Numerical Simulation of New Supporting System for Prestressed Structures of Highway Tunnel Based on FLAC Platform

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Abstract

In order to meet the needs of the growing economic and transport development, the construction of 4-lane highway tunnel is used as the representative of the large cross-section and the low flat rate highway tunnel needs. such low-level characteristics of the tunnel is the traditional tunnel support system, which is facing many difficulties, and the urgent need helps to develop a new type of tunnel support system. The stability of the double-arch tunnel is simulated and analyzed by FLAC, and the stability of the arch tunnel under complex geological conditions has correctly evaluated and used to solve the failure of the arch tunnel. Arch tunnel location, bottom drum and other tunnels geological hazards, control, guide and optimize the construction of arch tunnel.

Keywords: Highway tunnel, FLAC, Tunnel support system.

1. INTRODUCTION

In recent years we can adapt to the construction of multi-lane highway, the country has built a lot of large cross-section tunnel (Diallo .et al., 2014). Compared with ordinary highway tunnels, the structure of the large-span tunnel with double-carousel and eight-lane is more complicated, and the construction method is more diversified. At present, in the large cross-section tunnel rock, the deformation and stability research has a new development and improvement. It has achieved some research results (Gbanie et al., 2013; Todd et al., 2013). In the large-scale tunnel numerical simulation and model test, Huang Shengwen et al simulate the finite element method of large-span tunnel surrounding rock stress. Li Liang et al. have analyzed the response characteristics of large cross-section tunnels under high-speed train vibration load. WU Meng-jun and HUANG Lun-haigive a model test and numerical simulation analysis of the construction process for the four-lane highway tunnel (Zhang et al., 2013).Different construction methods are carried out to obtain the dynamic construction mechanics characteristics of the four-lane tunnel in different construction methods. Li Zhigang et al simulate the deformation and stress of the core soil in the construction of the super-large section tunnel. Yuan Yong and Wang Shenghuihave proposed the four-lane large cross-section tunnel into the first structural support concept, and based on the concept of the first stressed structure (Zhou et al., 2015). Huang Chengzao et al. have proposed the use of a pair of pull bolts to control the deformation of the core soils in the four-lane super-large cross-section tunnels (using the guide hole method). Sun Zhaoyuan et al. have analyzed the deformation mechanism and surface deformation of the surrounding rock under different working methods. In the construction of auxiliary measures for large cross-section tunnels, Huang Mingqi et al. have studied the radial grouting technology of large-scale tunnel in weak surrounding rock. In the case of large cross-section tunnel monitoring, Tan Zhongsheng et al. have used field test methods to study the effects of deep-buried or shallow-buried loess tunnels. Gong Jianwu et al. have conducted a field monitoring analysis and study on the vibration response of large cross-section small-clearance tunnels under blasting load.

China is a mountainous and very complex country, 75% of the land is mountain or heavy hill, Chinese highway construction is booming, the construction of the tunnel is growing. Sexual problems are more prominent. Collapse accident occurred in the tunnel construction process has become the delay caused by life and people's lives and property loss of an important security risk (Wu et al., 2015). Therefore, this paper proposes the application of FLAC3D in the process of advancing the tunnel pressure. According to the law, reducing the impact of ground pressure and other dynamic disasters helps to ensure the safety of staff, increase production efficiency. At present, for the large cross-section tunnel has not yet formed a unified design and construction standards. Because of the four-lane tunnel in the cross-sectional area, span and flat rate has obvious differences, making the four-lane tunnel rock and lining of the force, deformation, and stability. Three lanes of the tunnel need to carry out the relevant theory of four-lane tunnel research. In addition, the four-lane tunnel excavation span is large, the flattening rate is low, the construction process is complicated, and many blasting caused many disturbances to the surrounding rock, especially the core soil force is particularly complicated. Therefore, it is one of the important research projects in the construction of the four-lane large-span highway tunnel by means of monitoring and timely feedback of the supporting system during tunnel construction.

