SHIELD TUNNEL EXCAVATION ANALYSIS WITH/ PIPE SHED SUPPORT

Honghua Zhao, Yunpeng Ji
Dalian University of Technology, Dalian, China

Introduction

Pipe shed pre-support is to carry out pre-reinforcement to the surrounding rock before tunnel excavation, and its mechanism is to set up an arch-shell-like structure along the tunnel cross section in the stratum in front of tunnel excavation, form a pre-support system, reinforce the excavation face and the surrounding rock in front, guarantee that tunnel construction can be carried out in a relatively safe and stable environment. Pipe shed support has played an important role in improving the strength of soil, effectively controlling surface settlement and vault settlement, can ensure tunnel excavation construction safety, also has the characteristics of low cost, convenient construction, long support distance and high benefit, is commonly used advance pre-support method.

Scholars have carried out a lot of research on the mechanism of action and mechanical models of pipe sheds according to the stress characteristics of pipe sheds [1-4]. Wang et al. [5-6] analyzed the control effect of pipe shed parameters on the settlement of tunnel vault by establishing a theoretical calculation model of the pre-support deformation of the pipe shed. Wang et al. [7] established an analysis model of pipe shed under a single cyclic excavation footage based on Pasternak's elastic foundation theory, and analyzed the mechanical response of pipe shed for the main technical parameters such as hoop spacing and pipe diameter. Wu et al. [8] used the two-parameter foundation beam model to analyze the support effects of two kinds of advanced pipe sheds with different pipe diameters according to the stress mechanism of the tunnel advance pipe shed. Chen et al. [9] analyzed the variation law of the spacing of the pipe shed and the position of the pipe shed, as well as the influence of the diameter of the pipe shed and soil parameters on the spacing of the pipe shed. Gou et al. [10] monitored the deformation of the pipe shed, analyzed the stress characteristics of the pipe shed during tunnel excavation according to the results, discussed the action mechanism of the pipe shed, and established the corresponding stress model of the pipe shed. The motivation of this study is to investigate the soil deformation of shield tunnel excavation with large pipe shed under advancing and insufficient support conditions through finite element numerical simulation.

1. Finite element model

To investigate the soil deformation with advancing of shield tunnel and insufficient support, a series of FEM model was established for the analysis. The embedment depth is set as C/D=1.0, considering with pipe support and no pipe support. The shied tunnel moves backwards to simulate insufficient support. The simulation conditions are listed in Table 1. The length of the model is 35m, the width of the model is 24m, and the height of the model is 32.5m. The model is shown in Fig.1.

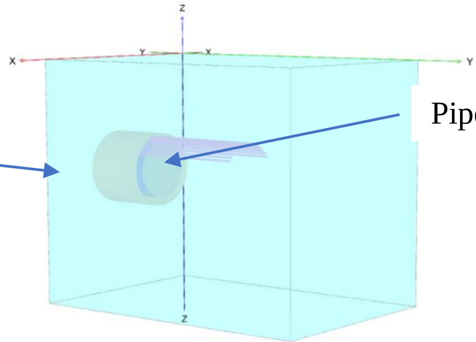


Fig.1 The shied tunnel model with pipe shed support

The shield tunnel has an outside radius of D=7m, the interior radius is 6m. The distance between the arch and the ground surface is 7m or 10.5m, that is embedment ration C/D=1.0, 1.5. The bottom of the model is all fixed. The top surface of the model is free. The four side surfaces are constrained in x and y directions. The shield tunnel model with C/D=1.0 consists of 103455 element and 148234 nodes, while the model C/D=1.0 consists of 93264 element and 134475 nodes.

In this study, the soil adopts the Mohr-Coulomb model as its constitutive model, using solid element to model soil. The interface between the soil and shield machine is modelled with interface element. Pipe roof is modelled with beam element, located within 0.5 m above the tunnel arch, with a length of 20m, the hoop spacing of 0.5m, the diameter of 0.2m and the thickness of 8mm. The material types are all elastic, and the elastic modulus is 2.1×108kN/m^2.

2. Soil and shield tunnel parameters

Only sand is considered in the model. Its properties are listed in Table 1.

(a) Table 1 Parameters of Sand Soil

Soil	γ (kN/m^3)	E(MPa)	v	φ
Sand	17.5	40	0.3	25

The mechanical parameters of the shield machine and pipe roof are listed in Table 2. The outside radius the pipe is 0.2m and the interior radius of the pipe is 8 mm. The shield machine has a diameter of 7m, and a thickness of 0.5m.

