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Stability Analysis on Surrounding Rock of Tunnel

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Abstract

The stabilization of underground engineering's surrounding rock is related to the safety of its construction and running. In this paper, it used finite element analysis method to introduce calculation model of the finite element deforming principle and the choice of calculation parameter. This paper relied on the diversion tunnel of Liu Ping hydropower station and based on related design parameter to study. It built the whole three-dimensional model, simulated complicated geological surrounding rock's stability of diversion tunnel on condition of excavation, run-time after the construction, seismic conditions. It indicated that construction support was more favorable for the stabilization of the tunnel than no support. It also indicated that the surrounding rock was main suffered compressive stress, and by lining can control the deforming effectively. By contrast the result to analyses, it obtained that the safety factors of the three work conditions were all greater than 1, and the stabilization of the surrounding rock was also good. It got the conclusion that the vertical deforming exceeded the horizontal deforming largely, so the result can provide reference for construction and structure design.

Keywords: Numerical simulation; Diversion tunnel; Surrounding rock; Stabilization.

1. Introduction

Underground engineering has broad prospects for development, and underground caverns are widely applied in several fields. For example, the fields include municipal engineering in the subway, tunnel traffic engineering, military engineering in the underground bunker, protective engineering, hydropower, nuclear power plant in the diversion tunnel. [1-5]

Generally, underground engineering surrounding rock instability refers to interfere with the production or safety breakage or deformation phenomenon, such as the cracking, collapse, spalling, floor heave, coming out of water of underground cavern, etc.

This paper relied on the diversion tunnel of Liuping hydropower station project, used three-dimensional finite element method to establish a three-dimensional model. It studied the stability of surrounding rock of diversion tunnel under poor geological condition in different working conditions, and the corresponding conditions of the stress and deformation characteristics of surrounding rock.

2. Overview and the three-dimensional model

Liu Ping power station uses a diversion type to develop. A diversion tunnel is arranged at upstream, three pressure pipes are disposed at downstream, the surge chamber is arranged between the diversion tunnel and the pressure pipes. According to the results of geological survey and exploration data, upper part and dome of surge chamber locate in rock of weak weathered and weak unloading; the stability of surrounding rock is poor. The maximum flow of the diversion tunnel is $240m^3/s$, and the length of the tunnel is 11km.

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The visualization model that have not excavated is shown in Fig.1. The mesh generation of three dimensional is shown in Fig.2. The underground cavern region uses hexahedron, and the surrounding rock region uses tetrahedral elements.

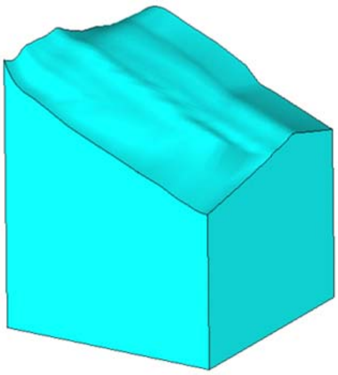

Fig.1 Visualization model

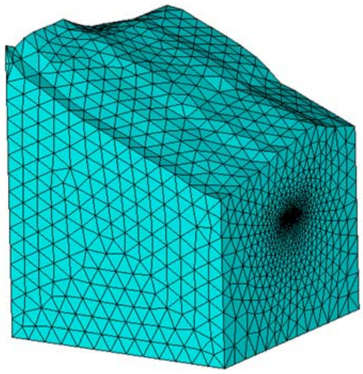

Fig.2 Mesh division of numerical calculation

3. Overview and the three-dimensional model

3.1 Calculation software

FALC^{3D} is the abbreviation of Fast Lagrangina Analysis for Continuum, meaning as continuous medium fast Lagrange analysis way. FALC^{3D} software is famous numerical simulation software. The basic principle of FLAC^{3D} is similar with the discrete element program, but it applies the condition of node displacement's continuity. It can be used for large deformation analysis of medium, and has strong before and after processing function. FLAC^{3D} can simulate the rock, soil and other materials of large deformation, and plastic flow. [6-8]

3.2 The finite deformation theory

(1) The mathematical model description.

The mechanical characteristics of object deduced by the Newtonian mechanics. According to the definition of stress, Newton theorem, and ideal of material properties constitute equation. Using Lagrange Tcha formula and particle characteristics is defined by the vector element of x_i, u_i, v_i and dv_i/dt, they represent the spatial position, particle deformation, velocity and acceleration respectively. And specified tensile or extension direction is positive.

(2) Stress.

Medium point stress state is represented σ_{ij} by symmetric stress tensor. In the surface direction of [n], drawing vector is defined by Cauchy formula as follow,

$$t_i = \sigma_{ij} n_j \quad (1)$$

(3) Strain rate and rotation rate.

