

The Numerical Simulation Analysis of the Stability of the Face of Huangzhushantunnel under Partial Infiltration Condition

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ABSTRACT: Huangzhushan Tunnel is a key control project on Jiangyu Expressway with a total length of 4165m. Combining with numerical simulation, this paper carries out numerical simulation analysis of the stability of the face of Huangzhushan Tunnel under partial infiltration condition, reveals the variation rules of surface displacement, axial force, pore water pressure and safety factor of the face before and after reinforcement under partial infiltration condition, which can provide technical reference for safe entry into the tunnel.

Key words: Partial infiltration; Palm surface; Stability; Numerical simulation

I. PREFACE

Huangzhushan tunnel is a key control project on Jiangyu expressway, with a total length of 4165m. According to the separated design, the tunnel site is located in the slope zone of transition from Yunnan Guizhou Plateau to hills in Western Hunan, which belongs to low mountain structure erosion landform. The line passes through Huangzhu mountain. The overall terrain is high in the middle and low at both ends. The lowest part of the axis ground is located at the entrance of the tunnel, with an elevation of 601m. The highest part is the top of Huangzhu mountain, with an elevation of 928m. The relative elevation difference is 327m. The terrain slope is 35 ° to 55 ° and some parts are steep cliffs. Several gullies and ridges are developed along the slopes on both sides of Huangzhu mountain. Gullies and ridges alternate with each other, which is conducive to the discharge of surface water. The highest part of the terrain is about 603.75m higher

than the tunnel roof. The tunnel entrance is located on the slope on the right side of the gully. The terrain gradient is about 25 ° to 30 ° and the slope above the entrance is steep. The terrain gradient is 40 ° to 50 ° and there is a gully below. The gully section is in "U" shape, and the width of the gully bottom is generally 40-60m. There is water in the gully all the year round. The water flows through the right side of the gully. During the survey period (April May 2017), the measured flow is 2.0l/s. The entrance of the tunnel is silty clay of Quaternary eluvial deposit. The bedrock is exposed at the steep slope above. The vegetation on the surface is developed, mainly trees and shrubs. The slope is stable. The exit of the tunnel is located on the gentle slope on the left side of the gully. The overall terrain is relatively gentle, with a slope of 8 ° to 15 ° in general. Due to the cultivation of local villagers, a multi-level ridge is formed, with a height of 1.0-2.0m in general. On the right side of the outlet is a small ditch formed by the upper gully catchment. The width of the ditch is 7.0-9.0m and the cutting depth is 1.5-2.5m. There is water in the ditch all the year round. During the survey period (April May 2017), the measured flow is 1.0l/s. The mouth of the cave is silty clay formed by Quaternary eluvium and slope, which is mainly cultivated land, shown in Fig.1. The vegetation is relatively developed, and it is mainly economic crops such as grapes cultivated by villagers. The overall stability of the exit slope is good. Combined with the numerical simulation, this paper carried out the numerical simulation analysis of the stability of tunnel face under the condition of partial infiltration in Huangzhushan, and tried to provide technical reference for safe entry.