(b)Tab. 2 Mechanical parameters of shield machine and pipe roof

	γ (kN/m^3)	E(MPa)	D(m)	d(m)
Pipe roof	78.50	210×10^3	0.2	0.008
Shield machine	120	23×10^3	7	0.5

For the advancing of the shield tunnel machine, total excavation distance is 2m.

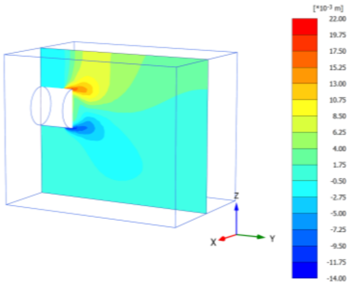
For the withdraw of the shield tunnel machine, the supporting pressure is initially evenly applied along the longitudinal direction of the tunnel on the excavation face, and the supporting pressure is the Rankine active earth pressure F_{u0} when the in-situ stress is balanced, then gradually reducing the supporting pressure to simulate insufficient support.

3. Simulation results and analysis

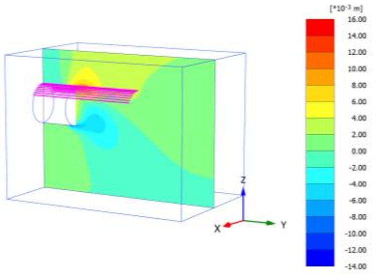
The simulation is done on the shield tunnel excavation considering advancing insufficient support conditions, considering different pipe shed support and embedment length. The obtained results are presented below.

Vertical displacement

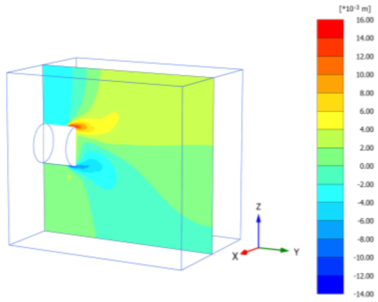
The vertical displacements during tunnel advancing are showed in Fig. 2 along the central axial plane. Comparing the displacement with pipe shed and without pipe shed, it is clear that the maximum vertical displacement is smaller for those with pipe shed. Both the maximum uplift and the maximum settlement occur at the vault and the bottom of the shield tunnel without pipe shed. While with pipe shed support, the maximum uplift also occurs at the vault top, but with a larger area of a high uplift displacement, while a narrower area close to the tunnel surface on top of the vault without pipe shed. That means that the pipe shed resisted the soil uplifting load from shield machine advancing and mobilized more soil mass to take the load. With deep embedment depth, the soil displacement were reduced a bit due to overburden effect.



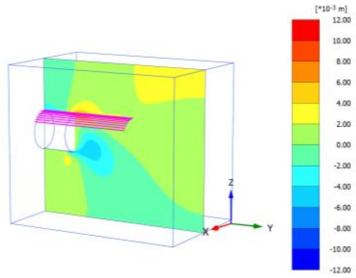
(a) No pipe shed, C/D=1.0



(b) With pipe shed, C/D=1.0



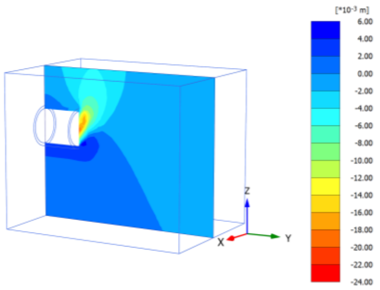
(c) No pipe shed, C/D=1.5



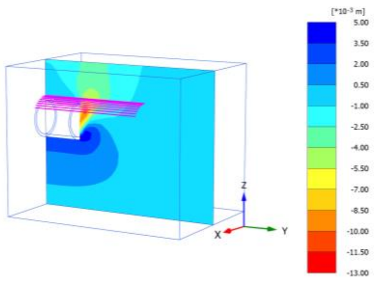
(d) With pipe shed, C/D=1.5

Fig.1 Numerical simulation results of axial section vertical displacement during tunnel excavation: (a) C/D=1.0, no pipe shed, (b) C/D=1.0, pipe shed, (c) C/D=1.5, no pipe shed, (d) C/D=1.5, pipe shed

