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Research on Construction Optimization Simulation of Large Section Tunnel with Shallow Buried Soft Surrounding Rock

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Abstract

How to carry out fast and safe construction of large section tunnel under poor geological conditions such as shallow buried soft surrounding rock is the key in tunnel construction. Based on a highway tunnel of F3 section of E60 expressway in Georgia, the displacement deformation and plastic distribution of five different supporting conditions of shallow buried tunnel are analyzed by three-dimensional finite difference software.The results show that the anchorage reinforcement of the advanced core soil not only has an obvious effect on the pre-convergence and extrusion displacement of the tunnel, but also has an obvious effect on the tunnel convergence. The lead pipe shed and the anchor on the face of the anchor are complementary to inhibit the development of the plastic zone of the arch and the lead core soil.

Keywords

Shallow Buried Tunnel; Advanced Large Pipe Shed; Face Stability; Numerical Simulation.

1. Introduction

Tunnel construction in shallow buried and soft strata is easy to induce partial or large-scale collapse of the face due to the limitations of surrounding rock itself[1], which not only brings difficulties to construction, but also threatens the safety of site construction personnel and increases project investment. At present, the research on the stability of tunnel working face mainly focuses on the following aspects: the analysis of the stability of tunnel working face under the condition of weak surrounding rock[2], the influence of core soil deformation on the stability of tunnel working face[3], and the deformation control method of advanced core soil -- ADECO-RS[4]. The calculation methods of tunnel working face stability mainly include limit analysis method[5], limit equilibrium method[6], test method[7] and software numerical simulation[8]. In recent years, the longitudinal stability of tunnel palm surface has begun to receive more attention and attention. Some scholars have tried to study the instability mode, instability mechanism and dynamic instability prediction model of tunnel palm surface[9-12], but the research depth is still insufficient, and there are still a lot of problems to be solved in the project.

In this paper, taking the highway tunnel of F3 section of E60 expressway in Georgia under shallow buried and soft geological conditions as an example, the influencing factors and solutions of the instability of the face of the finger during tunnel construction in shallow buried and soft strata are studied. To solve this problem, this paper puts forward a variety of support reinforcement methods, simulating the pre-convergence and final convergence values of the tunnel and the extrusion displacement of the face, analyzing the deformation control of surrounding rock by different reinforcement methods, and selecting the appropriate support reinforcement method according to the

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specific situation. The research results of this paper have certain reference significance for the subsequent construction and research.

