The effect of the rheological stability of a dam tunnel' surrounding rock linking to different buried depth

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ABSTRACT: This paper is based on a diversion tunnel excavation project, the rheological stability analysis was carried out on the excavation process. Due to large buried depth, tectonic stress and stress have influence on the safety of engineering. Based on the theory of unloading rock mass and rock rheology theory, and applied two software ANSYS and FLAC to the surrounding rock of tunnel of different buried depth before and after applying lining in order to analyze the stress and displacement of the plastic zone. The results showed that in the process of excavation of tunnel hole weeks, it is necessary to consider unloading rock mass action. The influence of buried depth of tunnel surrounding rock near point displacement cannot be ignored. When the tunnel after excavation reaches a certain depth, if continue to excavate, we need to strengthen the strength of the lining.

INTRODUCTION

With the deepening of the engineering construction in our country, more and more water and electricity and geotechnical engineering projects are confronted with the problem of high ground stress and buried depth, deep underground cavern excavation and late stability problem is very important. Zheng et al [1],using finite element strength subtraction and combining the method of model test and numerical analysis, he got the position of failure surface of tunnel surrounding rock and the safety factor of stability of surrounding rock; Wu et al[2] based on a practical project and found the classification method of the failure modes of deep buried tunnel surrounding rock, which had a certain guiding role for similar projects; Wu et al[3] analyzed the process of excavation and support of the secondary hydropower station diversion in Jinping adopting elastic-plastic finite element method, and expounded the scope of plastic zone, stress distribution and variation law of surrounding rock mass and the deformation law of surrounding rock in the process of excavation and supporting system in the project. Through experimental study of shear rheological characteristics of containing the rigid structure of the marble, Zhu et al[4] proposed the creep equation and applied it to engineering practice, which is a case combining indoor rheological test with specific engineering example.

It can be seen that most of the research is aimed at a specific engineering, however, many models and parameters of hard rock cannot be applied in this project because of the difference of geological conditions and rock types. So basing on the theory of unloading and rheological theory[5], this article analyzed the stability of tunnel surrounding rock under different buried depth, considering the influence of unloading effect under high buried depth, which can be a reference for specific engineering.

basic theory

Unloading rock mass theory

Rock mass is the final product after a long rock movement and tectonic action, different degree of residual stress of rock mass was remained by added loading constantly in this process. With the increase of buried depth, residual stress will also increase. If the excavation continues, rock mass unloads,

For example, hoop stress s_q of round underground caverns concentrates when releases load after the excavation, and radial stress s_r reduced locally, which is also further releasing process of residual stress. Rock damage accumulating led to its mechanics parameters deteriorating.

The analysis of tunnel rheological stability shown in Figure 1 defines the degradation parameters considering the release of residual stress, which has a guiding value for related project.

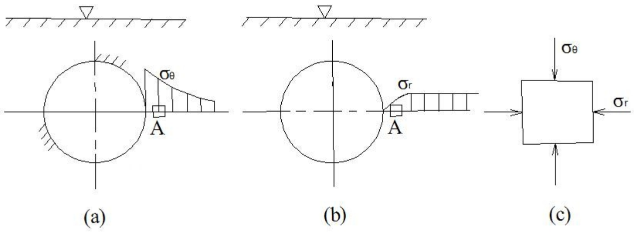


Figure 1. The unloading stress analysis chart of circular tunnel.

Rock rheological theory

Many problems of the stability of geotechnical engineering are closely related with the change of time, in order to ensure the long-term stability of the geotechnical engineering and safety, people pay more and more attention to the rheological study. This paper studied the excavation of tunnel in rock mass, rock rheological problems was valued. According to rock rheological problem, there are mainly eight typical component rheological models: Maxwell, Kelvin, generalized Kelvin, ideal viscoplastic, Bingham, Butyl- Thomson, the original in the west, Burgers. Every kind of rheological model has its own rheological state, and the rheological model has its applicable scope. So we should choose corresponding rheological model for the rock involved in this project. Quartz mica schist mainly consists of the composition of the project in the excavation section, which belongs to the category of soft rock, In order to get rheological properties of the rock, we made sampling from field and got 50mm x 100mm standard specimen. Acoustic test methods was used to exclude larger discrete sample. It was shown in Figure 2. Different model has different application scope, and Burgers model can have attenuation and steady creep characteristics under the condition of high stress and low stress. So Burgers model was preliminary selection of the corresponding rheological test sample inspection.

Figure 2. The prepared sample of indoor test.

