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Numerical simulation study on mechanical response of tunnel dynamic construction

Zhang Yi Hai

Department of Civil Engineering, University of Science and Technology Beijing, Beijing 100083,China

* Corresponding author: b20150015@xs.ustb.edu.

Abstract: Using Lagrange finite difference method, detailed simulation of Beijing Chengde Expressway Hejiagou tunnel (NATM) of the whole construction process was carried out, the tunnel stability was analyzed, and tunnel excavation and excavation under tunnel excavation face space mechanical effect were compared. Based on the analysis of the above simulation results, the mechanical distribution law of tunnel surrounding rock is obtained, which provides a scientific basis and technical guidance for tunnel.

1.INTRODUCTION

Tunnel rock mass is not only a general material, but also a geological structure. It has heterogeneous, unconnected, nonlinear and complex loading and unloading conditions and boundary conditions, which makes the tunnel rock mass mechanics usually cannot simply with analytical method of solving problem. The numerical simulation analysis has a wide applicability. It can not only simulate complex mechanics and structural characteristics of rock mass, but also analyze various boundary problems and construction process conveniently. Therefore, the rock mass mechanics numerical analysis method is one of the effective tools to solve the problem of geotechnical engineering. In this paper, using FLAC3D numerical simulation software, the finite difference method is applied to simulate the HeJiaGou tunnel NATM excavation construction process in detail. The space mechanical effect of Step-by-step excavation of tunnel is analysed. Through the numerical simulation, the tunnel surrounding rock mechanics in the process of distribution and the stress of tunnel lining is obtained. The construction of the tunnel provides a scientific basis and technical guidance .

2.THE CONSTITUTIVE RELATIONSHIP AND CALCULATION PARAMETER

In calculation model, the surrounding rock of FLAC3D is adopted to provide Mohr-Coulomb strength criterion, and the excavation uses the Null model. The initial support (shotcrete and anchor bolt) are adopted respectively in the cell Shell element and Cable element, the second support (lining) Zone unit is used to simulate, and the constitutive model is the Elastic. The initial ground stress field of rock mass considers the gravity stress and tectonic stress, and lateral pressure coefficient is 0.43.

Anchorage and shotcrete support is widely used in NATM. There are two kinds of the mechanics mechanism of support by rock bolt and shotcrete. One is to start with structural features, the shotcrete layer and part of surrounding rock are combined together and regarded as composite beam or bearing arch, while the bolt is regarded as suspension rod fixed in the surrounding rock and become a composite bearing structure. The other is from the point of view of surrounding rock and shotcrete support. The support from the surrounding rock pressure to the surrounding rock to pressure (the socalled supporting role or internal pressure) makes the hole on the indoor walls in triaxial stress state. So to improve the stress of surrounding rock to limit its deformation, at the same time it modifies the future support by rock bolt and shotcrete can improve the intensity of surrounding rock to improve the bearing capacity of the surrounding rock. The latter view for supporting the weak and broken rock cavern surrounding rock stability analysis is more suitable. When this method is used for numerical simulation, there are usually two methods:

One method is to improve the surrounding rock parameters of the anchorage zone to simulate the effect of the shotcrete support. There are two prominent problems with this approach. It is not possible to analyze the stress characteristics of bolt and shotcrete itself and its influence on surrounding rock after failure to determine the increase ratio of parameters in the reinforcement range.

Another treatment is to treat the bolt as a bolt element hinged at the node of the rock element. This kind of treatment results and bolt pull-out test results is similar. In this simulation, shell element is used in the spray layer and body element is used in the secondary liner. In the process of simulation, the rock mass, anchor and physical and mechanical properties of concrete material are shown in table 1, 2, 3.

Table1 Setting word's margins.

Category	label	density / 10^3 kg•m^{-3}	Elasticity modulus / GPa
shotcrete	C20	2.2	21.0
	C25	2.3	28.5

friction / °	cohesion /MPa	extension / MPa
28	0.7	2.5

Table2 Physical and mechanical parameters of bolt

Bolt type	length /m	diameter / mm	equivalent sectional area / m^2	Elasticity modulus/GPa	pulling resistance/kN
mortar Bolt	3.0	22	1.57×10^{-3}	210	250

Mortar stiffness /MN•m^{-1}•m^{-1}	Bond strength /MN•m^{-1}	Mortar peripheral /m
80.0	1000	1.0

Table3 Physical and mechanical parameters of concrete

Category	label	density / 10^3 kg•m^{-3}	Elasticity modulus / GPa
shotcrete	C20	2.2	21.0
	C25	2.3	28.5

Poisson's ratio	bulk modulus / GPa	shear modulus / GPa	thickness / cm
0.25	14.0	8.4	20
0.25	19.0	11.4	45