2. RELATED KNOWLEDGE AND CALCULATION

2.1 FLAC

FLAC is an abbreviation of Fast Lagrangian Analysis of Code. It is a finite difference calculation program developed by Itasca Consulting Group, Inc. in the United States. Its built-in constitutive model and structural unit are very suitable for the simulation of rock and support structure (Hasanpour, R., 2014). The finite element is matrix-based implicit solution; FLAC uses an explicit time-history method to solve the problem and uses the Lagrangian method to update the coordinates to analyze large deformation problems. For plastic analysis, FLAC is simpler, and the plastic equation can be solved in one step, and the finite element is required to bring the stress of each element to the yield surface. In addition, FLAC can deal with any constitutive model without adjusting the solution algorithm, and many finite element programs require different solutions to deal with various constitutive models. FLAC in the solution build the model after the grid and the quality of the corresponding nodes in each explicit time.The node by the imbalance force needs to calculate the new rate and displacement, according to the constitutive equation yields a new stress or force as the initial imbalance force of the next step, so repeatedly the until model is stable, the imbalance force is small enough.

2.2 Calculate the total internal lining force

We can calculate the total lining internal force by the following formula.

$$\begin{aligned} M &= M_p + \sigma_h M_{\bar{\sigma}} \\ N &= N_p + \sigma_h N_{\bar{\sigma}} \end{aligned} \tag{1}$$

The calculation is listed in Table 1.

Table 1. Lining total internal force calculation table

Lining total internal force calculation table					
S	M_p	M_σ	σh	σhMσ	[M]
0	832.14868	-2.87320	210.71392	-605.42408	226.72461
1	680.24576	-2.48213	210.71392	-523.01899	157.22676
2	267.79530	-1.33376	210.71392	-281.04178	-13.24648
3	-282.96622	0.49891	210.71392	105.12641	-177.83981
4	-759.25453	2.71601	210.71392	572.30174	-186.95279
5	-1046.84423	4.34931	210.71392	916.46032	-130.38392
6	-1022.11162	4.49980	210.71392	948.17129	-73.94033
7	-640.50924	2.81997	210.71392	594.20663	-46.30261
8	15.91038	-0.06616	210.71392	-13.94093	1.96945

We can check the accuracy of the calculation as follows.

According to the vault cutting point, the relative rotation and relative horizontal displacement should be zero conditions to check.

$$\frac{\Delta S}{E_h}\sum\frac{M}{I}+\beta_a=0 \quad (2)$$

And

$$\frac{\Delta S}{E_h}\sum\frac{M}{I}=-575.444332\times10^{-6} \quad (3)$$

$$\beta_a=M_8\overline{\beta}_a=573.713183\times10^{-6} \quad (4)$$

Closed difference is as follows.

$$\Delta=\frac{573.713183-575.44332}{-575.44332}\times100\%\approx0.3\% \quad (5)$$

$$\frac{\Delta S}{E_h}\sum\frac{My}{I}+f\beta_a=0 \quad (6)$$

We can get the follow relationship.

$$\begin{aligned}&\frac{\Delta S}{E_h}\sum\frac{My}{I}=-4585.72677\times10^{-6}\\&f\beta_a=4622.75081\times10^{-6}\end{aligned} \quad (7)$$

Closed difference:

$$\Delta=0.8\% \quad (8)$$

2.3 Calculation of lining cross section strength

We can check a few control section.

When the vault is in section 0.

$$e=0.175820<0.45d=0.2025m \quad (9)$$

$$k=\frac{aR_abd}{N}=3.00991>2.4 \quad (10)$$

R_a -- Extreme compressive strength of concrete, we set $1.4\times10^4 KPa$ 。

When the vault is in section 7.

$$\begin{aligned}&e=-0.02882m<0.2d=0.09m,\\&\frac{R_abd}{N}=4.18163>2.4\end{aligned} \quad (11)$$

Eccentric inspection of the wall is in section 8.

$$e = 0.00122m < \frac{d}{4} = 0.1164m \quad (12)$$

Other cross-section eccentricity is less than 0.45d.

