12#	21	11	0.35	Entity unit	Mohr-Coulomb
Segment	0.35	25	27500			0.2	Plate unit	Elastic

5. Analysis of the field of displacement and stress field under different spacing conditions

5.1. Deformation analysis of existing tunnel



(a) Clear distance 1.5m. (b) Clear distance 1D. (c) Clear distance 1.5D.

Fig 6. Displacement vector cloud map of existing tunnel.

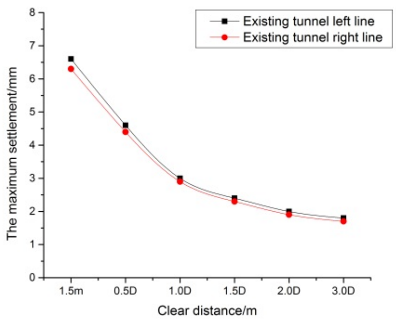


Fig 7. The maximum settlement curve of existing tunnel.

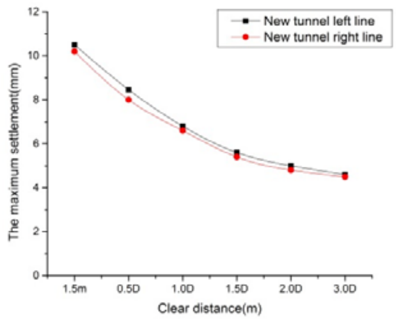


Fig 8. The maximum settlement curve of new tunnel.

From the existing tunnel settlement curve 6 and 7, we can see:

The maximum settlement of the existing tunnel on the left and right lines of Line 3 decreases with the increase of the distance between the two tunnels on Line 3 and 5, and the settlement rate slows down gradually. When the distance between the two tunnels is 1.5m, the settlement of the existing tunnel is the largest, reaching 6.6mm. When the distance between the two tunnels increases gradually to 1D, the maximum settlement of the existing No. 3 tunnel decreases to 3 mm, which meets the minimum requirements of the code. When the net distance of tunnel on Line 3 and Line 5 is less than 1.5D, the settlement curve of tunnel on Line 3 decreases greatly, which indicates that the effect of distance on the settlement of existing tunnel is greater in the range of net distance. When the net distance of two tunnels is greater than 1.5D, the settlement curve of tunnel on Line 3 decreases slowly, indicating that the net distance between the two tunnels is larger than 1.5D. The spacing effect has little effect on the settlement of existing tunnels.

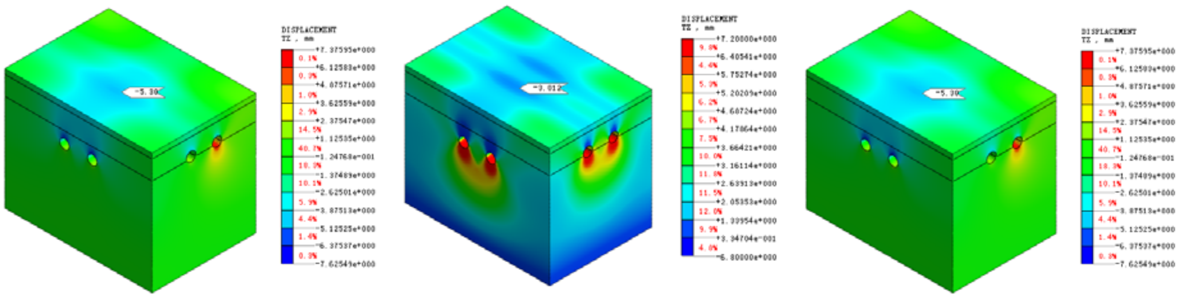
5.2. Deformation analysis of new tunnel

From the new tunnel settlement curve 8, we can see:

The maximum settlement of the left and right tunnel of Line 5 decreases with the increase of the distance between the two tunnels, and the settlement rate slows down gradually. When the net distance of the tunnel of Line 3 and Line 5 is less than 1.5D, which indicates that the spacing effect also has a great influence on the settlement of the new tunnel in the range of the net distance; when the net distance of the two tunnels is greater than 1.5D, the spacing effect has little effect on the settlement of the new tunnel.