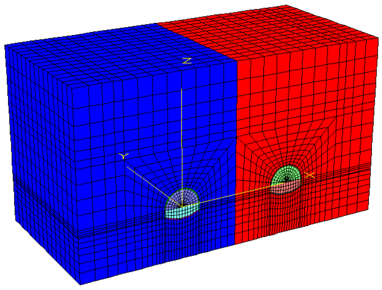

Figure 1 The calculation model of separated two - hole tunnel

3.NUMERICAL SIMULATION PROCESS

There are three main ways to excavate the separated tunnel: Two holes are dug in opposite directions and both holes are dug in the same direction and double hole and synthetic excavation and excavation in advance to a higher one double hole. Finally, this part is mainly a way of excavation. In each of the tunnel, the concrete simulation process is as follows:

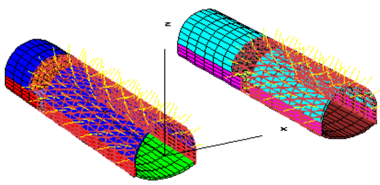

Figure 2 Excavation and support of tunnel

Boundary and initial conditions: The boundary around and at the bottom of the model is normal constraint and the surface is free. Under the action of gravity stress and structural stress, the initial stress equilibrium state is reached first. This "load first, after excavation" method overcomes the other software"load after excavation", the first defects. This is also the difference between underground structures and overground structures which are under stressed.

Excavation: In the simulation, the tunnel is pushed along the Y-axis direction, in which the left tunnel is dug only after 12 m ahead of the right tunnel. The upper step of the tunnel is the arch part of the tunnel, and the lower step is the straight wall and invert of the tunnel. The actual simulation was completely carried out in accordance with a step length of 4 m per day for the field construction. The right tunnel is dug in 12 steps, while the left tunnel is dug in 9 steps. The interval between the upper and lower steps is one step. After each step of excavation, the model is solved immediately, so that it is in a state of stress equilibrium.

Support: After the upper steps are dug, 20 cm thick concrete is sprayed on the arch part of the tunnel, and 3 m long mortar anchor rods are staggered; The first support for the tunnel is to spray concrete on the side wall after the lower steps are dug. In this simulation scheme, the secondary support of the tunnel lags behind the initial support of a step.

4.The results of numerical simulation

In the process of numerical simulation, a general program is written using FLAC3D embedded FISH language. As long as relevant parameters of the tunnel are input, the stress and deformation of surrounding rock can be simulated without support, primary support and secondary support. By comparing the simulation results of these three conditions, the mechanical response of tunnel structures is studied.

4.1. No support analysis of the calculation results

1）Deformation analysis

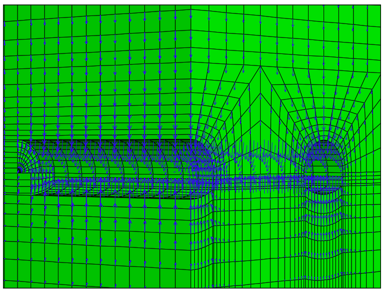

Figure 3 Displacement vector diagram of unsupported tunnel

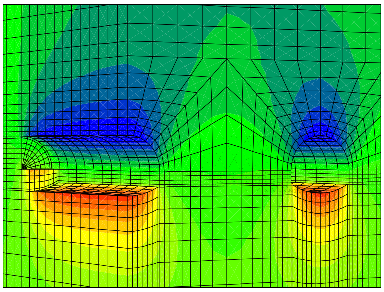

Figure 4 The vertical displacement of the contour map

The Figure 4 is the displacement vector diagram of the upper step of the right tunnel when it is excavated to 48 m. It can be seen from the figure that the deformation of surrounding rock of unsupported tunnel is all towards the hole. Along the axial direction of the tunnel, the amount of deformation increases with the increase of the excavation distance. However, when the distance is 5 times of the excavation step, the deformation is basically stable, and the maximum displacement is 1.89 cm. On the cross section of the tunnel, the tunnel vault, and the inverted arch deformation is opposite bigger. In the design of cross section it should be appropriately increased when the reserved deformation, the construction process should pay attention to the roof and floor heave. The deformation is relatively small at the vertical wall of the tunnel.