2.4 Internal force map

The internal force calculation results are plotted as a moment diagram M and axial force map N, shown in Figure 1.

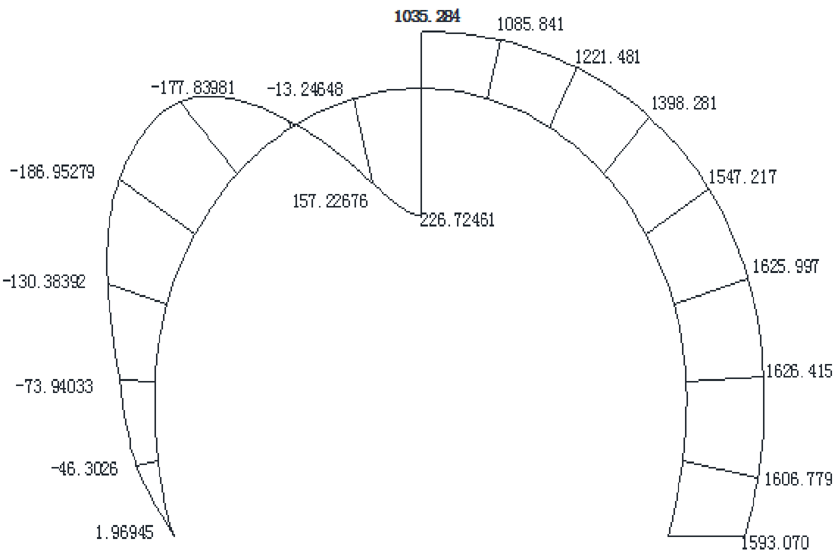

Figure 1. Lining internal force map

3. MODEL ESTABLISHMENT AND RESULT ANALYSIS

Since the average coal in this area is 3 degrees and relatively small, it can be considered as a horizontal formation approximately. Therefore, this paper simplifies the model to the excavation of horizontal stratum (Wang et al., 2013). Based on the geological conditions of 1302N working face, a numerical model has established as shown in Fig.2. The model size is 400m*500m*77.24m, and it is divided into 22,720 units and 25,704 nodes (Yu et al. 2014). The x-axis direction of the model is the inclination of the working face, the y-axis is the advancing direction of the working face, and the model is surrounded by a fixed boundary condition.The upper boundary is a free boundary condition, a compressive stress of 16.6 MPa is applied, and a compressive stress of 16.6 MPa is applied along the x and y directions of the model to simulate the horizontal stress (SUN et al. 2014).