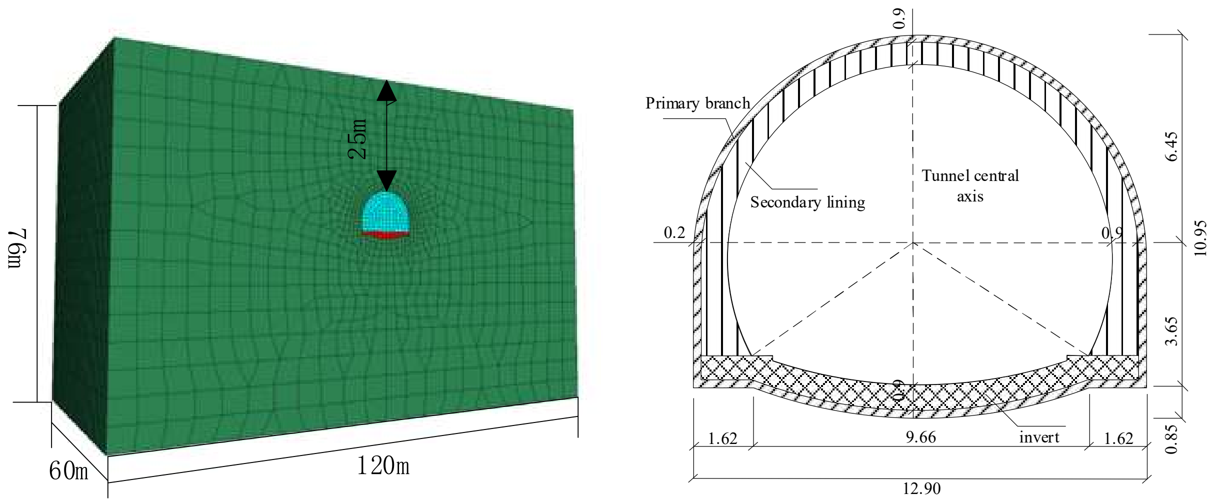
2. Project Overview

The project is based on the B2V section of the construction section K10+875 ~ K10+935 of the F3 highway tunnel AT line of Georgia E60 Expressway for simulation. The excavation method is full section method, and the tunnel excavation footage is 1m/ step. The highway tunnel is located in a shallow buried section dominated by intrusive igneous rocks dominated by silky gray granite, quartz porphyry and metamorphic rocks dominated by quartz gneiss. The tunnel will be excavated through pink and grey granite, quartz porfyites and quartz gneiss.

3. Numerical Calculation Model

3.1 Model Building

Combined with the actual engineering parameters, a three-dimensional model is established by using the finite difference method to simulate the strata of the tunnel crossing B2V section. In order to eliminate the boundary effect, according to the Saint-Venant principle and the influence range of underground engineering excavation, the tunnel is 12.90m wide and 10.95m high, and the transverse length of the model is 120m, the vertical height is 76m, and the longitudinal length is 60m, that is, the left and right boundary is about 5 times the width of the excavation section of the underground engineering, and the upper and lower boundary is about 7 times the total height of the excavation section. See Figure 1 for the model. The Moell-Coulomb constitutive model is used in the formation, and the displacement boundary conditions are used in the numerical model to constrain the displacements at the bottom, left and right sides, front and back sides respectively.



(a) Numerical model (b) tunnel cross-section diagram

Figure 1. Tunnel model

3.2 Mechanical Parameters of Materials

The physical and mechanical parameters of surrounding rock are selected according to the results of on-site geological report and the parameters of supporting structure are shown in Table 1.

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Table 1. Parameters of surrounding rock and supporting materials

name	D(Kg/m3)	E(GPa)	c(MPa)	v	φ(°)
Class B surrounding rock	2500	1	0.03	0.4	30
Anchor bolt	1850	45	--	0.2	--
Pipe shed	--	210	--	0.35	--
Primary branch	2500	10.5	--	0.25	--
Grouting area	2500	1.95	--	0.3	--

3.3 Numerical Simulation Scheme

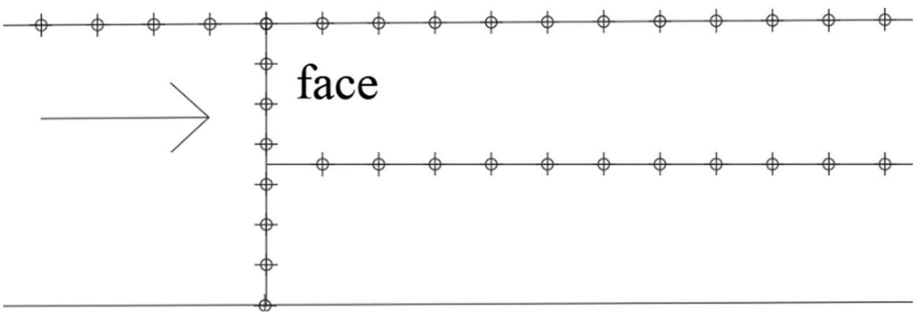
By applying different support measures to control the deformation of surrounding rock during tunnel excavation for B2V cross-section type strata, the supporting effect of deformation monitoring points is compared and analyzed based on the principle of innovative method. The supporting scheme is shown in Table 2.

Table 2. Different support schemes for B2V section types

Support type	working conditions				
	1	2	3	4	5
Primary support	have	have	have	have	have
Lead pipe shed	no	have	no	have	have
Palm face bolt	no	no	have	have	have
Radial bolt	no	no	no	no	have

3.4 Data Collection Point Layout

In the numerical simulation calculation, the pre-convergence displacement in front of the face, extrusion displacement of the face, surface settlement and convergence displacement of the tunnel are timely monitored at the monitoring points arranged on the arch of the excavation face, the palm face and the tunnel arch. And monitoring along the excavation direction (monitoring points are shown in Figure 2). In order to analyze the change characteristics of the pre-convergence and extrusion displacement of the excavated tunnel, a monitoring line is set up in front of the tunnel top and the center of the palm surface, and the central axis of the palm surface and the surface, respectively. The monitoring points are evenly arranged in the tunnel arch and the front of the palm surface at an interval of 1m, and the surface monitoring at a interval of 50m.



