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Study on the Effect of Adjacent Construction of Large Diameter Shield Tunnels on Ancient Building in Soft Soil

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Abstract: Shield tunnel construction can cause soil disturbance, further cause adjacent structure appear deformation. In order to clarify the effect of adjacent construction of large diameter shield tunnel on ancient buildings in soft soil, a three-dimensional numerical model contained structure and soil was establishing. The effect of double line shield tunnel construction on the deformation of adjacent ancient buildings was studied. The result shows that, the method of simultaneously reinforcing the surrounding area of the tunnel and the bottom of the building can significantly reduce the effect of shield tunnel construction on the deformation of adjacent ancient building. It is recommended to adopt the method of reinforcing the inside and outside of shield tunnels in the project to ensure safety.

1. Introduction

With the development and utilization of urban underground space, there are more and more shield tunnel constructions in urban environments, and the effect of shield tunnel construction on surrounding buildings has become a hot topic, especially for ancient buildings.

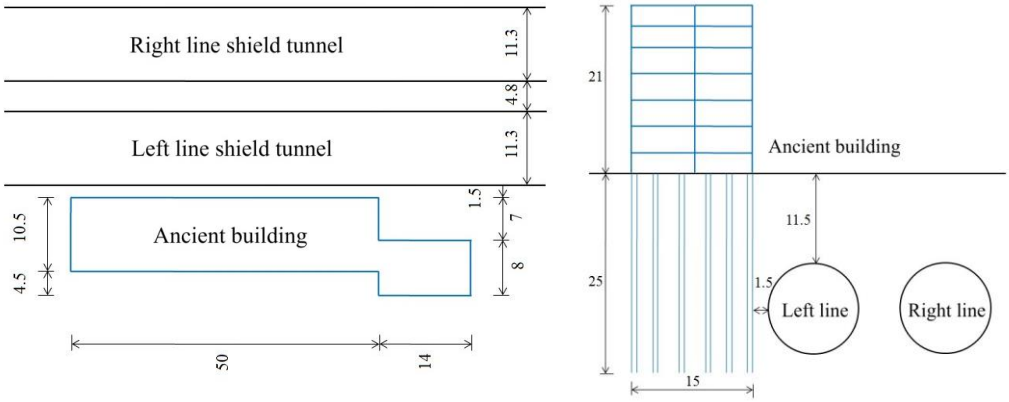
Due to the effect of shield tunnelling construction disturbance on the surrounding soil[1-3], the pile foundation structure of adjacent buildings will appear deformation and crack[4-7], threatening personal safety. In order to clarify the effect of shield tunnelling construction on adjacent structure, many researchers studied it by analytical method or numerical simulation. Yan[8] developed a three stage analysis method to calculate the ground settlement curve induced by the excavation of the three-line tunnels, analysed the settlement response of the ground surface and adjacent buildings. Zhang[9] established a jointed masonry model in masonry buildings by numerical simulation, studied the potential damages and cracking on masonry buildings due to shield tunnel construction. Peng[10] investigation the settlement and distortion of masonry structure during the construction process of double-line parallel shield tunnels by field measurement method. Based on on-site monitoring data, Li[11]analyzed the effect of shield tunnel crossing at different distances on adjacent pile foundations. Research shows that when the distance between the tunnel and adjacent pile foundations is less than tunnel diameter, significant deformation and damage may occur to the pile foundations.

Therefore, it is necessary to adopt different reinforcement measures to protect the safety of adjacent structures before shield tunneling construction. In this paper, a three-dimensional

numerical model was established by plaxis software, the effect of shield tunnel short distance through adjacent structures under different reinforcement measures was studied, the research results are expected to provide technical support for the safe construction of shield tunnel.

2. Engineering background

The engineering project is located in the main urban area of Hangzhou, China. The shield tunnel consists of two parallel lines, the diameter of tunnel is 11.3m, the segment thickness is 0.5m, and the two tunnels spacing is 4.8m, the burial depth of the two lines shield tunnel near the ancient building is 11.5m. The service life of the adjacent building has exceeded 60 years. The height of the ancient building is 21m, the span is 15m, and the distance from the side of the tunnel is 1.5m. The bottom of the building is embedded with many immersed piles, the length of immersed piles are all 25m, as shown in Figure 1. The soil layer from top to bottom consists of miscellaneous fill soil, clayey silt, silty clay, and silty clay mixed with silt, detailed mechanical parameters are shown in Table 1.



