Study on the Treatment Timing of Large Deformation of the Tunnel in Swelling Rock

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Abstract. When large deformation of the tunnel occurred in the swelling rock, the large deformation treatment will not only greatly delay the construction time, but also lead to instability or even collapse of the tunnel. Selecting the reasonable timing for large deformation initial support replacement can solve this problem effectively. Based on the LiRang tunnel, the deformation and stress of the tunnel in anhydrite were analysed by FLAC software after excavation. Then replace the deformed first liner at different vault settlement value. The displacement and stress of surrounding rock were analysed when the model reaches equilibrium state again. The results showed that stress concentration at the arch wall and arch foot of the tunnel, and the stress release at the vault and invert is very large after excavation. If the large deformation was treatment when the crown settlement of the tunnel reaches 90% ~95%of the final predicted settlement value, the tunnel deformation and the final stress state could be in a small value. This study can provide a reference for the treatment of large deformation in the swelling rock tunnel.

1 Introduction

Swelling rock is a kind of rock that the water content and the volume increases with time after the physical and chemical reaction with water. In the tunnel engineering, the swelling rock produces large swelling force when it meets water, and causes continuous deformation of rock mass. After applied the first liner, the restrained swelling heave leads to the development of swelling pressure that damages the tunnel lining, even lead to the tunnel collapse. The hydraulic conductivities in the rock mass around the tunnel can increase greatly due to tunnelling; it can be increase by up to 6 orders of magnitude compare to the intact rock [1, 2]. In recent years, the tunnel engineering hazards caused by swelling rock increased sharply with the rapid development of highway and railway construction. Marco Barla[3] introduced a laboratory-based approach to predict the swelling behaviour around a tunnel through numerical simulation. Dehnavi R N etc.[4], Butscher C etc.[5], Pimentel E etc.[6] have studied the deformation mechanism of swelling rock, and have found that the probability of large deformation can be greatly reduced by the measurement of implement rock anchors, reinforced lining, mechanical resistance, reducing the swelling pressure by allowing deformation et. al[7-9]. However, due to the complex condition of the surrounding rock, large deformation events caused by swelling rock still often occur. Making repeated rehabilitation work necessary. Although scholars have also studied the treatment methods of large deformation tunnel, few studies have been done on the treatment timing. The usual method is to apply temporary support to reinforce the deformed first liner, then replace the deformed first liner when the deformation of the tunnel gradually decreases and tends to be stable [10].

However, this treatment method has the following disadvantages: (1) after applied the temporary support, in the deformation late stage of surrounding rock, the deformation rate decreased slowly. It needs a long period to the rock mass getting stable, for example, the deformation rate become less than 3.0mm/d. This will seriously delay the construction schedule. (2) As the swelling rock deformation, the strain energy become very large under the constraint of strong support, and the swelling potential become very high. If remove the support, the sudden stress release easily causes the tunnel instability. Therefore, it is necessary to study the timing of replacement of large deformation, so that the deformation of tunnel can be the smallest during the replacement process and the replacement, and the stress become the lowest when the support and the surrounding rock reaches equilibrium again.

2 Engineering background

The rock of LiRang tunnel is composed of Jurassic rhyolite and tuff of Jurassic Tao Bei Ying group (J3t). Along the axis of the tunnel, there are 150m gypsum rocks. The gypsum swelling rock mass scope is very large, so the swelling problem is a very serious problem in this tunnel. During the construction, the cracks get open and the enriched groundwater enters the gypsum rock, which is easy to cause the swelling deformation of the tunnel. In order to solve the large deformation problem in a fast and safe way, study the timing of large deformation treatment using the FLAC code. Through the gypsum rock softening freshwater immersion test [11], the mechanical properties of gypsum rock under the natural state are as follows: σ_c=31.157MPa, E=4.001MPa, μ=0.128, C=3.64MPa, internal friction angle is 45.

3 Numerical simulation

The numerical model was set up and calculated using the 2D finite difference method FLAC, as fig 1. The model size is 80m*80m, the tunnel span is 15.6m, the height is 9.7m, and the overburden thickness is 153m. The monitoring point is shown in fig 1. Due to the rock swelling in tunnel excavation, swelling potential and plastic deformation will seriously influence the rock stability and liner bearing capacity, it need to choice the elastic-plastic model which can consider the influence of swelling force. This paper adopts the Swell constitutive model based on the Mohr-Coulomb constitutive. Its mechanics and deformation mechanism based on non-associated plastic flow shear and tension associated plastic flow rule, and the swelling mechanism is the three-dimensional swelling constitutive under the control of the double semi logarithmic linear relationship.