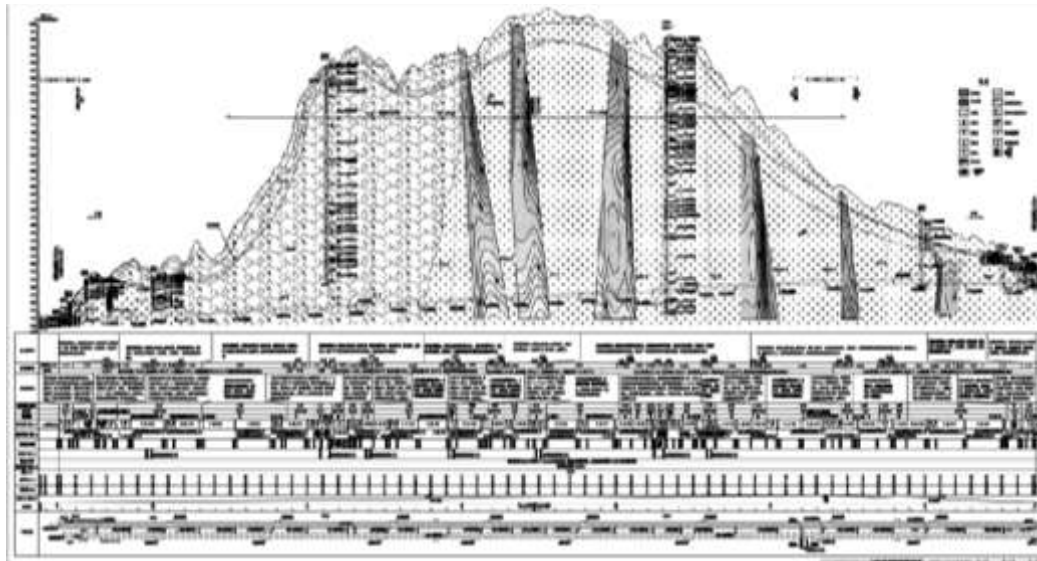


Fig. 1 longitudinal section of tunnel

II. MATERIAL PARAMETERS AND BOUNDARY CONDITIONS FOR MODEL CALCULATION

The isotropic material needed in the model is established, and the model type of grouting reinforcement in soil layer and above is set as Mohr Coulomb model; The anchor rod, C20 and C30 shotcrete models are set as elastic models, and the specific parameters are obtained through the exploration documents, concrete structure design specifications and highway tunnel design specifications. The required parameters are listed in Table 1; Load input self weight.

The boundary conditions include element attribute change group, boundary constraint group, boundary head group and seepage surface group; Boundary constraint for regular model, the software's function of automatic adding constraint is used. The displacement of the front and back of the model is limited in Y direction, the left and right boundaries are limited in X direction, and the bottom boundary is constrained in XYZ direction; According to the most unfavorable water level, the boundary head is 43.8m; The seepage surface group is used as the seepage surface of the main tunnel after each excavation step for seepage analysis.

Table 1 material parameters required for the model

Material	density $\gamma(kN / m^3)$	Elastic modulus $E(GPa)$	Poisson's ratio μ	friction angle $\varphi(^{\circ})$	Cohesion $c(kPa)$	Permeability coefficient (m / s)
Mud stone	20.0	1.4	0.38	20	24	1.8e-6
bolt	78.5	210	0.3	-	-	-
C20Spray mixing	24	25.5	0.2	-	-	-
Strongly weathered rock mass	20	0.4	0.38	21	200	1e-9

In GTSNX, a new analysis condition is built, and the solution type is selected in the construction stage. The influence of groundwater on tunnel excavation is not calculated, and the option of "automatically considering water pressure" is checked in the analysis control option; The analysis steps are as follows.

① The initial seepage field and stress field are

analyzed, and the displacement of the initial stress field is cleared;

②The construction of side pilot tunnel is advanced support, side pilot tunnel excavation, side pilot tunnel anchor and shotcrete construction, and the main tunnel excavation follows the side tunnel;

③Main tunnel advance support construction, main tunnel excavation, main tunnel anchor and shotcrete

construction; Steady seepage analysis is carried out at the same time of each excavation step of the main tunnel.

The establishment and analysis process of the model is mainly realized in the excavation stage of the front section of the tunnel. The longitudinal length of the model is set as 12M, and the excavation footage of the pilot tunnel and the main tunnel is set as 1m. The side pilot tunnel is excavated. After the side pilot tunnel is excavated for 2m, the main tunnel is excavated. The advance support of each tunnel is 4m ahead of the tunnel face. This is the whole process from the excavation of the left tunnel to the initial support.