Assuming the particle moving as velocity [v], and in micro time dt, the medium produce a micro strain $v_i dt$. The corresponding strain rate tensor unit can be displaied as follow,

$$\xi_{ij} = \frac{1}{2}(v_{i,j} + v_{j,i}) \quad (2)$$

Without considering deformation rate ζ_{ij} caused by tensor, a volume element experienced the moment rigid body deformation that depends on the transmission speed [v] and angular velocity, it can be displaied as follow,

$$\Omega_{ij} = -\frac{1}{2} e_{ijk} \omega_{jk} \tag{3}$$

In above, e_{ijk} is a permutation symbol, $[\omega]$ is rotation rate can be displaied as follow,

$$\omega_{ij} = \frac{1}{2}(v_{i,j} + v_{j,i}) \tag{4}$$

(4) The motion equation.

Cauchy motion equation can be displayed as follow,

$$\sigma_{ij,j} + \rho b_i = \rho \frac{dv_i}{dt} \tag{5}$$

In above, ρ is the material proportion, b_i is object force of unit material, $d[v]/dt$ is velocity of the material derivative. The above formula is the motion state of particle at the action of external force, In the state of static equilibrium, the acceleration is 0. The formula (5) can be illustrated as follow,

$$\sigma_{ij,j} + \rho b_i = 0 \tag{6}$$

(5) The boundary and initial conditions.

The boundary condition consists of the following components: the drawing vector that imposed by on the boundary, the movement velocity of particle, the body force. At the same time, the initial stress state of object also should give set.

According to the Hammersley-Clifford theorem, the random field ***X*** is a MRF on S with respect to a neighborhood system if and only if its distribution on S is a Gibbs distribution. The MLL model, a Gibbs distribution, can be specified by the joint probability,

$$P(X = x) = \frac{1}{Z} \exp\left\{ -\sum_{c \in \Lambda} V_c(x) \right\} \tag{7}$$

where Z is a normalized constant, and $V_c(x)$ is the clique potential over the clique c. Spatial dependencies characterizing the texture are captured in the potential functions $\{V_c(x), c \in \Lambda\}$. For the nonsingle-site clique, the clique potential is

$$V_c(x) = \begin{cases} \beta_c & x_s = l, s \in c \\ -\beta_c & otherwise \end{cases} \tag{8}$$

where β_c is the potential parameter for the clique c. In real segmentation problem, taking the parameter estimation and segmentation performance into consider, we only include pair-site cliques in the energy function. For the spatio-temporal neighborhood system, there are spatial cliques, temporal cliques, and spatio-temporal cliques. Thus the clique potentials are defined with the parameter β_p for spatial pair-site cliques and β_t for other cliques. Then, the parameter $\theta_X = \{\beta_p, \beta_t\}$ determines the MLL model.

4. The calculation parameter and condition introduction

4.1 Calculation method, procedure and parameter selection

Using the FALC^{3D} software established the numerical analysis model, and calculated by finite element deformation theory. According to the engineering geological data, it can be established three-dimensional numerical model of Liu Ping Hydropower Station surge chamber area. Firstly according to the surge chamber area terrain conditions to build model that excavated before, then according to the calculation conditions to apply corresponding load respectively.

According to the reference value of standard and the suggested value of design, selected physical and mechanical parameters of surrounding rock, the physical and mechanical parameters of steel, and parameters of concrete used in the calculation. The physical and mechanical parameters of materials are shown in Table 1.

Table 1 The mechanical parameters of surrounding rock and concrete

Material category	Density (kN/m^3)	Deformation modulus E_0 (GPa)	Poisson's ratio μ	Internal friction coefficient f' (°)	Cohesion c' (MPa)	Tensile strength σ_t (MPa)
Class IV of surrounding rock	26	3.0	0.35	0.55	0.30	0.27
Grouting area of surrounding rock	26	4.5	0.33	0.63	0.40	0.37
Sprayed concrete of C20	24	25.5	0.167	—	—	—
Steel arch and bolt	78	200.0	0.30	—	—	—

4.2 The calculation condition introduction.

For the stability calculation of surrounding rock excavation, it considered the diversion tunnel under the conditions of excavation and no support, excavation and support, and earthquake condition. It analyzed the tunnel stress, deformation, and the stability safety degree.

As to the stress analysis of diversion tunnel after excavation, it did not consider the external water and rock pressure that acted on the lining.

The seismic intensity of the area was VIII degrees, and the seismic peak acceleration was 0.25g. In accordance with the response spectrum, it inputted the seismic wave load to the surge chamber along the horizontal direction uniformly.

As to the stability analysis under seismic, it mainly analyzed stress, deformation, and the stability safety degree under the condition that after support, without internal water.