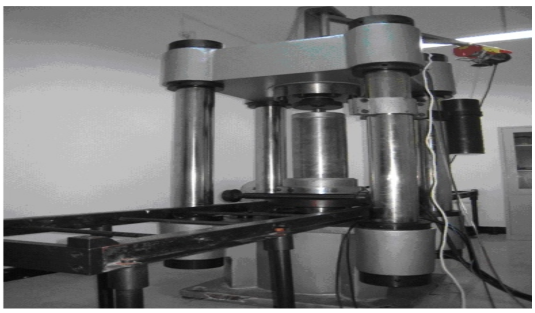


Figure 3. The RLW-2000 rock three axial rheology test machine.

In the light of the quartz mica schist, we conducted loading the rheological and triaxial unloading confining pressure rheological test. It is shown in Figure 3 and inverse the test data through the Burgers model. Bolzman linear superposition and regression method is used respectively to quartz mica schist of triaxial creep curves are unconstrained optimization regression, and got all levels corresponding burgers creep model parameters. Comparing the curve of rock rheological test data and use the burgers inversion, fitting degree is higher. So finally choose Burgers model later rheological simulation analysis. Burgers model as a typical component model, composed of elastic element, viscous components and plastic components, is a kind of suitable for viscous, viscoelastic and unstable creep, viscoelastic plasticity. Constitutive equation is as follows:

$$\ddot{s}+(\frac{k_2}{h_1}+\frac{k_1}{h_2}+\frac{k_1}{h_1})\dot{s}+\frac{k_1k_2}{h_1h_2}s=k_2\ddot{e}+\frac{k_1k_2}{h_1}\dot{e} \quad (1)$$

$$e=\frac{s_0}{k_2}+\frac{s_0}{h_2}t+\frac{s_0}{k_1}(1-e^{-\frac{k_1}{h_1}t}) \quad (2)$$

Rheological curve can be seen in the formula above. Burgers equation mainly consists of four parameters (sticky elastic parameters), modulus of elasticity (sample), (constant strain rate coefficient of viscoelasticity creep stage), (rock steady uniform rheological phase flow rate) control. The rheological test data will be averaged (only inversion result list is listed). It is shown in Table 1.

Table 1. The integrated burgers rheological parameters obtained from the test.

The parameter types	The axial creep model parameters			
	k_2/MPa	h_2/MPa*h	k_1/MPa	h_1/MPa
Add axial compression rheological (general average)	1.74E+03	9.86E+07	2.54E+05	2.57E+08
Ding confining pressure rheological (general average)	5.01E+03	2.12E+07	4.17E+04	1.19E+07

Calculation mode

Cross section shape of the tunnel is round, which includes two parallel tunnel, the hole diameter is 16m.

In order to analysis changes of the tunnel under different buried depth in the long-term stability before and after the reinforcement, and get the lining of the tunnel after excavation, according to need of the engineering, we consider four different embedment depths the 600m and 800m, 1000m and 1200m. The calculation model generates through ANSYS combined inversion of in-situ stress in the 3D model under different buried depth profile. And then divide the model adopting tetrahedral mesh. The unit number of calculation model under different buried depth and section size ranged from 10000 to 15000, in which draw the part of tunnel surrounding meshing thick, and the other parts of the grid relatively sparse. It is shown in Figure 4 and Figure 5.

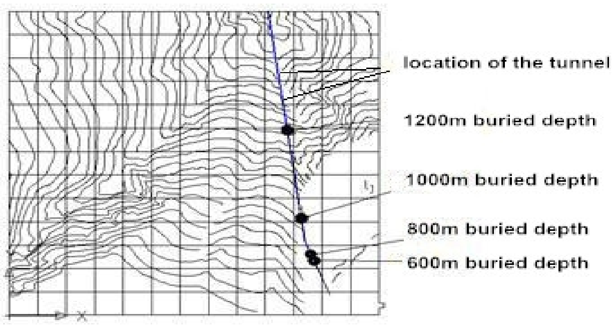


Figure 4. The map of Tunnel in different depths.

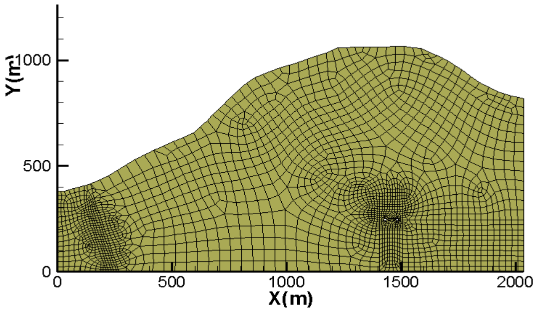


Figure 5. The rheological model at the buried depth of 800m.