Numerical simulation analysis of 3 huangzhushan tunnel construction stage

III. DISPLACEMENT CURVE OF EXCAVATION FACE CORRESPONDING TO REDUCTION FACTOR

3.1 calculation of stability coefficient of tunnel face

(1) Introduction of calculation method

It is assumed that the strength reduction factor is f , and the parameter is adjusted to equation 1 after reduction.

$$c' = c / F \quad ; \quad \phi' = \arctan\left(\frac{\tan \phi}{F}\right)$$

(1)

At present, the strength reduction theory in shield tunnel uses the maximum displacement of the center point of the excavated face to reach the warning value as the basis for instability. The single tunnel is a multi arch tunnel, and it is a non-circular tunnel. The excavation face is an asymmetric section, and the maximum displacement is not at the center point. Therefore, in this paper, the instability basis is set as the maximum displacement of the excavation face, and the location is not limited; After consulting the relevant literature, we did not find the specific calculation method of the warning value. Combined with the research on the strength reduction method of Qin Jianshe, the instability basis is improved to be the safety factor when the reduction coefficient changes little, but the extrusion displacement of the tunnel face changes sharply; After trial calculation, the maximum horizontal displacement of the excavation face is recorded under five conditions of reduction factor F of 0.8, 0.9, 0.95, 1.0 and 1.1.

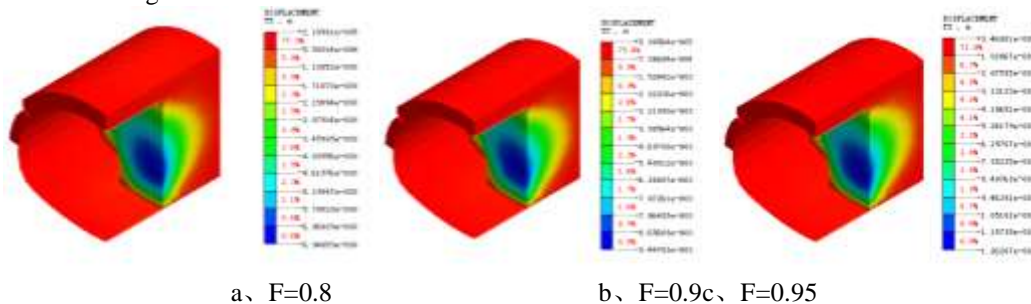
(2) Collation of calculation results

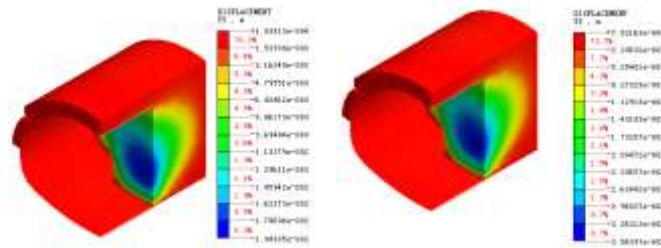
According to the reduction coefficient, the cohesion and internal friction angle under four states are shown in Table 2.

Table 2 Corresponding parameters of different working conditions

Parameters Working conditions	Cohesion c (kPa)	Friction angle ϕ (°)
F=0.8	30	27.5
F=0.9	26.6	25
F=0.95	25	22.2
F=1.0	24	20
F=1.1	21.8	18.3

The longitudinal displacement of the excavation face is obtained by modifying the model parameters in five cases, as shown in Fig. 2.





d、F=1.0e、F=1.1

Fig. 2 Displacement nephogram of numerical simulation corresponding to reduction coefficient (unit. m)

Considering that the follow-up steps in the model will be shorter and shorter, the same construction step in the middle, that is, the construction step when the excavation reaches 6m, is selected as the displacement acquisition surface. It can be seen from the Fig.2 that the maximum

longitudinal displacement, that is, the extrusion displacement of the heading surface, occurs on the heading surface. Under different reduction factors, the maximum displacement of the excavation surface is collected for the same construction step, as shown in Fig. 3 and table 3.