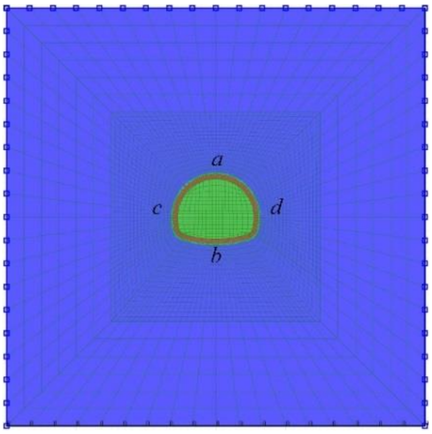


Figure 1 The geometric model of tunnel and location of monitoring points

The wetting-induced strain can be expressed by the following logarithmic function of the total compressive stress σ_{yy} . The mechanical parameters of the swelling rock mass are obtained by the test result and the field conditions, as shown in Table 1.

$$\varepsilon_{yy} = c_1 \log[a_1 - (-\sigma_{yy} / p_a)]$$

$$\varepsilon_{xx} = \varepsilon_{zz} = c_3 \log[a_3 - (-\sigma_{yy} / p_a)]$$

Where: a_1, a_3, c_1, c_3 -soil swelling properties;

p_a -the atmospheric pressure

4 Result and discussion

4.1 Stress analysis of tunnel in swelling rock

The strata direction of the swelling rock is horizontal in this model. When the swell rock expands with water, it is mainly swelling in the direction perpendicular to and parallel to the stratum. According to the parameters in Table 1, the swelling strain of the swelling rock in the vertical direction was larger than that in the horizontal direction. From the numerical results in figure 2, the stress release was occurred at the edge of the arch waist of the tunnel, while the stress increased greatly in the surrounding rock of the arch foot and the arch waist. The maximum principal stress reaches 6.00MPa, and the minimum principal stress reaches 2.50MPa. The stress concentration appears at the arch foot with large curvature. The stress release is large in the vault and arch bottom. Although there is no tensile stress, the stress value is much less than the original rock stress, which will cause larger deformation value of the tunnel. Therefore, special attention should be paid to the support of roof and floor, so as to prevent large arch crown settlement and arch bottom heave.

Table 1. Parameters of swelling rock mass.

Density (kg/m^3)	Elastic Modulus (GPa)	Poisson's ratio	Cohesion (MPa)	friction angle（°）	a1	c1	a3	c3
2270	1.2e9	0.13	1.10e6	39	1.533	-0.5e-2	0.5	-0.2e-2

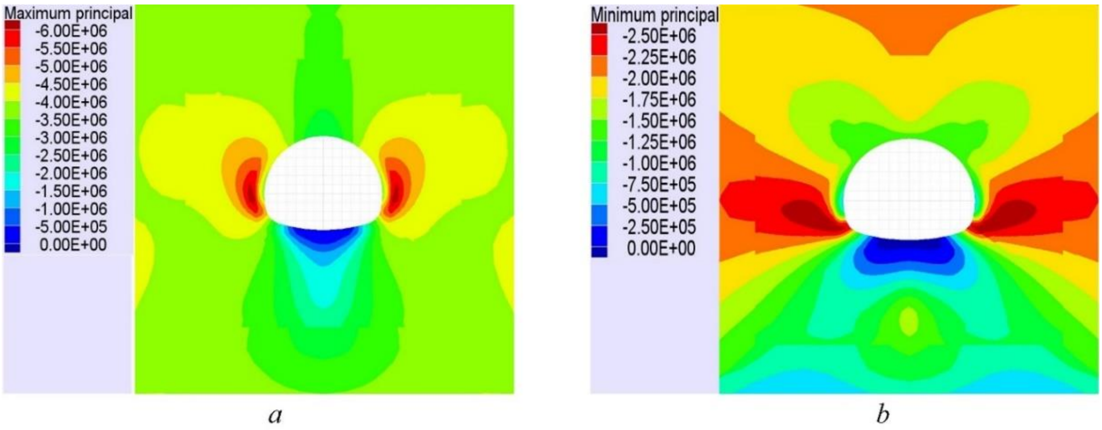


Figure 2 The maximum and minimum principal stress distribution after excavation

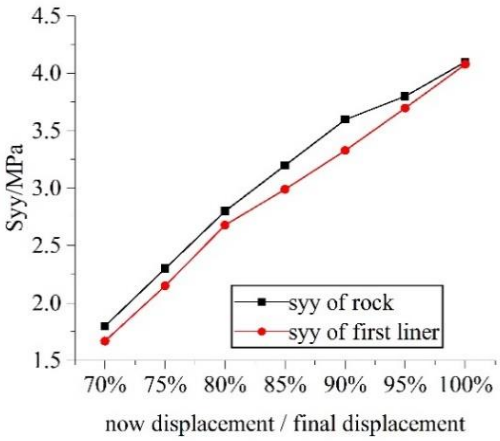


Figure 3 The displacement of tunnel when large displacement treatment at different time

4.2 Study on replacement timing of deformed lining

The monitoring stress of the surrounding rock and support in different deformation periods shown that the stress increased with the increase of deformation, as shown in figure 3. The sudden release of large stress and stored strain energy drop will seriously reduce the stability of the tunnel, and cause the rock block falling even tunnel collapse. In order to study the best treatment time of large deformation. Firstly, the predicted final displacement d_0 was calculated when the tunnel gets stable. Then the deformed first liner was removed when the displacement reached 70%d_0, 75%d_0, 80%d_0, 85%d_0, 90%d_0, 95%d_0, 100%d_0. Finally, the displacement and the stress were recorded when the model become balanced again after applied the strength first liner.