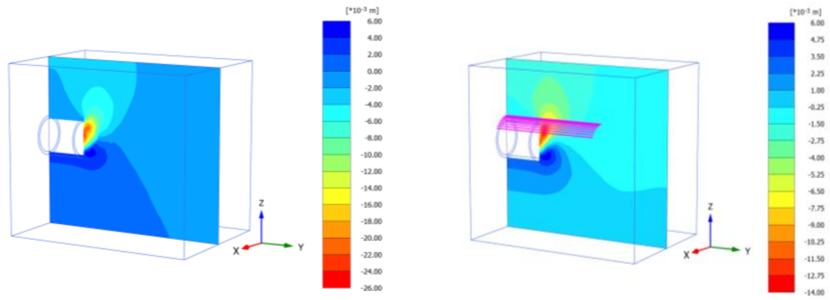
For the insufficient support case, the vertical displacements on the central axial plane are shown on Fig. 3. Without pipe shed support, the soil flows towards the tunnel face and the maximum displacement value is 24mm, while with the pipe shed support, the soil settlement greatly reduced to 13mm. The settling of the soil was prevented by the pipe shed and the deformed soil zone is smaller in front the shield tunnel face. The uplift zone and the maximum uplift value is also smaller with pipe shed compared with no pipe shed. Similar observation was for the shield tunnel with C/D=1.5. A bit higher value of settlement with C/D=1.5 without pipe shed.



(a) No pipe roof，C/D=1.0



(b) With pipe roof，C/D=1.0

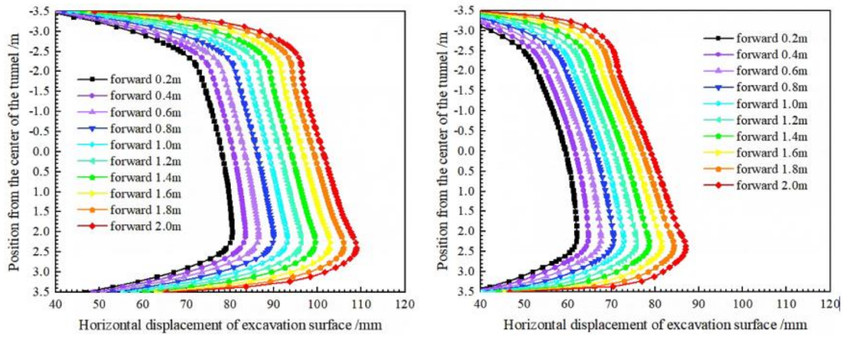


(c) No pipe roof, C/D=1.5　　　　(d) With pipe roof，C/D=1.5

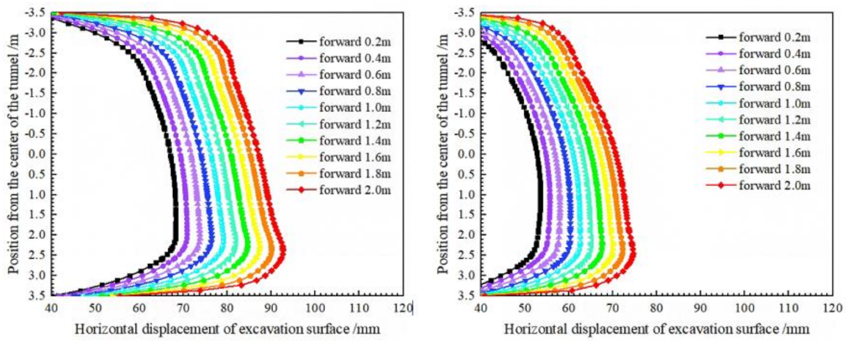
Fig. 2 Numerical simulation results of axial section vertical displacement during tunnel retreat: (a) C/D=1.0, no pipe shed, (b) C/D=1.0, pipe shed, (c) C/D=1.5, no pipe shed, (d) C/D=1.5, pipe shed

Horizontal displacement

The horizontal displacements of the soil in front of the tunnel face are plotted in Fig. 4. The horizontal displacement is not uniform with larger value directly in front of tunnel face. With more excavation, the horizontal displacement becomes larger with the largest value occurs close to the bottom face of the shield tunnel. Obviously, the horizontal displacement with the pipe shed support is smaller than the one without pipe shed support. The pipe shed support also restricted the soil deformation horizontally. With deep embedment length, the horizontal displacement is reduced, which is more significant for the one with the pipe shed support.