Table 3 displacement of excavation face under different reduction factors

Value of reduction factor	0.8	0.9	0.95	1.0	1.1
Longitudinal displacement of excavation face (mm)	6.94	9.45	12.6	19.5	35.4

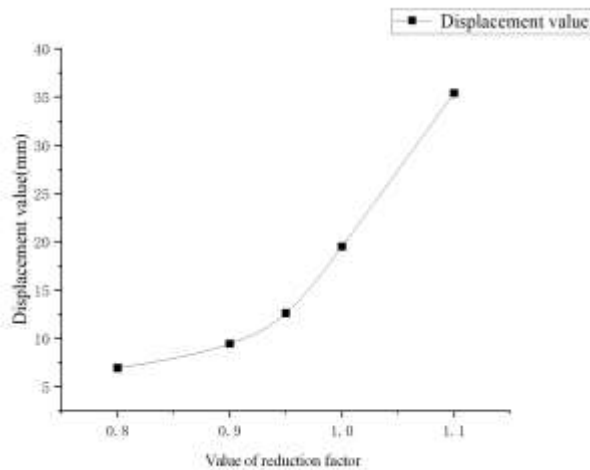


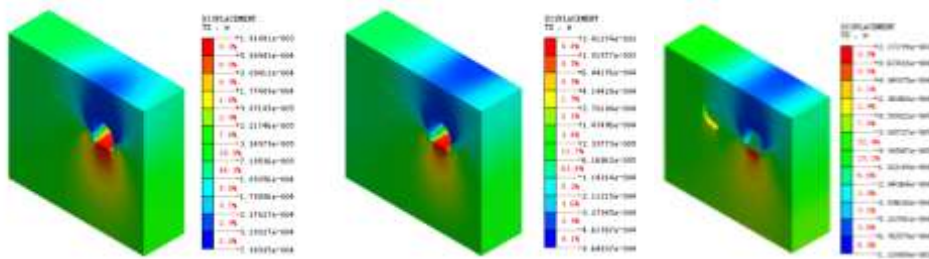
Fig.3 Displacement curve of excavation face corresponding to reduction factor

When the reduction coefficient increases from 0.8 to 0.95, the displacement increases slowly; When the reduction coefficient increases from 0.95 to 1.0, the displacement value changes at a maximum rate; Combined with the previous criterion, the displacement value mutation of excavation face occurs between the reduction factor (0.95 ~ 1.0), here

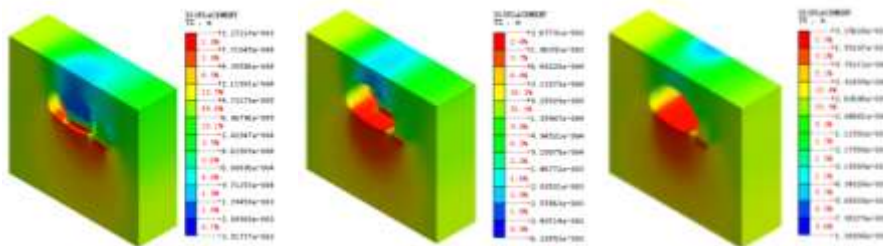
the median value of 0.975 is taken as the safety factor of tunnel face stability.

3.2 Settlement prediction of main tunnel after excavation

The size of the original model is large, and the results of the middle part of the model are intercepted for viewing. The soil settlement caused by each excavation process is shown in Fig. 4.



a、Excavation of middle pilot tunnel 6m b、Excavation of middle pilot tunnel 12m c、Excavation of side pilot tunnel



d、Excavation of main tunnel 6m e、Excavation of main tunnel 12m f、Excavation of main tunnel 12m

Fig. 4 settlement of soil caused by excavation (unit. m)

Select the ground line at the longitudinal midpoint of the model as the observation line, take out the surface settlement data of the tunnel from the middle pilot tunnel to the main tunnel excavation after passing through the line, and draw its settlement, as shown in Fig. 5. Combined with the settlement curve, it can be seen that in the process of tunnel excavation, the settlement suddenly increases to 11mm when the tunnel passes through this position, and the settlement of the initial support vault in the tunnel is more than 13mm, which exceeds the

monitoring and early warning value, so reinforcement measures need to be taken.