(a) Tunnel deformation monitoring point

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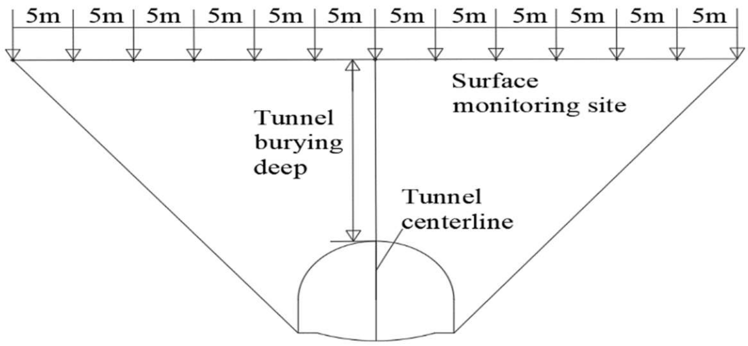

(b) Surface subsidence monitoring site

Figure 2. Monitoring site diagram

4. Numerical Simulation Results and Analysis

4.1 Displacement Field Analysis of Surrounding Rock

(1) Analysis of convergence and pre-convergence deformation of surrounding rock during excavation

In order to study the pre-convergence of the leading core soil before and after the tunnel face and the tunnel convergence rule in different support schemes, the arch roof convergence displacement of the characteristic section of K10-895 was selected for research, as shown in Figure 3.

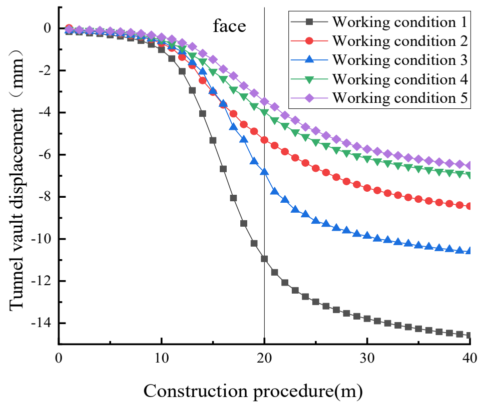

Figure 3. Tunnel convergence and pre-convergence deformation

As can be seen from Figure 3, working conditions 1, 2, 3, 4 and 5 all have a certain inhibition effect on controlling the deformation of surrounding rock above the vault. Due to the differences in supporting characteristics of different working conditions, the deformation of surrounding rock vault settlement is also different to different degrees. Taking the final convergence value and maximum pre-convergence value of operating condition 1 as 1, the final convergence value and pre-convergence value of operating condition 2, 3, 4 and 5 are 57.93% and 48.46%, 72.71% and 62.46%, 47.54% and 36.22%, 44.70% and 31.75%, respectively. The pipe roof support in condition 2 has obvious effect on the convergence value and pre-convergence value of the tunnel surrounding rock, while the face bolt in condition 3 has less effect on the convergence value and pre-convergence value of the tunnel surrounding rock than that in condition 2. However, the combined support of the face bolt and pipe shed in working condition 4 has further improved the inhibition effect on the convergence value and pre-convergence value of the tunnel surrounding rock. In working condition 5, the radial bolt support added on the basis of the original support measures has a certain increase in the inhibition effect on the convergence value and pre-convergence value of the tunnel surrounding rock, but the improvement is limited.

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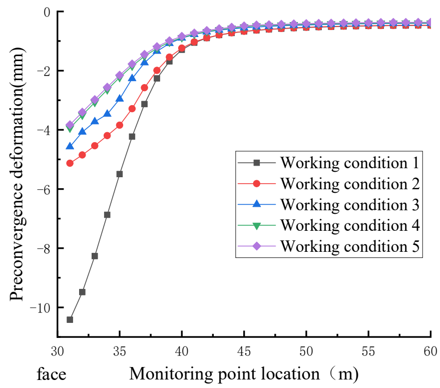

Figure 4. Pre-convergence deformation of advanced core soil arch

As can be seen from Figure 4, the pre-convergence deformation of the advanced core soil arch under different supporting conditions gradually tends to 0 at one time hole diameter in front of the palm face, which is caused by the spatial arch effect formed under different supporting conditions. The three supporting schemes under working conditions 1, 2, 3 and 4 have obvious differences in the pre-convergence inhibition effect of the advanced core soil arch. However, the comparison between working condition 5 and working condition 4 shows that the application of radial bolt support has no inhibiting effect on the pre-convergence of the advanced core soil.