(a) No pipe roof，C/D=1.0　　(b) With pipe roof，C/D=1.0



(c) No pipe roof，C/D=1.5　　(d) With pipe roof，C/D=1.5

Fig.3 Numerical simulation results of axial section horizontal displacement during tunnel excavation: no pipe shed, C/D=1.0, (b) pipe shed, C/D=1.0, (c) no pipe shed, C/D=1.5, (d) pipe shed, C/D=1.5

During shield machine retreat, the horizontal displacement is plotted in Fig. 5. The deformation has a symmetry pattern along the central axis of the tunnel with a parabolic shape. The maximum horizontal displacement happens at the center of the tunnel face. With the pipe shed support, the horizontal displacement is greatly reduced. With deep embedment length, the displacement value is larger correspondingly.

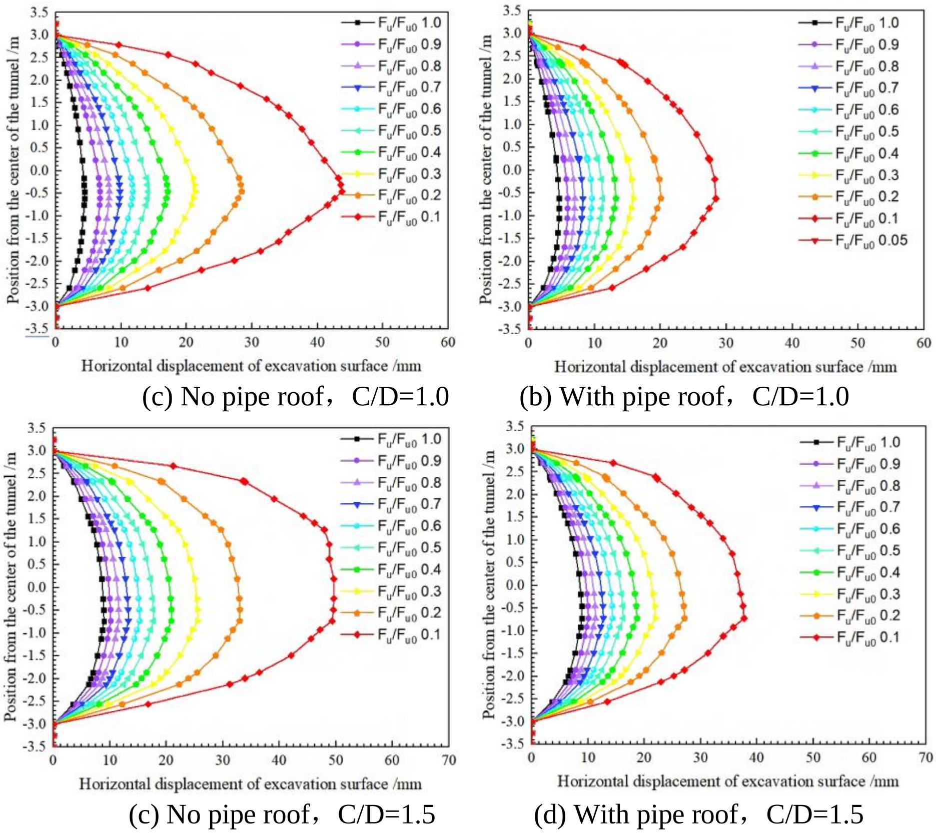
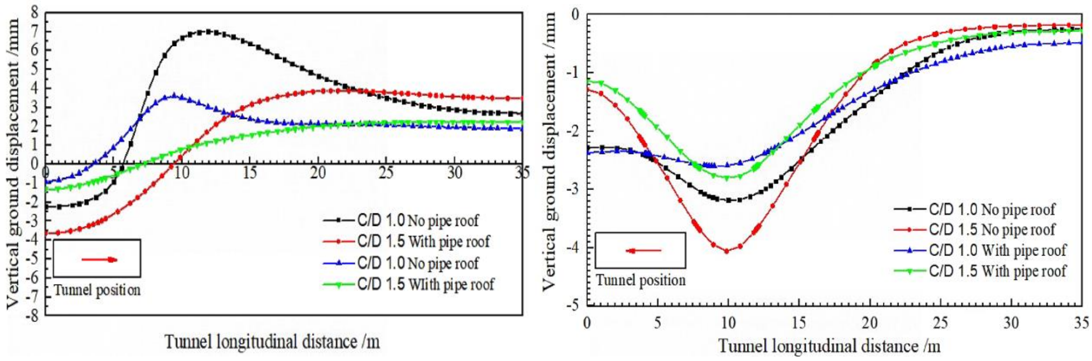