3.3 Prediction and analysis of initial support internal force

The axial force in XX direction and bending moment in YY direction are selected for analysis. The axial force and bending moment corresponding to each construction stage of the plate element are shown in Fig. 6.

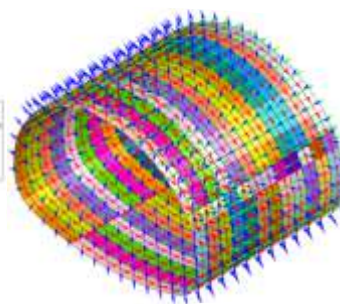
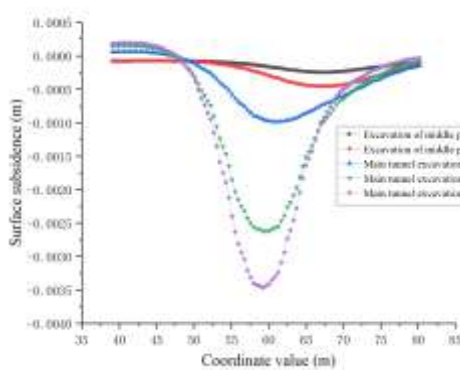
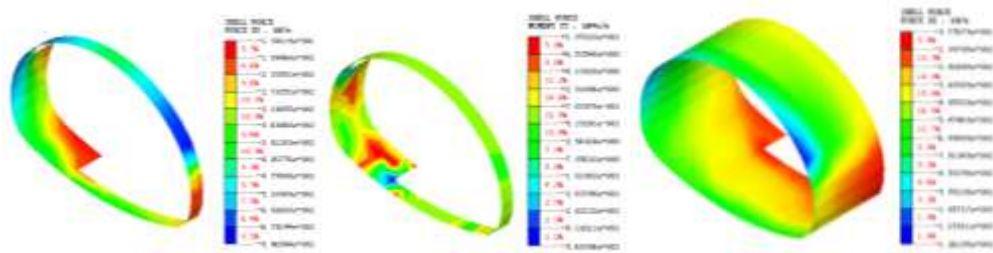
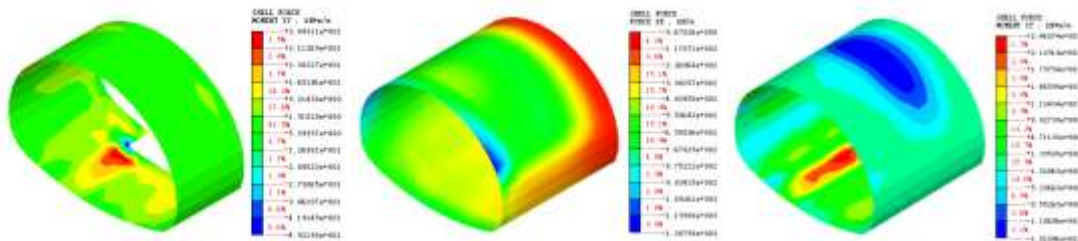


Fig.5 Surface settlement curve Fig. 6 local coordinate system of initial support unit



a. The bending moment of the axis b. and bending moment of the initial support ring 1m c. Axial force of initial support ring



d. Bending moment of initial support ring e. 12m axial force f. and 12m bending moment

Fig.7 analysis of internal force of initial support (unit.kN/m; kN*m/m)

According to the axial force diagram of initial support, the axial force appears in the form of pressure in the process of tunnel excavation. In the first ring of initial support closed loop, the maximum pressure (axial force) appears at the left and right spandrels, and its value is 806kN / m. when the

tunnel is excavated to 6m, the axial force gradually increases to 1260kN / m. when the tunnel is excavated to 12m, the axial force increases to 1310kN / m. the axial force variation curve is shown in Fig. 8.