5.3. Analysis of ground settlement

From the surface subsidence map 9 and 10, we can see:



(a) Clear distance 1.5m. (b) Clear distance 1D. (c) Clear distance 1.5D.

Fig. 9 Displacement vector cloud map of new tunnel.

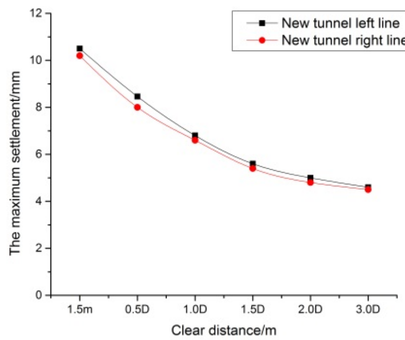


Fig. 10 Maximum surface subsidence curve.

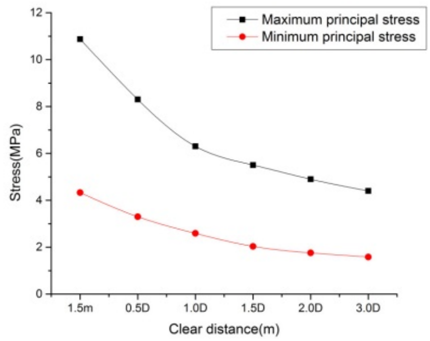


Fig. 11 Stress curve of existing tunnel.

The maximum ground settlement is affected by the spacing effect. When the net spacing of the tunnels of Line 3 and Line 5 is less than 1 D, the spacing effect has a great influence on the ground settlement.

5.4. Stress analysis of existing tunnels

From the principal stress curve of existing tunnel 11, we can see:

The principal stress of the existing tunnel on the left and right lines of Line 3 decreases with the increase of the distance between the two tunnels on Line 3 and 5, and the settlement rate slows down gradually. When the net spacing of tunnels on Lines 3 and 5 is less than 1D,the maximum principal stress decreases from 10.87MPa to 6.3MPa, and the minimum principal stress decreases from 4.33MPa to 2.59MPa. The stress curve decreases greatly, indicating that the spacing effect has a significant effect on the principal stress of existing tunnels. When the two tunnel spacing is greater than 1D, the spacing effect has little effect on the main stress of the existing tunnel.

6. Conclusion

Aiming at the spacing effect of the new shield tunnels crossing the existing tunnels at short distance, the influence of the new tunnels on the existing tunnels is analyzed and summarized with the aid of numerical calculation method, and a reasonable spacing range is obtained.

(1) With the increase of the net distance between the existing tunnel and the new tunnel, the thickness of the surrounding rock between the two tunnels increases, and the adverse effects caused by the construction of the new tunnel are more absorbed by the surrounding rock deformation, so that the deformation and stress of the existing tunnel are reduced accordingly. For example, when the net distance is 0.5D and 1D, the maximum settlement of the existing tunnel is reduced by 34.8%, the principal stress of the existing tunnel is reduced by 24.1%.

Therefore, it is very necessary to keep a certain distance between the two tunnels in the construction of new tunnels under the existing tunnels at close distance. Increasing the distance between the two tunnels is helpful to reduce the impact on the existing tunnels.

(2) According to the numerical results, when the net distance is less than 1.5D, the maximum settlement of existing tunnel, the settlement of new tunnel, the maximum settlement of surface and the principal stress curve of existing tunnel decrease greatly; when the net distance is more than 1.5D, the four groups of curves decrease slowly. It can be seen that the spacing effect is more obvious in the range of 0~1.5D.

(3) In engineering practice, with the increase of the net distance between the new tunnel and the existing tunnel, the buried depth of the new tunnel increases, and the construction cost increases greatly. Considering the influence of various factors, it is suggested that the reasonable range of net distance should be between 1D and 1.5D.

Acknowledgments

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