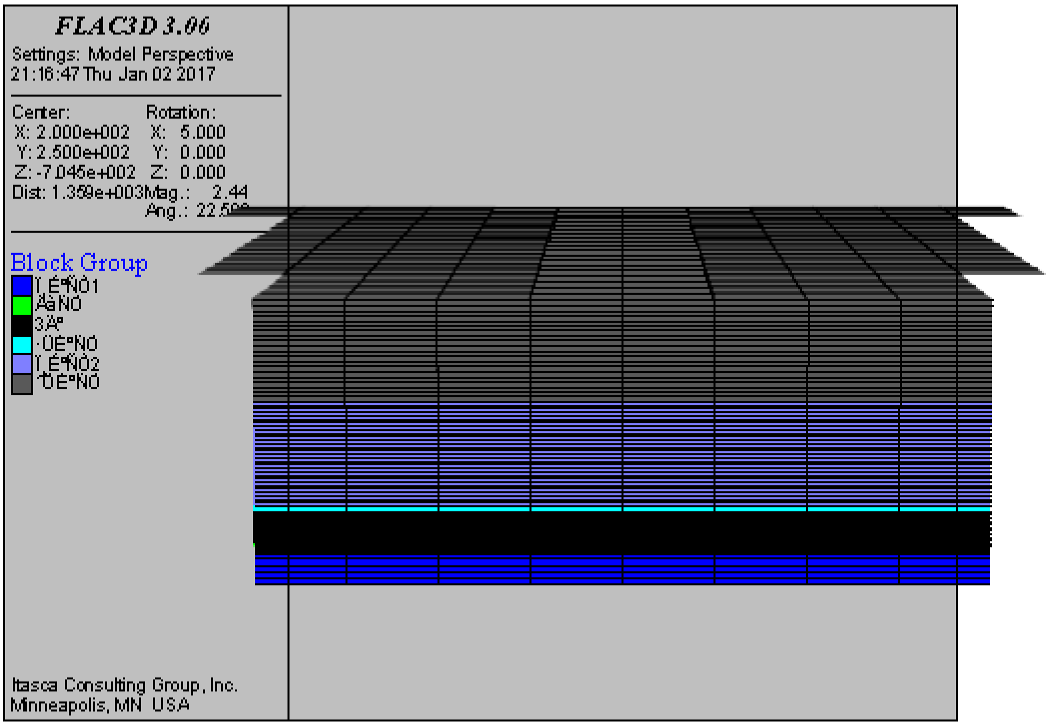

Figure 2. Highway tunnel model

3.1 Displacement contour

We can enter the displacement map in the analysis result. First, we must confirm the displacement in the X direction.

1) In the working directory tree,we select the post-processing form;

2) Double-click on the CS: Level IV Surrounding Rock Construction Phase Analysis> New Stage # 1-last step> Displacement> 'DX';

3) Select the post-processing data form in the form toolbar;

4) Click the ↓ button to the right of the result group button labeled 'New Stage # 1-last step.

5) Move the result group button to see the DX changes in each construction stage;

6) Click to close;

7) Click the result group button on the left side of the ↓ button to assign the result group to 'new stage # 1-last step';

Click Post Processing Data Sheet to the right for application; the result of displacement contour is in Figure 3.

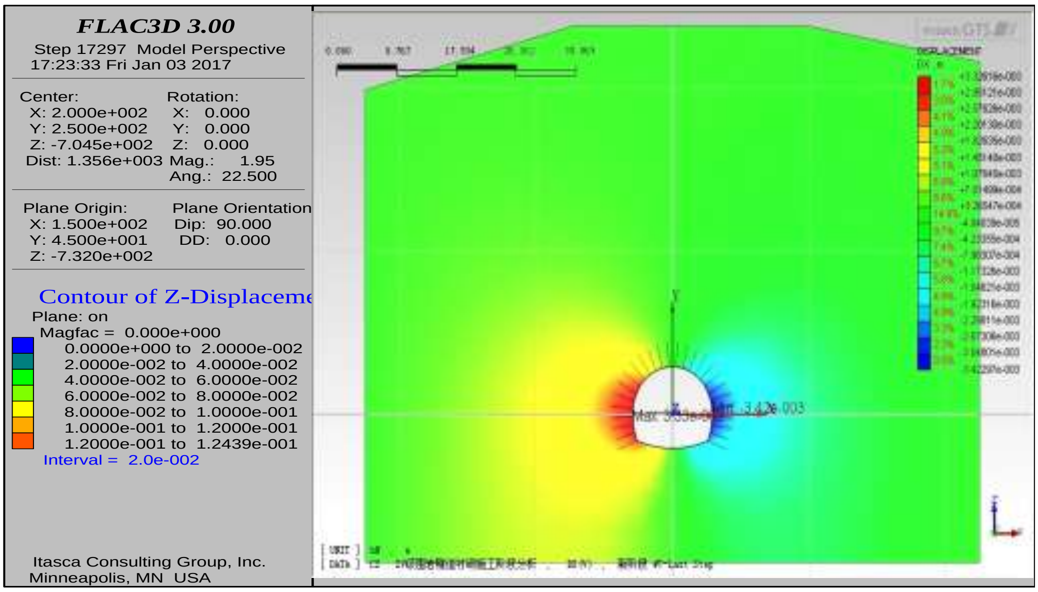

Figure 3. The result of displacement contour

3.2 Anchor shaft force map

Check the bolt axial force in the analysis results. View the truss Fx as the anchor is a truss unit.