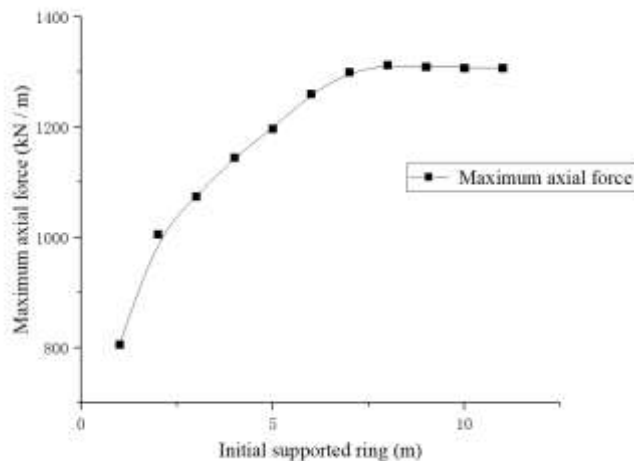


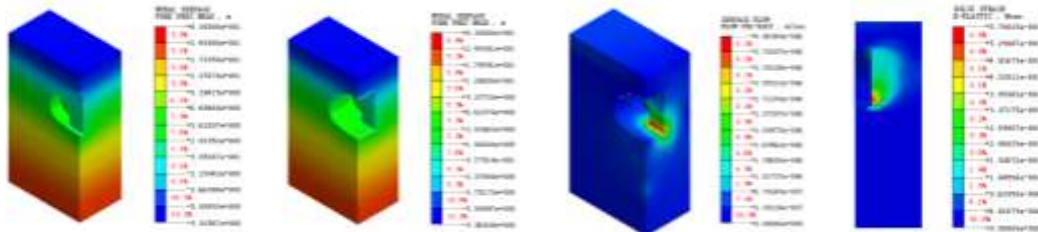
Fig. 8 maximum axial force diagram of initial support

As for the change of bending moment, with the closed-loop of initial support, the maximum negative bending moment and maximum positive bending moment appear at the joint of primary support of main tunnel and primary support of side pilot tunnel at 1m and 6m of tunnel excavation, which indicates that joint treatment should be done well in the construction of pre and post primary

support to prevent support cracking caused by stress concentration; When the tunnel is excavated to 12m, the larger bending moment appears at the vault and the center of the invert to the left, so it is necessary to strengthen the protection and monitoring measures at the vault and the arch bottom; In the whole excavation process, the maximum bending moment is 56.8kN/m, which is much smaller than the axial

force. The axial force and the maximum bending moment are not in the same position, and the maximum compressive stress is 5.04MPa, which is

less than the compressive strength of C20 concrete. 3.4 Prediction of seepage velocity, pressure head and plastic zone in front of main tunnel



a. Pore pressure head of 1m in of facemain excavation
 b. Pore pressure head of 6m in excavationmain tunnel

a. Pore pressure head of 6m in Seepage velocity
 b. Plastic zone 6m of main tunnel

Fig. 9 Pore pressure head

Fig. 10 Seepage velocity and plastic zone (unit: m; m/s)

According to the contents of Fig. 9 and Fig. 10, the water head in front of the tunnel face is regarded as the seepage surface, and the water head value decreases along the phreatic line to the inside of the tunnel. When steady seepage is formed, the seepage velocity reaches the maximum at the bottom of the tunnel face, which means that the risk of water

inrush is easy to occur at the bottom of the tunnel face.