(2) Extrusion deformation analysis of surrounding rock palm surface

In order to analyze the extrusion displacement and deformation rule of tunnel palm surface under different support schemes, horizontal extrusion displacement of the palm surface of characteristic section K10-905 was selected for analysis, as shown in Figure 5.

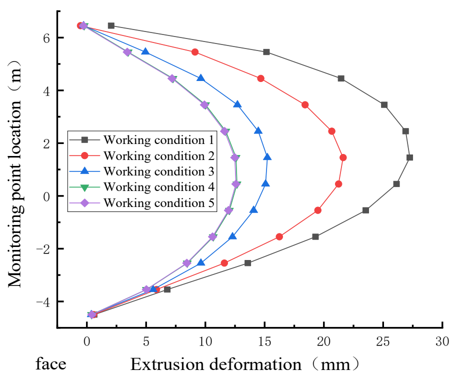

Figure 5. Extrusion deformation curve of palm surface longitudinal symmetry axis

The extrusion deformation displacement curve on the longitudinal symmetry axis of the palm surface is shown in Figure 5. When the tunnel is excavated, due to the lack of the restraint force of surrounding rock, the original triaxial stress state of the palm face changes into a biaxial stress state. The surrounding rock at the edge of the palm face still plays a certain role in the deformation of the palm face, so the deformation of the edge of the palm face is relatively small, making the deformation of the palm face extrude into the tunnel in an arc shape. The extrusion deformation of the palm surface showed a trend of small on both sides and large in the middle. The maximum extrusion displacement of palm surface under different working conditions is 79.35%, 55.90%, 46.50% and 46.16% in working conditions 2, 3, 4 and 5, respectively. Compared with condition 1, conditions 2, 3, 4 and 5

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have a certain inhibition effect on the extrusion displacement of palm surface through the combination of different support methods. Therefore, the reinforcement of core soil can effectively restrain the extrusion deformation of the palm surface, while the effect of pipe shed is small. The effect of condition 4 on the extrusion displacement of the palm surface is also significant, but the addition of radial anchor support on this basis has no significant difference in the extrusion displacement of the palm surface.

(3) Pre-extrusion deformation analysis of advanced core soil

The maximum pre-extrusion deformation curve of advanced core soil is shown in Figure. 6. In working condition 1, the pre-extrusion deformation within 8m in front of the palm face is positive, while the pre-extrusion deformation range in front of 8m is negative (that is, the pre-extrusion deformation direction is consistent with the driving direction). The possible reason is that the pre-convergence of the tunnel contour in front of the palm face is extremely large. At this time, the normal pressure acting on the periphery of the advanced core soil will have a component consistent with the direction of excavation, and the effect of this pressure component begins to show at a certain depth in front of the palm face. This situation is mainly because the finite difference calculation program assumes the surrounding rock as the continuous medium for calculation, which is impossible to appear in the real situation. Compared with working conditions 1 and 2, in working conditions 3, 4 and 5, the pre-extrusion deformation is obviously smaller in a certain range in front of the palm face (near 39m), but it becomes larger further ahead. This is mainly because the axial tension of the anchor bolt in the palm face reaches the maximum near 39m, which has a restrictive extrusion effect on the advanced core soil behind 39m. However, there is a "stretching" effect to the rear of the advanced core soil in front of 39m, so the deformation of pre-extrusion is obviously larger than that without bolt support on the palm face. The conditions 4 and 5 of integrated pipe shed support and anchor bolt reinforcement can restrain the advance displacement, the final displacement and the extrusion deformation of the face at the same time.