As shown in figure 4, if replace the deformed first liner when the displacement reach 70% and 75% of the final displacement, there still will be a large deformation after the tunnel get balance finally. The settlement of vault decreases gradually with the delay of deformation time. When the treatment timing reached 90% of the final displacement, the displacement after treatment become a low value, and the it is almost the same as replacing at 95% and 100% of the final displacement. From the view of the convergence, the value is small, and its impact on the tunnel stability is small.

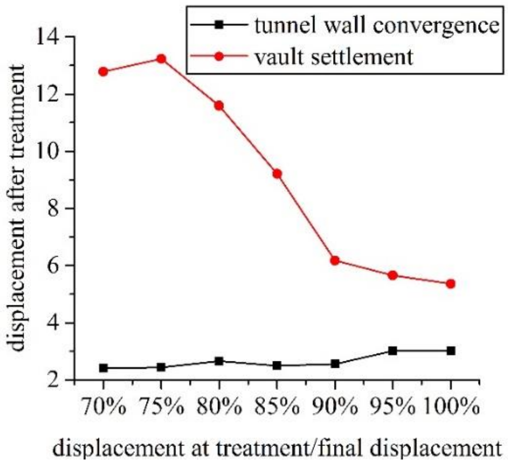
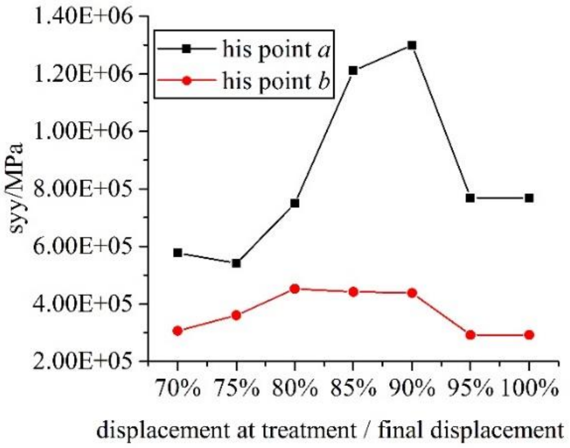


Figure 4 The tunnel settlement and convergence after large deformation treatment at different timing

Since the swelling of the rock in the vertical direction is greater than in the horizontal direction, only the stress in the vertical is calculated. Figure 5 represents the stress of the rock mass after treatment. The stress in the arch waist is greater than that at the vault and arch bottom. From the monitoring data in the bottom and the arch, as shown in Figure 5 (a), if manage the large deformation when the displacement get between 80% and 90% of the final deformation, the vertical stress has a great growth. As the deformation exceeds 90%, the stress decreased sharply. Because this stress will be directly applied on the first liner, it is directly affect the force of the liner and the stability of the tunnel. It needs special notice of the stress in these locations. From the figure 5 (b), the final stress has a large drop as the delay of the treatment time. The stress drops to the minimum when the deformation reaches 90% of the final deformation. But if the treatment time reaches 95% or 100% of the final deformation, the stress increased slightly. It indicated that it is beneficial for the final stress environment to replacement the deformed first liner at an earlier time. Considering the displacement and the final stress, it is better to replace the deformed first liner when the displacement exceeds 90% of the final predicted deformation. Next, we can study the stiffness and strength of the first liner by the swelling property of the surrounding rock and the timing of treatment.



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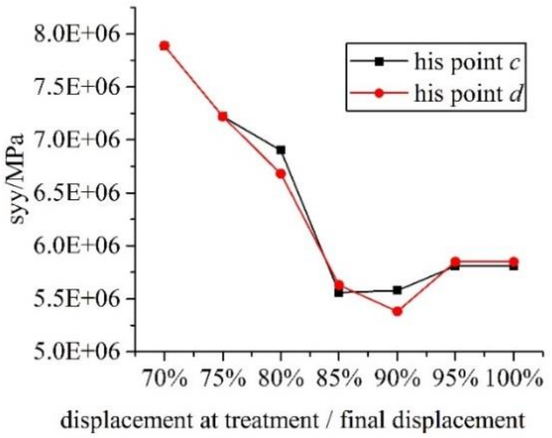

b

Figure 5 The stress of the rock mass at different location after treatment at different timing

5 Conclusion

In this paper, a typical tunnel in the swelling as the representative, through the numerical simulation, the following conclusions:

(1) In the swelling rock which strata is along the horizontal direction, tunnel arch wall and foot will appear stress concentration after the excavation. While the stress in the vault and the arch bottom decreases sharply. It is necessary to pay particular attention to settlement of vault and arch bottom bulge;

(2) With the deformation of the tunnel, the stress of the rock mass and support in the vault increases gradually. The strain energy stored in the surrounding rock. It may be more dangerous if remove the deformed first liner when it gets the final displacement.

(3) The displacement and stress was analysed after replace the deformed first liner in different deformation timing. The result shown that it is better to do the treatment when the vault settlement is between 90% and 95% of the final settlement. This makes both the deformation and stress smaller when the tunnel become balance again after treatment and the tunnel become more stable.

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