3.5 Stability analysis of huangzhusan construction stage under the reinforcement of small advance conduit

3.5.1 Settlement prediction of pilot tunnel and main tunnel after excavation

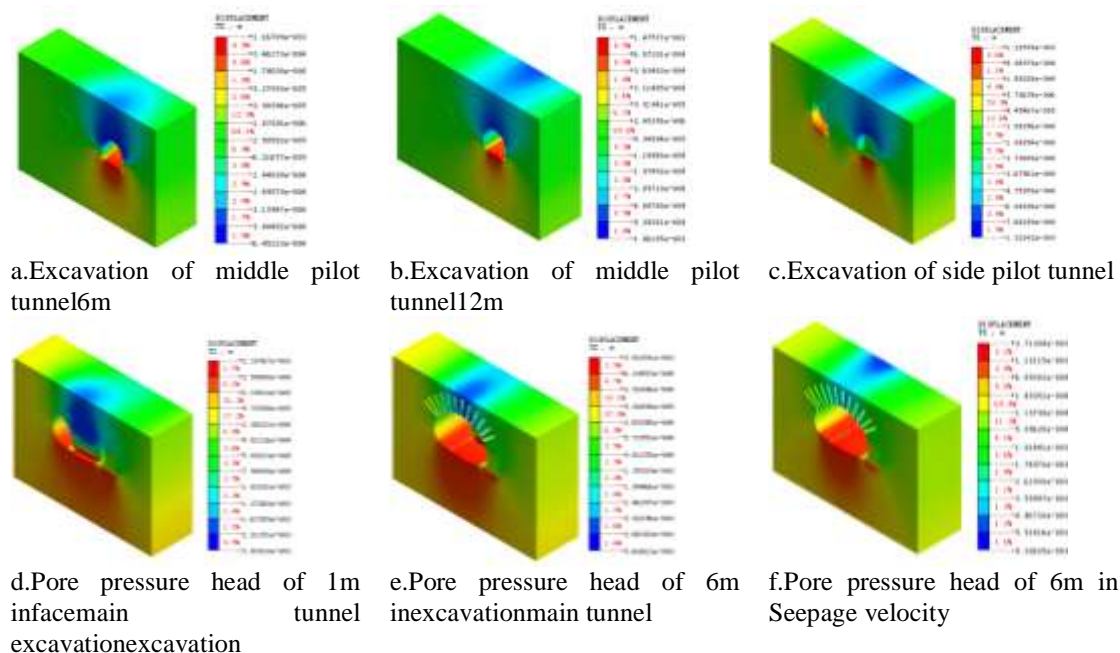


Fig. 11 Settlement of soil caused by excavation after reinforcement in tunnel (unit: m).

(1) Analysis of soil settlement during excavation

According to method 11, select a line in the

soil layer above the tunnel vault at the longitudinal midpoint of the model as the observation line, take out the surface settlement data of the tunnel after passing through the line from the middle pilot tunnel excavation to the main tunnel excavation, and draw the settlement as shown in Fig. 12. The maximum settlement of the initial support of the tunnel is

8.3mm, which is more than 13mm and 5mm less than that without reinforcement, It is lower than the monitoring warning value. The settlement curve comparison before and after reinforcement is shown in Fig. 12. The reinforcement effect has obvious improvement on the ground settlement.