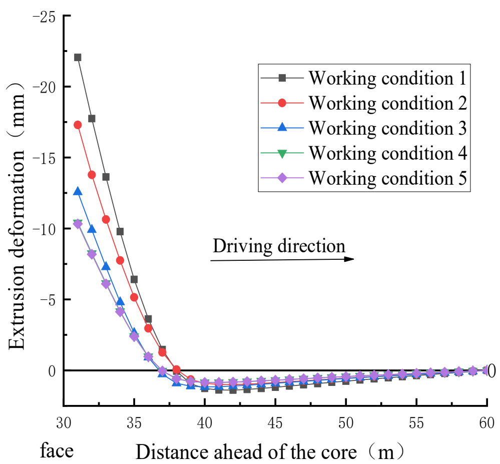

Figure 6. Pre-extrusion deformation of advanced core soil

(4) Surface settlement analysis

In order to analyze the influence law of tunnel excavation on surface settlement and deformation under different support schemes, surface monitoring of characteristic section K10-895 was selected for deformation analysis, as shown in Figure 7.

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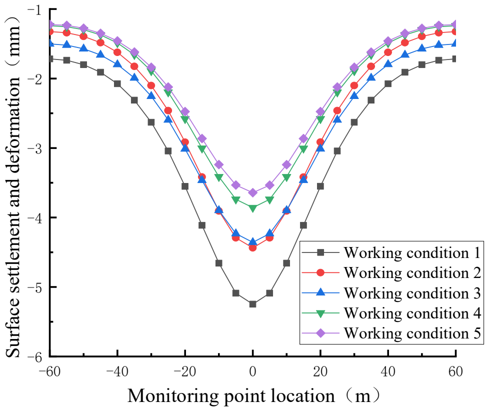


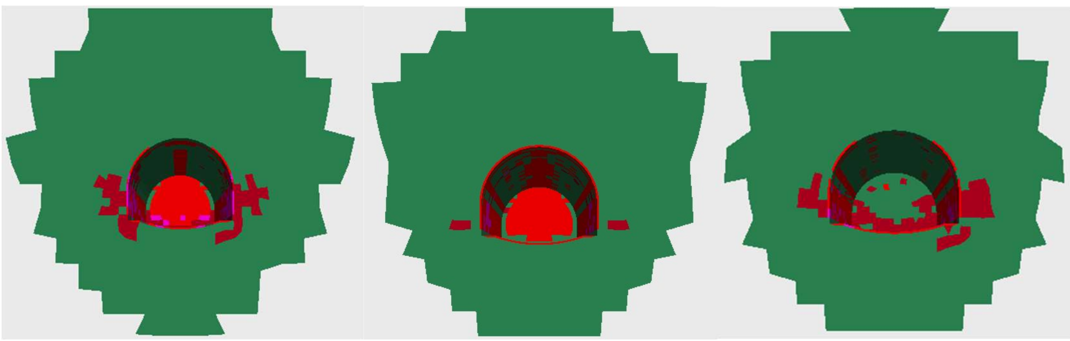
Figure 7. Surface settlement and deformation

In order to optimize the support scheme more suitable for the tunnel, control the surface settlement, and do not affect the normal use of surface buildings and roads. Therefore, the ground settlement should be strictly controlled in tunnel construction. In numerical calculation, a monitoring point is set every 5 meters in the range of 60m above the surface directly above the central axis of the tunnel, and the surface settlement curves corresponding to different positions under different supporting conditions are drawn (Figure. 7). As can be seen from Figure 7, the surface settlement caused by the five support schemes is larger within 40m or so of the tunnel Central Line, and the surface settlement caused by the tunnel central axis is the largest. The land surface settlement in the area 40m away from the left and right sides of the tunnel axis does not change significantly with the distance. It can be found that the affected area of ground subsidence is about 3 times the diameter of the tunnel. According to Figure 7, under different supporting conditions, the maximum surface settlement value of working condition 1 is 1, and the maximum surface settlement deformation of working condition 2, 3, 4 and 5 is 84.56%, 83.03%, 73.53% and 69.43%, respectively.

According to the analysis results, working condition 5 has the best control effect on surface settlement, but compared with working condition 4, the control effect is almost the same. Combined with cost control, the supporting scheme of working condition 4 can not only effectively inhibit surface settlement, but also save costs and improve work efficiency during tunnel excavation.