1) Click the grid shape button on the left side of the deformation data in the Post-processing Data toolbar;

2) The choice of deformation;

3) Double-click on CS in the working directory tree: Surrounding Rock Construction Stage Analysis> New Stage # 10-last step>1D Element Force> Truss FX;

4) Click in the Properties window, Anchor shaft force map is shown in Figure 4.

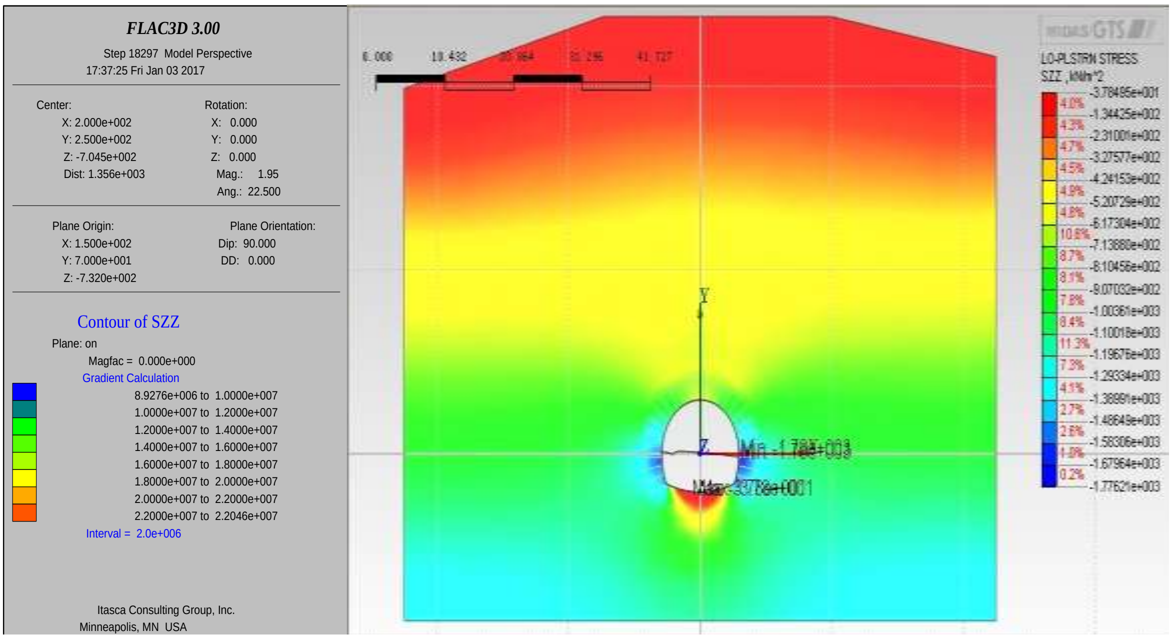

Figure 4. The result of Anchor shaft force map

5. CONCLUSIONS

The four-tunnel large-span highway tunnel span is large, the flattening rate is low, the construction process is complicated, and the multiple blasting excavations have caused many disturbances to the surrounding rock, especially the core soil force is particularly complicated and the feedback mechanism. It is the key to ensure the safety of large span tunnel construction. In this paper, according to the different construction process under the support system stress on-site monitoring test system analysis, the following conclusions are as follows.

Four-lane large cross-section large span tunnel section area has large span and low flat rate, complex construction process, multiple blasting excavation have caused many disturbances to the surrounding rock, especially the core soil force is particularly complex. The stress monitoring of the tunnel shows that the tunnel has been over. In the process, the stress conversion is very complicated. Only by monitoring and measuring the stress state of the supporting system, the design parameters and the construction process should be corrected. In the construction process of large-span tunnel, the large-scale changes in the stress of the supporting system caused by the step excavation on the right guide hole.The step excavation of the left guide hole and the step excavation on the core soil indicate that the above construction procedure. The influence of the supporting system is great, which is the key process of the stability control of the supporting system. Especially when the step is excavated under the steps of the left hole and the core, the stress conversion is frequent and the magnitude is large, which is the most important task of the construction stability control.

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