Calculation results and analysis

To test the necessity of unloading effect in this paper, the article considered two cases of unloading and unloading of four buried depths before the rheological calculated. when considering unloading, tunnel surrounding rock stress turns larger; Poisson's ratio and cohesion strength turns weak, instability will be more likely to happen.in order to simulate the effect of unloading on tunnel, mechanics parameters of rock mass of a certain distance in the excavation of tunnel surrounding in the process of calculation was weaken. the maximum vertical displacement of tunnel t the top of surrounding rock before lining was analyzed by contrast .It is shown in the figure below. The diagram shows that when buried depth increases, the deformation of tunnel surrounding rock goes more and more big, because tectonic stress and gravity stress increased with the buried depth accordingly, and the stress of the tunnel surrounding release in a short time because of the effect of unloading in excavation. Rock mass produces unloading damage as a result of the damage of surrounding rock in the process of excavation. What shows in the following picture is that the displacement of roof does not change significantly with the increase of buried depth without considering unloading. The change characteristic of increase in stress caused by buried depth on tunnel rock displacement can't be reflected. So it is very necessary to consider the effect of unloading and weaken strength parameters correspondingly in the process of the excavation of tunnel hole weeks. As is shown in Figure 6

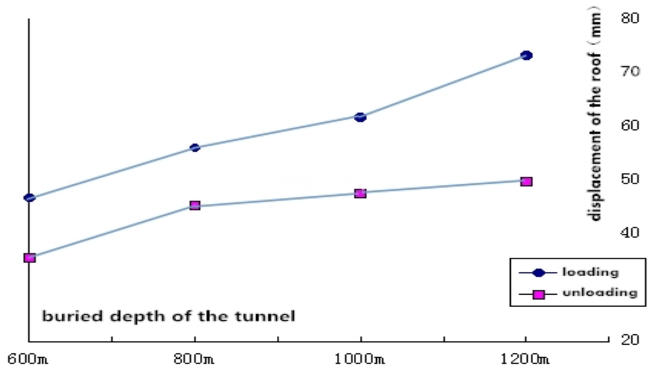


Figure 6. The maximum displacement of roof under unloading and loading effect.

To verify the feasibility of rheological parameters, article based on the tunnel face of specific constraint under 1200m as the modeling and analyzed the fit between measured displacement and creep displacement calculation in particular. Diameter of test hole was 8m, similar to water diversion hole depth, same to the direction of excavation, and the model area was defined loading and unloading. Considering the unloading effect in process of tunnel excavation, its stress state is unloading, which is same to mechanical characteristics of unloading confining pressure in the test of rheological. therefore, take the rheological parameters of confining pressure tested above in this section of the area, the other areas mainly affected by tectonic force and gravity stress, its stress state was loading, therefore, take rheological parameters of rheological test of loading for this area. And got displacement change trend of the point near the edge of tunnel location during four stages in excavation, natural deformation, expansion of digging, natural deformation in test hole section.It is shown in Figure 7.

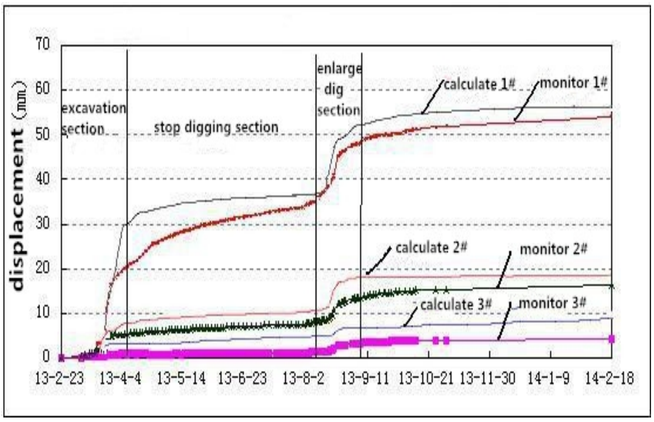
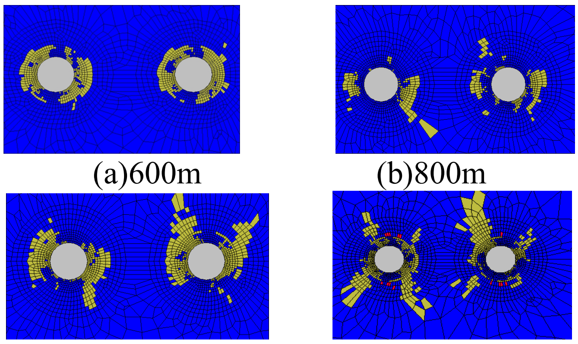


Figure 7. The observed displacement compared with the trend of rheological figure at a section.

