Influence of shield tunnel construction on neighboring building

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Abstract. The construction of underground project or the underground tunnel will influence the subsiding of neighboring building on the earth surface. In view of soil disturbance, 2D finite element method is adopted in this paper to study and shield tunnel construction of adjacent structures. Our research indicates that surface settlement together with force and deformation of the lining increase by the existence of buildings, simultaneously, additional stress and deformation of adjacent structure are induced during tunnel excavation construction. When L/D=0.5 to 2, great surface settlement is produced with more settlement difference between building head and tail, and the building is in danger in the region. At the same time, the value of inner force also increases obviously. Out of the region, the influence on the buildings is ignored.

1. Introduction
At present, China’s subway construction has entered the period of rapid development, the method of shield tunnels has become the main form of urban subway tunneling engineering. However, shield tunneling can cause the movement of surrounding soil, which can easily lead to a series of accidents such as inclination, cracking and even collapse when passing through adjacent buildings. Therefore, It is significant for us to do some relevant research. At present, the main research methods about the influence of shield tunneling on adjacent buildings are analytical method, finite element method and measurement method. Zude Ding et al[1] used Midas/GTS software to calculate the foundation settlement and structural stress of buildings. Jenck et al[2] used FLAC 3D software to simulate the shield tunneling of adjacent buildings and studied the influence of building rigidity on the ground displacement. In this paper, the two-dimensional finite element method is used to simulate the shield tunneling about adjacent buildings.

2. Two-dimensional finite element simulation
In the actual construction, the interaction between tunnel and adjacent buildings is very complicated, so it can be simplified to consider as the plane strain model. The two-dimensional model can also solve this problem better[3]. In actual construction, it is very difficult to quantify it, this paper[4]simplifies it as a homogeneous, isopachous and elastic equivalent circle zone.

In actual shield construction, the structure of shield tail is shown in Figure. 1. This paper simplifies the equivalent circle zone as a homogeneous, elastic but unequal thickness layer. As shown in Figure. 2, the elastic modulus, Poisson's ratio and the thickness of the upper edge of equivalent circle zone are given in the paper [5]. The thickness of the lower edge is calculated by half of the thickness of the upper edge. In this case, the finite element results coincide with the Peck formula better, as shown in Figure. 3.
The tunnel’s lining adopts beam element with thickness of 0.3m and is considered as the linear elastic material, the material is the C30 concrete. Considering the stiffness’s reductive factor, the elastic modulus is 25.78GPa. The material’s parameters of the soil, equivalent circle zone and lining are shown in Table 1. The plane 42 solid element is used to simulate the building foundation. The foundation is 2m deep and 16m long. There is a six-storey building on the foundation, which is simulated by beam element. The top floor live load is 0.5kPa and the other floor live load is 2.35kPa. Considering the wall weight transferring to the frame beam, the load of each floor is 4.8kPa.

The dimension of tunnel and the building are shown in Figure. 4. The whole model takes 120m in the horizontal direction and 50m in the vertical direction. The modulus of elasticity is 21 MPa, the depth of tunnel is 9.4 m and the diameter of shield is 6.2 m. The meshing result is shown in Figure 5.
3. The calculative results of finite element

3.1 Analysis of ground deformation

The calculation results are shown in Figure 6. When L/D = 0, the land subsidence in the range of -8m to 8m is almost the same, the maximum settlement is 45mm. This result shows that when the center of the tunnel passes through the axis of the building, the whole building will sink.

When L/D=0.5, the ground subsidence increases and the building inclines; when L/D=1, the ground subsidence caused by shield tunnel construction is the largest, the maximum settlement is 71mm, the building inclines toward the side of the tunnel, and the differential settlement between the beginning and the end of the building foundation is the largest, which is about 69mm. At this time, the building is prone to cracking or even inclination; when L/D=1.25, the ground subsidence decreases by 6mm compared with L/D=1. When L/D=1.5, the land subsidence decreases, the maximum land subsidence is 53mm, and the differential settlement between the beginning and end of building foundation is about 55mm. When L/D=2, the maximum land subsidence is 42mm and the differential settlement between the beginning and end of building foundation is about 35mm; when L/D=3, the maximum land subsidence is 32mm, which is almost the same as that without building. The inclination degree of building is small and the differential settlement between the beginning and end of building foundation is about 7mm; when L/D=5, the land subsidence is slightly smaller than that without building and the differential settlement between the beginning and end of building is very small.
The change of soil parameters and stress release rate of different soils are shown in Table 2. L/D=0 is taken by considering soil changes. As shown in Figure 7, the maximum land subsidence and the range of subsider increase obviously with the soil’s deterioration. It can be seen that when the soil quality is poor and the shield is pushed through with the load stress distribution at the bottom of the foundation, the grouting treatment should also be done for the other stratum situated at the load stress distribution except the horseshoe-shaped stratum around the tunnel[6].

Table 2. Parameters of soil

| parameter  | Density (g. cm⁻³) | Elastic modulus(MPa) | Poisson ratio | Cohesion (kN) | Internal frictional angle(°) | Stress release rate(%) |
|------------|-------------------|----------------------|---------------|--------------|-----------------------------|-----------------------|
| Silt       | 2.0               | 32                   | 0.27          | 16           | 33                          | 8                     |
| clay       | 1.9               | 21                   | 0.30          | 19           | 25                          | 10                    |
| Soft clay  | 1.8               | 10                   | 0.40          | 12           | 15                          | 12                    |

Figure 7. Ground deformation induced by tunnel excavation under different soil conditions.

In addition, the depth of tunnel will also have a great influence on the land subsidence. With the decrease of the depth of tunnel, the land subsidence will increase obviously. The results of paper [7] shows that the influence of changing the depth of tunnel on land subsidence is very small, when the depth of tunnel is more than 14 m.

3.2 Force Analysis of Buildings

According to the Code for Design of Building Foundation, the allowable value of differential settlement of frame structure is shown in Table 3.

Table 3. Permissible settlement difference of frame constructions

| Compressed value | Medium and low compressed soil | High compressed soil |
|------------------|-------------------------------|----------------------|
| Allowable settlement difference | 0.002L₀ | 0.003L₀ |

Figure 8 shows the settlement difference curve of neighboring plinth of buildings. As shown in the figure, with the increase of L/D, the settlement difference increases sharply at first and reaches peak value when L/D is about 1 and then decreases gradually. When L/D=1, the settlement difference of adjacent plinth of buildings is the largest, which is about 35 mm. At this time, the inclination of the building is 2.56‰. It can be seen that the building is in a danger. In construction, some relevant measures should be taken for the need of security.
The stress concentration occurs at the joints of buildings and foundations, which should be paid more attention to during the construction. At the same time, the transmission of load from foundation to superstructure is downward, but due to the phenomenon of stress concentration caused by tunnel excavation, the stress value of soil which is near the tunnel is large and the transmission is irregular, which is in good agreement with the result of finite element simulation in paper [8].

4. Conclusion
The interaction among tunnel, soil and building must be considered comprehensively in the study of shield tunnel construction under the conditions of adjacent buildings. The deformation of soil and lining caused by shield tunnel excavation largely depends on the existence of adjacent buildings. Ignoring the load of buildings will underestimate the ground deformation caused by tunnel excavation and the internal force of the lining.

The influence of buildings on tunnel excavation exists in a range. The influence of buildings on tunnel construction can be neglected when it is beyond this range. The horizontal distance $L$ from the building axis to the tunnel axis is an important factor. When the building is 16m, it is considered that when $L/D=0.5~2$, the building in this area is in danger.

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