5. Analysis of the calculation results

Because of the limited space, this paper only lists the results of typical figure. The calculation results of Zdisp and zones of surrounding rock under the conditions of excavation and no support, excavation and support, and earthquake are in fig.3 to fig.8. It indicated that the maximum vertical displacement were 22mm, 4mm, 45mm respectively. Under the three conditions, the vertical displacement performed as the roof's subsidence and the bottom's rebound deformation, and the bottom's rebound deformation was bigger than the roof's subsidence. The safety coefficient of the wall were 1.0~1.5, 1.5~2.5, 1.0~2.0, and the safety coefficient was biggest under the condition of excavation and support. The calculation results under different conditions are in Table 2. The displacement vector of the typical section under the excavation and no support condition is in Fig.9.

From the calculation results and Table 2, we can get 6 points analysis conclusions.

(1) Under the three conditions, the surrounding rock of the diversion tunnel is mainly affected by stress. The maximum principal stress appears in the two side walls, the maximum and the minimum principal stress have little difference, there doesn't appear concentration phenomenon to tensile stress.

(2) Under the three conditions, the horizontal displacement of the deformation appears to inside of the tunnel. The horizontal displacement of the left side wall is little bigger than the right side walls.

(3) The horizontal and vertical displacement of the diversion tunnel is all very big under the conditions of excavation and no support and earthquake. Under the earthquake condition, vertical displacement is up to 45mm, but the diversion tunnel is in safe state.

(4) Under the excavation and support condition, and after the lining, the horizontal displacement of the maximum can reach 0.8mm and the maximum vertical displacement can reach 4.0mm. It controls displacement and deformation of the surrounding rock effectively through lining.

(5) Under the three conditions, the safety factors are all greater than 1; it indicates the tunnel surrounding rock's stability is good. After support, the lining structure of surrounding rock's safety factors is between 1.5 and 2.5. It indicates that support can enhance surrounding rock's stability obviously.