4.2 Plastic Zone Analysis of Surrounding Rock

The distribution of tunnel plastic zone is shown in Figure 8 and Figure 9. It can be seen that under conditions 2, 4 and 5, pipe shed support has a good inhibition effect on the development of plastic zone of arch roof, while under conditions 3, 4 and 5, it has a good inhibition effect on the development of plastic zone of advanced core soil in front of the palm face. The volume of plastic zone in 5 supporting conditions was calculated by using FISH language. The results are shown in Table 3.



(a) Working condition 1 (b) Working condition 2 (c) Working condition 3

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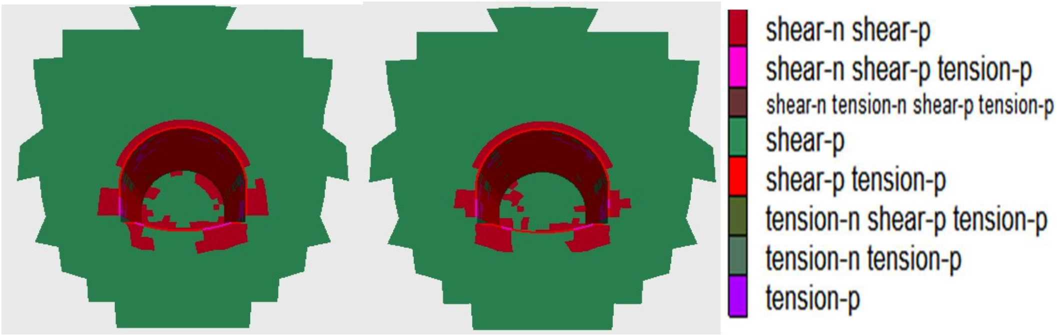
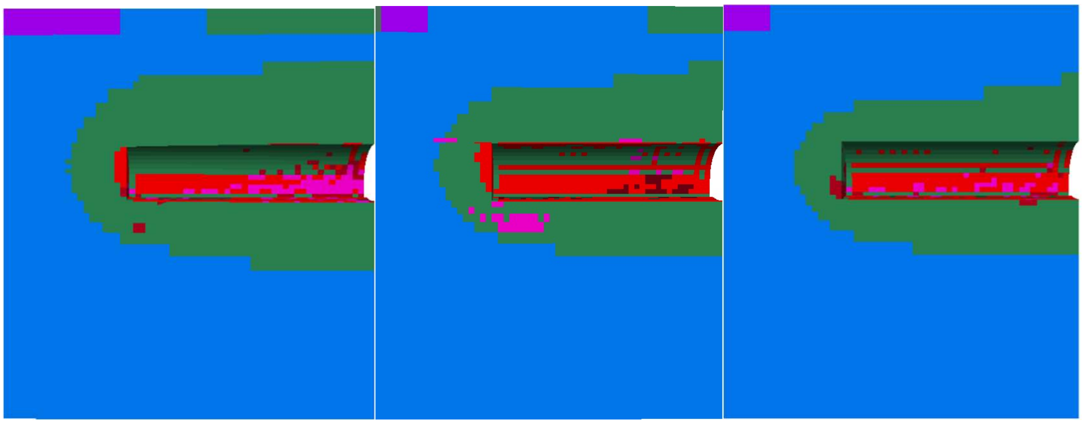
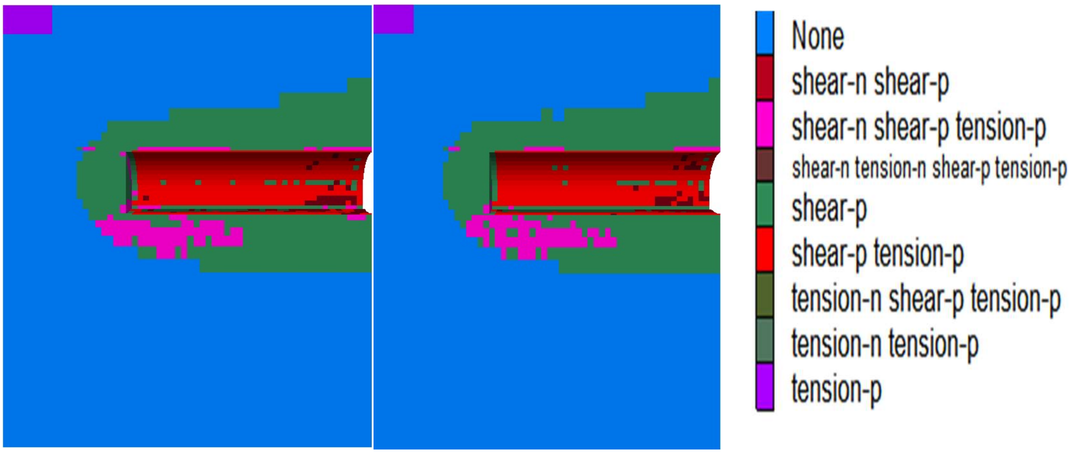