(a) Plan view (b) Side view

Figure 1: Diagram of the location relationship between shield tunnel and ancient buildings

Table 1: Geological parameter table of shield tunnel crossing area

Soil layer	E_s/MPa	v	γ/(kN/m^3)	c/kPa	φ / °	H/m
miscellaneous fill soil	4.38	0.29	18.4	15	8	2.6
clayey silt	4.08	0.25	18.2	26	13	2.6
silty clay	2.0	0.33	17.3	12	10	5.3
silty clay mixed with silt	3.5	0.35	17.7	13	13	13.3
silty clay	8	0.30	18.3	24	21	4.4
silty clay mixed with silt	9.8	0.29	18.5	26	24	7.0

3. Three dimensional numerical calculation model

3.1. Geometric model and material parameters

In this paper, plaxis software was used to establish 3D model, the overall model included 67366 units and 70707 nodes. The Y direction is the tunnel axis direction, the Z axis is the depth direction, and the X axis is the width direction. The size of model is 120m×100m×40m. In order to improve calculation speed, the grid becomes sparser as the distance from the tunnel axis increases

horizontally, similarly the grid becomes sparser as the distance from the tunnel bottom increases vertically. Horizontal constraints perpendicular to each side of the soil are set, vertical constraints are set on the bottom surface, and the upper surface is free. The shield shell and tunnel segment are simulated by shell element, the grouting pressure at the tail of shield is simulated by applying radial pressure on the tunnel. The mechanical parameters of shield shell and tunnel segment are shown in Table 2. The building is simulated by solid element, and the immersed pile at the bottom of the building is simulated by pile element, the pile top is fixed to the bottom of the building, the parameters of the building and the immersed pile are shown in Table 3.

Table 2: Parameter table for tunnel segment and shield shell

Object	Elastic modulus /MPa	*Poisson's ratio*	Density/(kN/m^3)	thickness/m
Tunnel segment	3.45×10^4	0.2	20	0.5
Shield shell	25×10^4	0.2	78	0.1

Table 3: Parameter table for ancient buildings and immersed pile

Object	Elastic modulus /MPa	*Poisson's ratio*	Density/(kN/m^3)	Height /m
Ancient buildings	3×10^4	0.3	25	21
Immersed pile	0.28×10^4	0.2	30	25

3.2. Simulation method for shield tunnel construction

After assigning the material parameters to the geometric model, the initial stress field of soil weight and ancient building was established. Then simulating excavate the tunnel step by step to study the deformation law of the ancient building. After completion of the left line shield tunnel construction, the right line shield tunnel will be constructed, the length of each excavation step in model is 2 m. In the model the excavation support force is simulated by applying horizontal stress to the soil in front of the excavation face, and the support force is set to 0.9 times the initial ground stress.

3.3. Calculation conditions

In order to analysis the effect of shield tunnel construction on adjacent building under different reinforcement measures, three different working conditions are selected to calculate, the detail as follow:

Case 1: Shield tunnel construction without any reinforcement measures;

Case 2: Adopt pre-grouting to form a 3m reinforcement circle around the tunnel before shield tunnel construction.

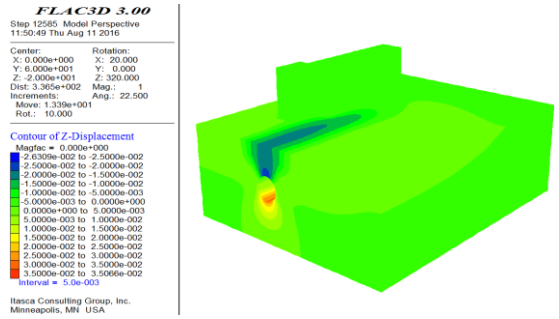
Case 3: In addition to adopt case 2, add pre-grouting reinforcement at the bottom of the ancient building before shield tunnel construction, the soil reinforcement parameters are shown in Table 4.

Table 4: Soil parameter table for reinforcement area

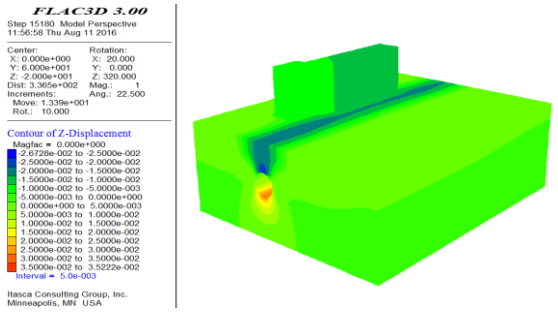
Elastic modulus /MPa	*Poisson's ratio*	Density /(kN/m^3)	cohesion/kPa	*Friction angle* / °
200	0.3	20	100	50

4. Calculation results

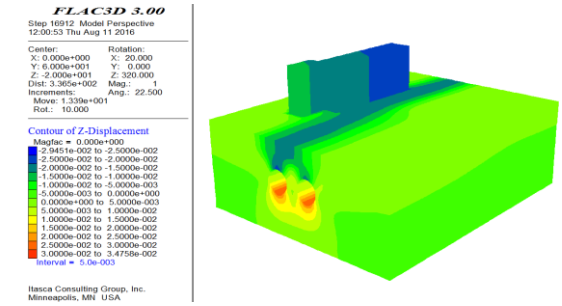
Figure 2 shows the vertical displacement of the shield tunnel and soil under different excavation steps in case 1, it can be seen that as the loss of surrounding soil increases due to shield tunnel excavation, the settlement of the ancient building gradually increases.