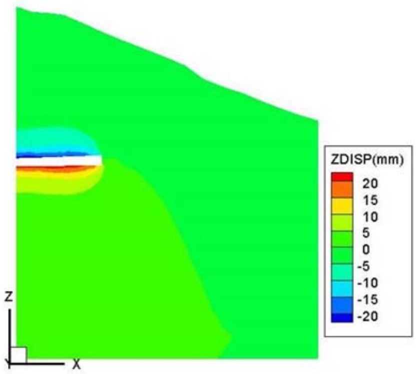

Fig.3 Zdisp of excavation and no support condtion

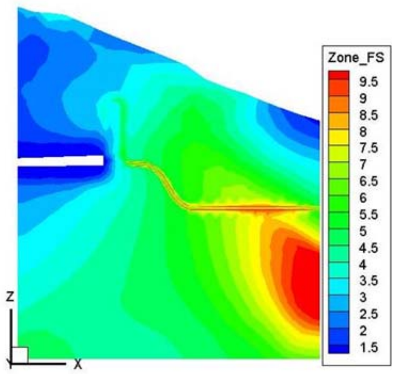

Fig.4 Zone_FS of excavation and no support condtion

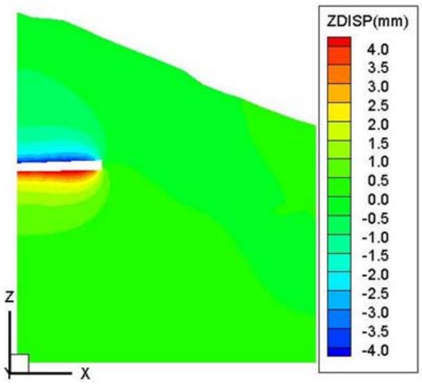

Fig.5 Zdisp of excavation and support condtion

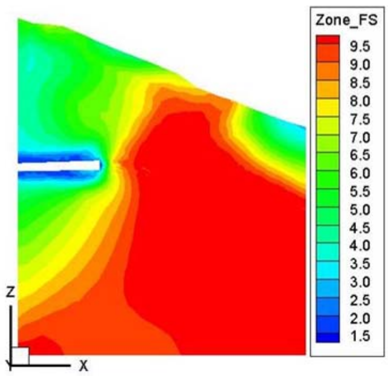

Fig.6 Zone_FS of excavation and support condtion

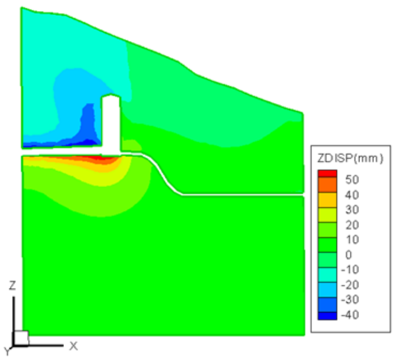

Fig.7 Zdisp of earthquake condtion

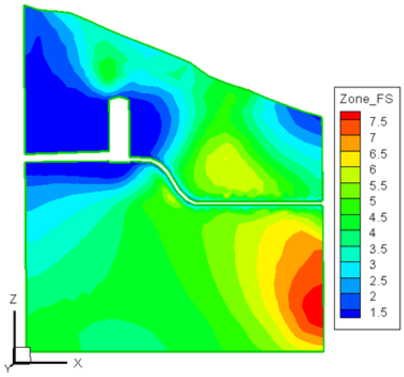

Fig.8 Zone_FS of earthquake condtion

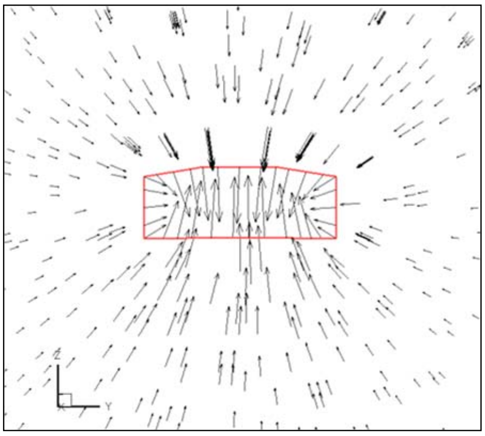

Fig.9 Result of the displacement vector of the typical section

Table 2 Calculation result of different condition

Calculation condition / Calculation parameters	excavation and no support	excavation and support	earthquake condition （VIII degrees）
The maximum principal stress (MPa)	-（8~9）	-（9~10）	-（8~9）
The minimum principal stress (MPa)	-（3~4）	-（1~3）	-（3~4）
The maximum horizontal displacement (mm)	9	0.8	20
The maximum vertical displacement (mm)	22	4	45
Safety factor	1.0~1.5	1.5~2.5	1.0~2.0

(6) From the calculation results of the displacement vector of the typical section, we can see that the displacement vector is obviously thicker in the surrounding tunnel, and the vector at the bottom is greater than that at the top.

6. Conclusion

(1) In the whole process of numerical calculation, the vertical deforming exceeded the horizontal deforming largely. Under the excavation and no support condition, vector value at the bottom is greater

than at the top. Therefore, in the construction and operation process, it needs to strengthen the safety monitoring on the top and the bottom of the diversion tunnel. [8-10]

(2) In the process of finite element analysis, it can draw scientific conclusion through the reasonable selection of calculation parameters and analysis model.

(3) Surrounding rock of the diversion tunnel is mainly affected by stress; the lining can effectively control the deformation of surrounding rock.

(4) It can enhance surrounding rock's stability effectively by support.

(5) Through the simulation of excavation and support to the poor geological conditions of diversion tunnel and the stability evaluation of surrounding rock, it can provide reference for construction and structure design.

References

[1] Singh P K. Blast vibration damage to underground coal mines from adjacent open-pit blasting. International Journal of Rock Mechanics and Mining Sciences, 2002, 39(8): 959-973.

[2] Hashash Y, Hook J J, Schmidt B. Seismic design and analysis of underground structures. Tunnelling and Underground Space Technology, 2001, 16(4): 247-293.

[3] Maier G, Jurina L, Podolak K. Model Identification Problems in Rock Mechanics. 1977.

[4] Hatzor Y H, Arzi A A, Zaslavsky Y, et al. Dynamic stability analysis of jointed rock slopes using the DDA method: King Herod's Palace, Masada, Israel. International Journal of Rock Mechanics and Mining Sciences, 2004, 41(5): 813-832.

[5] Eberhardt E. Numerical modelling of three-dimension stress rotation ahead of an advancing tunnel face. International Journal of Rock Mechanics and Mining Sciences, 2001, 38(4): 499-518.

[6] Eberhardt E, Stead D, Coggan J S. Numerical analysis of initiation and progressive failure in natural rock slopes-the 1991 Randa rockslide. International Journal of Rock Mechanics and Mining Sciences, 2004, 41(1): 69-87.

[7] Kuhlemeyer R L, Lysmer J. Finite element method accuracy for wave propagation problems. Journal of Soil Mechanics & Foundations Div, 1973, 99 (Tech Rpt).

[8] Itasca Consulting Group, Inc., FLAC 3D (fast Lagrangian analysis of continua in 3 dimensions) user's manual (Ver 2.00), USA: Minneapolis, 1997, 132-213.

[9] Lin H, Cao P, Li J, et al. Automatic Generation of FLAC~ (3D) Model Based on SURPAC. Journal of China University of Mining & Technology, 2008, 3: 013.

[10] Wieland, Martin, Qingwen Ren, and John SY Tan, Eds. New Developments in Dam Engineering: Proceedings of the 4th International Conference on Dam Engineering, 18-20 October, Nanjing, China. Taylor & Francis, 2004.