(d) Working condition 4 (e) Working condition 5

Figure 8. Cloud map of plastic zone of surrounding rock of tunnel



(a) Working condition 1 (b) Working condition 2 (c) Working condition 3



(d) Working condition 4 (e) Working condition 5

Figure 9. Cloud map of plastic zone of surrounding rock in advance of core soil

Table 3. Plastic zone volume of tunnel surrounding rock under different supporting conditions

Working condition	Shear failure /m³	Tensile failure /m³
1	36008.94	10834.82
2	26657.25	4738.81
3	30211.02	6136.62
4	26363.07	3263.22
5	25858.21	2589.58

Based on the analysis of the damaged volume of the plastic zone of surrounding rock in Table 3, the variation trend of the plastic zone volume under different strengthening conditions can be obtained, as shown in Figure 10.

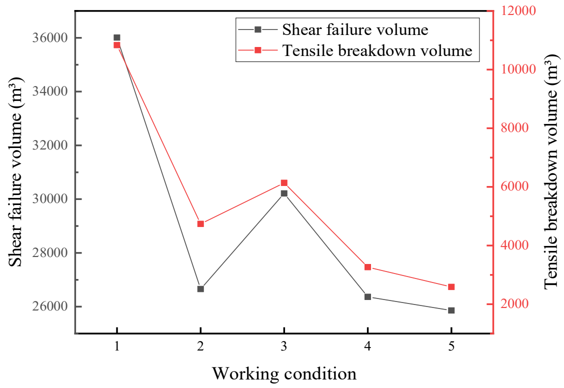


Figure 10. Failure volume of plastic zone

According to the comprehensive analysis of Figure. 8 to Figure. 10, it can be seen that the plastic zone formed by tunnel excavation is mainly shear failure, which is mostly concentrated in the advanced core soil area around the tunnel and a certain distance in front of the face. It can be seen from the change curve in Figure. 10 that the sudden change in the plastic zone volume in working condition 3 is due to the fact that the anchor bolt of the face reinforced the advance core soil in front of the face, which has a good control effect. However, because the reinforcement of working condition 3 gradually loses its effect with the excavation of the face of the face, it cannot be used as a permanent support to strengthen the surrounding rock like the reinforcement of the advance pipe shed in working condition 2. However, under condition 4, combined with the advantages of the face bolt and the lead pipe shed, the effect of restraining the tunnel plastic zone is remarkable. For this kind of surrounding rock, the radial bolt applied on the basis of the original condition 4 has no obvious inhibition effect on the plastic failure area.

5. Conclusion

Combined with Georgia E60F3 highway tunnel project, this paper uses numerical simulation method to analyze the reinforcement scheme of shallow buried and weak surrounding rock tunnel, and draws the following conclusions:

(1) Compared with without support, the reinforcement of advanced core soil bolt not only has a significant effect on the pre-convergence of tunnel arch and the extrusion displacement of the face of the tunnel arch, but also has a significant effect on the convergence of tunnel arch.

(2) After tunnel excavation, combined with the advantages of the face advance bolt and pipe shed, the control effect of the tunnel surrounding rock deformation is obvious, and the addition of radial bolt support has little effect on the tunnel convergence and the change of plastic zone.

(3) Compared with the case without support, the advance pipe shed reinforcement has a good inhibitory effect on the development of the arch plastic zone, but has no obvious inhibitory effect on the plastic zone of the advance core soil, while the shoe-face anchor reinforcement has an opposite and complementary inhibitory effect on the development of the tunnel plastic zone. Therefore, the development of plastic zone of the surrounding rock and the plastic zone of the core soil can be inhibited simultaneously by the integrated advance pipe shed and the anchor rod.

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