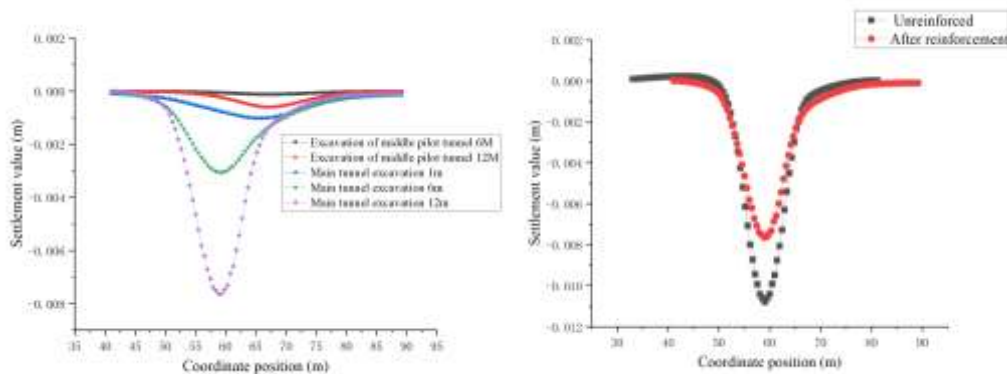


Fig. 12 Settlement curve of soil layer at vault after reinforcement

3.5.2 Prediction of seepage velocity, pressure head and plastic zone in front of main tunnel

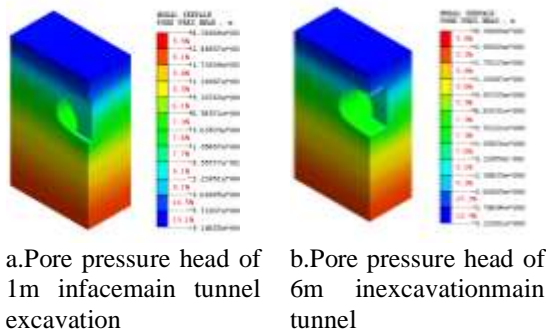


Fig. 13 Pore pressure head after reinforcement 1m in tunnel

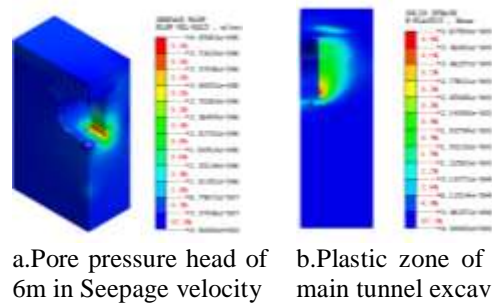


Fig. 14 Seepage velocity and plastic zone after reinforcement in tunnel. m; m/s

According to the contents of figures 13 and 14, the head in front of the face of the tunnel is reduced along the infiltration line to the tunnel because the face of the tunnel excavation face is the seepage surface, and the seepage velocity reaches the maximum value at the bottom of the face when the steady-state seepage is formed. The value does not change much from that of the reinforcement. Because the advance small pipe grouting is placed at the top of the tunnel head, there is no improvement to the seepage; Therefore, it is still necessary to pay attention to the risk of water inrush at the bottom of the face after reinforcement; The maximum plastic strain of the plastic zone caused by the tunnel excavation after reinforcement is obviously improved compared with the previous value.

IV. CONCLUSION

In this paper, MIDAS GTSNX used to analyze the coupling of stress and seepage, and the tunnel excavation models without reinforcement and reinforcement measures are established respectively. The previous theory is verified, and the stress-strain during excavation of the Huangzhushan is predicted and analyzed. The conclusions are as follows.

- (1) The strength reduction method based on finite element is used to simulate the tunnel excavation conditions under different reduction parameters, and the stability coefficient of tunnel face is determined by the displacement rate of tunnel excavation surface.
- (2) Through the data collection and analysis of the model, it is verified that the model size is enough. The numerical simulation and analysis of the

reinforcement and the reinforcement are compared. The settlement of the reinforced soil is 5mm lower than that of the reinforcement after the tunnel excavation, which is lower than the monitoring warning value, and the settlement of the stratum is improved obviously after reinforcement.

(3) The excavation of the middle tunnel leads to the inward convergence of soil on both sides of the middle tunnel. After 12m excavation, the maximum horizontal displacement after reinforcement is half less than that of the non reinforcement; During the excavation of the middle guide tunnel, the horizontal displacement of soil is symmetrical; The effect of reinforcement outside the tunnel on the horizontal displacement of soil in the tunnel is small. For the horizontal displacement in the tunnel, the excavation can be divided into upper and lower steps through the main tunnel.

(4) The initial supporting axial force appears in the form of pressure during tunnel excavation. With the excavation, the support which is constructed in advance gradually bears more load and tends to be stable gradually; The maximum moment value after reinforcement is 13.8kN * m/m lower than that of the non reinforcement; The internal force of the reinforced concrete is improved to a great extent by combining the improvement of axial force and bending moment.

(5) The head of the front face of the tunnel has no improvement on the seepage because of the grouting of the small pipe ahead of the tunnel head; Therefore, after reinforcement, we should pay attention to the risk of water inrush at the bottom of the face; The maximum plastic strain of the plastic zone caused by the tunnel excavation after reinforcement is significantly improved compared with the previous value.

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