A monitoring cross section of test hole at 1200m depth are numerically simulated, the result finds that the displacement of test hole in the first month after excavation is the most, but the rheological value calculate is slightly larger, for the section of excavation is soft rock and article does not consider the construction process of lining of tunnel displacement in the early influences, but the curve calculated in the four phases of test holes fit better with measured curve, which illustrates that the rheological model used in calculation and the inversion mechanical parameter are of good reliability, and after contrasting the displacement curve of subsequent digging segment, the author find that the displacement of the monitoring is convergent, which is in line with the actual situation. In the process of construction, water diversion hole reinforcement can be divided into initial lining and secondary lining, and the secondary lining time should begin after when the key hole reaches displacement amount of reserve requirements, So modeling for the diversion tunnel is calculated later, displacement change of key point in excavation in a long period of time after excavation.

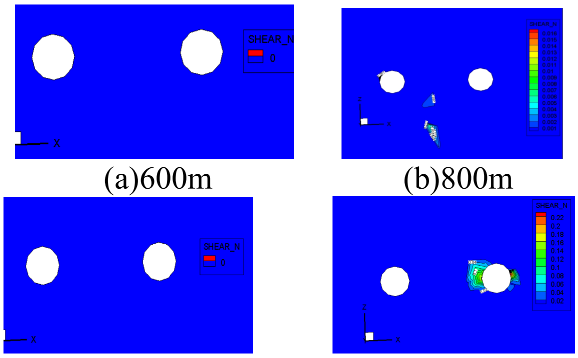
We choose to apply the secondary lining at the time when the displacement reaches 80% of the total displacement, the contrast of plastic zone between before and after applying lining is shown in Figure 8 and Figure 9:



(a)600m (b)800m

(c)1000m (d)1200m

Figure 8. The plastic zone of different depth without lining.



(a)600m (b)800m

(c)1000m (d)1200m

Figure 9. The plastic zone of different depth with lining.

The growth rate of horizontal displacement of tunnel without lining increases slowly when buried depth is less than 800m

When buried depth increases to more than 800m, the rate has an obvious increase, the reason of which may be that the surrounding rock stress experienced the process of "pressure arch" ranging from being into non-being with the buried depth being from shallow to deep, resulting in small change rate. The effect of pressure arch is no longer apparent when buried depth continue to increase.

Contrasting the plastic zone of tunnel before and after the lining, the author found that tunnel has larger plastic zone around the tunnel before lining, which shows that lining has obvious limit to the development of plastic zone.

When buried depth is more than 800m, stress of all directions increases with the increase of buried depth. So the plastic zone turns larger; the plastic zone of 600m buried depth mainly concentrated in the area of the circular around the tunnel. The influence of pressure arch under this buried depth is obvious, "pressure arch" releases vertical force along the circular hole, which makes the stress concentrate around the hole and plastic zone turns big. When tunnel buried depth reached 800m, for vertical stress is large, the influence of pressure arch is no longer obvious, with the increase of buried depth, plastic zone distributes gradually as "X" type. The horizontal displacement increase gradually, which shows that lateral deformation of cave walls will gradually become the main control factors affecting the stability of tunnel under high buried depth. After lining, the plastic zone around the tunnel under high buried depth has been obviously controlled, the plastic zone reduced obviously. Effect of the lining is obvious, which is the same with conclusion. a smaller range of plastic zone appears at 1200m deep, due to the increasing of buried depth, the effect of unloading around cavern increase, lining restrains the development of plastic zone, which led to no larger plastic zone around, but the strength of the lining should be strengthen when the excavation of the tunnel is at greater depth and it can be seen that from the 1200m depth of the plastic zone, it appears mainly in horizontal direction of the tunnel, therefore, under this embedded depth, there is need to monitor and support the displacement.

Conclusions

(1) By contrasting the displacement of tunnel roof loading and unloading, we found that it is very necessary to consider the unloading effect of the surrounding rock of tunnel in the process of tunnel excavation.

(2) Due to the effect of cavern excavation and unloading, the tunnel experiences the process of the pressure arch changing from appearing to disappearing with the development of buried depth from shallow to deep .when buried depth small, tectonic force and gravity lesser, the support effect of pressure arch on the upper tunnel surrounding rock is obvious; When the buried depth, tectonic force and gravity action increases, the effect of pressure arch is no longer apparent.

(3) In the process of the tunnel buried depth ranging from shallow to deep, the displacement in the horizontal direction is bigger and bigger, the hole lateral deformation will become one of the main factors to the stability of deep buried tunnel.

(4) The displacement near surrounding rock of the tunnel before and after lining changes obviously,

the plastic zone appears in the 1200m of tunnel on the right side. If buried depth of late tunnel excavation increases, it need to strengthen the strength of the lining.
(5) Due to the influence of high in-situ stress, the maximum point in the calculation is not in the tunnel vertices, but in the right side of the partial position

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