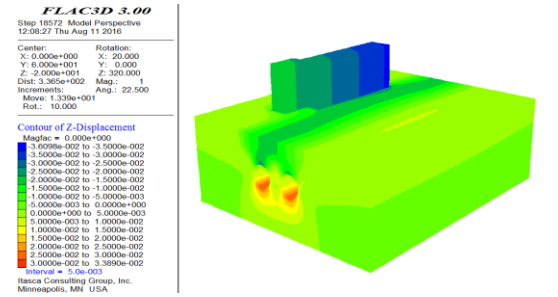
(a)Left line shield tunnel excavation of 60m



(b)Left line shield tunnel excavation of 120m



(c)Right line shield tunnel excavation of 60m



(d)Right line shield tunnel excavation of 120m

Figure 2: Vertical displacement cloud of structure and soil under case 1(unit:m)

Selecting point P1 and P2 from different areas of ancient buildings for analysis, as shown in Figure 3. Figures 4-6 show the point vertical displacement under different working conditions. It can be seen from that without any reinforcement measures, the maximum settlement of the building will reach 36.08 mm. When use the reinforcement scheme of case 2 the maximum settlement reduced by 33%, and use the reinforcement scheme of case 3 the maximum settlement reduced by 59%. To ensure the safety of the project, it is recommended to adopt the reinforcement scheme of case 3.

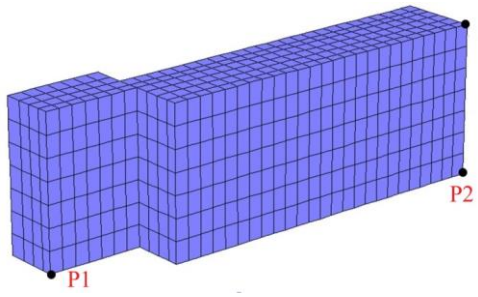


Figure 3: Diagram of measuring points

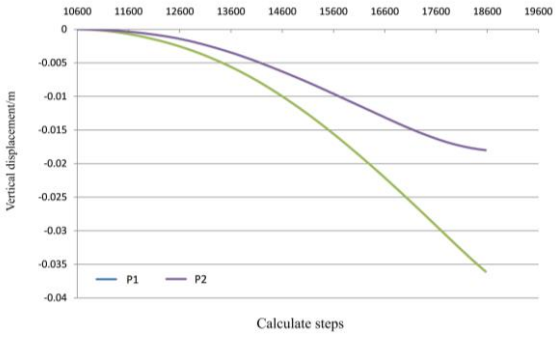


Figure 4: Point settlement curve under case 1

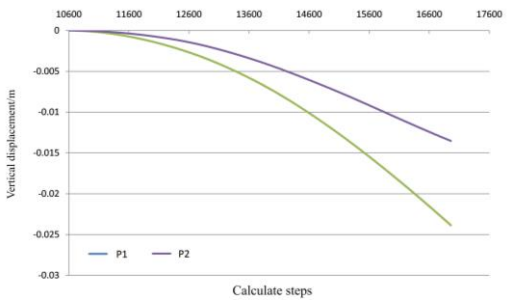


Figure 5: Point settlement curve under case 2

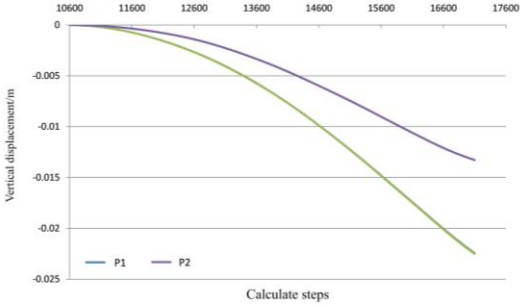


Figure 6: Point settlement curve under case 3

5. Conclusion

By establishing a three-dimensional numerical model, the influence of double line shield tunnel construction on the deformation of adjacent ancient buildings was studied, the result shows the method of simultaneously reinforcing the surrounding area of the tunnel and the bottom of the building can significantly reduce the effect of shield tunnel construction on the deformation of adjacent ancient building, it is recommended to adopt the method of reinforcing the inside and outside of shield tunnels in the project to ensure safety.

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