2）Stress analysis

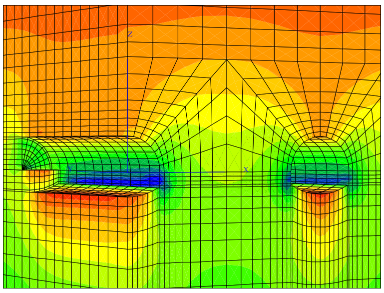

Figure 5 Minimum principal stress contour map

The minimum principal stress contour map shows that due to the excavation of the tunnel, the tunnel vault within the range of 45 ° and around each floor formed the stress release area, and from the arch foot straight waist to increased stress zone. The stress increase zone from the arch waist to the root of the straight wall is 2.0. It is suggested that the bolt with a length of not less than 3 m should be installed in the straight wall during tunnel construction. Along the axial direction of the tunnel, the stress state outside the range of 20 m from the palm is basically stable, and it is not affected by the advance of excavation. In addition, the net distance of 30 m makes the two tunnels in undisturbed zone avoiding the occurrence of stress superposition.

4.2 The calculation of the initial supporting the result analysis

For tunnel surrounding rock, the first support by improve the stability of the whole tunnel support by rock bolt and shotcrete. After the support, the steady settlement displacement of the tunnel vault decreases from 18.7 mm when there is no support to 16.4 mm after the initial support. The plastic zone of the tunnel is reduced by about 80%, but the change of stress state is not obvious, which indicates that the integrity of surrounding rock is strengthened .

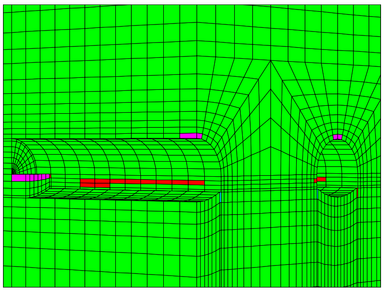

Figure 6 Plastic distribution diagram of primary support

4.3 Calculation results of the analysis of secondary support

Due to tunnel for permanent structures and according to the principle of the new Austrian tunnel construction method, the secondary lining of the tunnel for the modulus of concrete or reinforced concrete It shows that a supporting playsis the main role for safe.

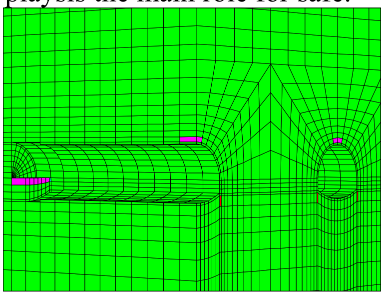

Figure 7 Plastic division layout of secondary support tunnel

After the initial supporting tunnel, there are still a range of plastic zone. After secondary lining, the displacement values of surface, arch, straight wall and invert are further reduced and the plastic zone is basically eliminated. It can be seen from the analysis that the primary support plays a major role in strengthening the stability of tunnel surrounding rocks, and the modular concrete only bears a small part of the load.

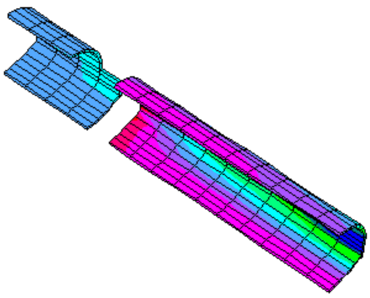

Figure 8 Minimum principal stress contour map of tunnel lining

The figure 8 shows the distribution of the minimum principal stress in the supporting structure. Since the compressive stress in FLAC3D numerical simulation is negative, the minimum principal stress is the first principal stress. The stress distribution law of lining structure can be clearly seen from the figure: The minimum compressive stress of the supporting structure occurred at the top arch and invert, about 0.5 MPa and then gradually transited to the maximum compressive stress at the straight wall, about 3.0 MPa. From the point of the results of numerical simulation, the straight wall and roof of the tunnel arch and inverted arch stress state is very different, straight wall and inverted arch junction to become a force of the weak link, this is because the two parts of the connection is not smooth mood. Therefore, special attention should be paid to the structural design and construction.

5.Conclusion

Three - dimensional numerical simulation was used and the distribution of stress, displacement and plastic zone of surrounding rock and structure in the construction of Hejiagou separated double tunnel is analyzed. Obtain the following conclusions：

1.After the tunnel was excavated step by step, the surrounding rocks of the arch and invert appeared great deformation and right wall deformation is relatively small. However, its stress concentration coefficient is large.

2.After a tunnel support, the deformation and plastic zone of the surrounding rock decreases obviously, but the stress changes little.

3.After the second lining of the tunnel, the deformation and plastic zone of the surrounding rock is further reduced, but it is not as effective as the reinforcement effect of shotcrete support. It shows that a supporting plays a major role on the stability of the tunnel.

4. The lining structure, uneven distribution of inner stress and compressive stress at the crown and the inverted arch is relatively small, and straight wall pressure stress is relatively large. The setting of secondary lining improves the bearing capacity of tunnel structure, restrains the expansion of surrounding rock plastic zone, restrains the development of tunnel peripheral displacement and improves the durability of tunnel.

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