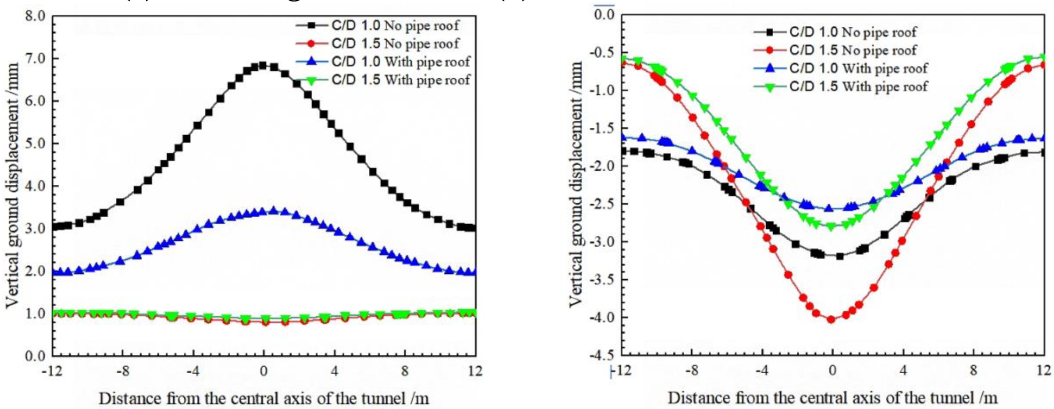
Fig. 4 Numerical simulation results of axial section horizontal displacement during tunnel retreat: (a) no pipe shed, C/D=1.0, (b) pipe shed, C/D=1.0, (c) no pipe shed, C/D=1.5, (d) pipe shed, C/D=1.5

Ground settlement

The ground surface settlement at central plane of the tunnel were analyzed to get to know the influences of shield excavation. The simulation results were plotted in Fig. 6. From the figure it can see that in the tunnel shield excavation process, after advancing 0.5m (one liner segment) the ground surface above the tunnel center presents the vertical displacement change of first settling down and then uplifting. The soil mass in front of the excavation is affected by the shield support thrust, resulting in the deformation of upward uplift caused by soil extrusion. While at the excavation section completed, the soil settles because of the remove of the shield support. With pipe shed support, the corresponding settlement and uplift are both less than those without pipe shed support. The pipe shed supports prevented the uplifting and settlement of the soil in front of and at the back of the shield tunnel. With C/D=1.5, its settlement at the back of shield tunnel is larger than that with C/D=1.0, while its up lift is much less than that with C/D=1.5, which indicates that the deep embedment can inhibit the uplifting of the soil because of overburden.



(a) Advancing (b) Withdraw



(c) Advancing (d) Withdraw

Fig.5 Results of longitudinal and lateral surface displacements for the tunnel: (a) Longitudinal surface displacements during tunnel excavation, (b) Longitudinal surface displacement during insufficient support, (c) Lateral surface displacements during tunnel excavation, (d) Lateral surface displacement during insufficient support

During withdrawn of the shield tunnel, as shown in Fig.6 (b) and (d), settlement ground settlement occurs, the settlement of the ground surface with pipe shed is less than those without pipe shed. Without larger C/D value, the settlement is also larger, but the pipe shed displays more significant role for the deep embedment case.

As for the lateral surface displacements, during advancing, there is a significant uplist displacement without pipe shed with maximum value above the tunnel center face, but with pipe shed, the uplift value is much smaller and much evenly distributed. Larger C/D value induces larger value of uplift displacement without pipe shed, while with pipe shed, the two has the similar value. During withdraw, lateral ground settlement occurs with a symmetric distribution pattern, maximum value at the top ground surface above the tunnel face center like an inverted bell. With the pipe shed, the ground settlement greatly reduced at the center and the edges of the tunnel. With C/D=1.5, the pipe shed plays more important role in controlling the ground settlement.

Conclusions

By utilizing the finite element numerical simulation method to simulate the shield tunnel excavation considering pipe shed support during advancing and withdrawn, we can find that, the pipe shed plays an important role in preventing the uplift settlement and settlement of the soil. The settlement and uplift values reduced with pipe shed and also becomes more evenly distributed. The pipe shed plays a more significant role with deep embedment length.

References

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