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Refinement Study of Tunnel Surrounding Rock Failure

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Abstract

In response to the current situation in the field of rock mechanics and subsurface rock engineering, where macroscopic tunnel model breakage is less frequently linked to the cracking mechanism of rock specimens. A new research idea that the failure analysis of the tunnel can be carried out by obtaining rock specimens and applying a similar stress path or stress condition to the rock specimen as the corresponding tunnel location is proposed. This research idea makes it possible to study a specific localized area of the tunnel in detail. Moreover, the location of the tunnel side is selected to verify this idea. The results demonstrate the rationality of this research idea.

Keywords

Tunnel Surrounding Rock; Specimen Destruction; Localization Study.

1. Introduction

As underground space continues to be exploited and utilized, energy extraction is gradually moving deeper. Due to the influence of high ground stress, the stability problem of tunnel becomes increasingly severe. Often, after excavation, cave walls are prone to deformation, rock spalling, rockburst, and sidewall deformation. In underground projects, such as Jinping Hydroelectric Power Station, Baihetan Hydroelectric Power Station, and Pubugou Hydroelectric Power Station, splitting cracks are produced in sidewalls after excavation [1]. This has had an unfavorable impact on the development of underground spaces.

However, previous studies have mainly focused on analyzing the mechanical characteristics of the actual tunnel project status or conducting indoor experiments on rock specimens to study the mechanical mechanism. Lack of linkage between breakage of actual tunnel project status and crack extension mechanism of indoor test specimens.

In response to the above, this paper summarizes and analyzes recent literature and proposes a research idea for using indoor stress paths to simulate the stress history and stress conditions of actual tunnels, and numerical modeling using PFC for validation.

2. Joint Study of Specimen Failure Mechanism and Surrounding Rock Failure

In fact, research linking tunnel models to rock specimens has long been underway and has yielded significant results. Zhang [2] analyzed the loosening and spalling of flaky rock sheets and bursting phenomena in the sidewalls after excavation of deeply buried tunnels. He processed brittle gabbro into cubic specimens and performed biaxial compression experiments and true triaxial loading and unloading experiments according to the real surrounding rock stress evolution. The results showed that under the two loading stress paths, the specimens were split and rockburst, and the closer to the free surface, the more serious the split damage, which is consistent with the actual condition in the field. Liang [3] conducted indoor unloading experiments by constructing thick-walled cylindrical cement mortar enclosure rock specimens using a method that conforms to the actual stress path of the enclosure rock to study the microscopic failure evolution of the enclosure rock under unloading. Niu [4] conducted triaxial loading-unloading surrounding pressure-uniaxial compression test and triaxial loading-unloading axial pressure-uniaxial compression test on white sandstone specimens and analyzed the damage pattern and stability of tunnel peripheral rock with the damage pattern of specimens and the stress-strain law.

Based on the above study, it can be seen that the tunnel failure analysis can be carried out by obtaining rock specimens and applying a similar stress path or stress condition to the rock specimen as the corresponding tunnel location to study a specific localized area of the tunnel in detail.

3. Verification Process

For ease of calculation, the circular tunnel sidewall is used as the research object for validation, as shown in Fig. 1.

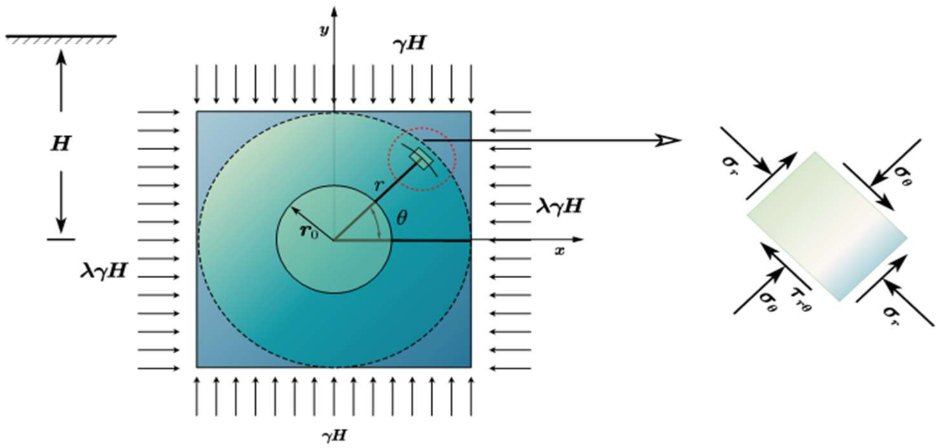

Fig. 1 Theoretical calculation model of tunnel

After determining the shape of the tunnel, the stress distribution in the wall of the surrounding rock is analyzed, which is mainly solved using the analytical method of elasticity theory. Let the initial stress field (vertical and horizontal stresses) be, as shown in equation 1:

$$\begin{cases} p_v = \gamma h \\ p_h = \lambda \gamma h \end{cases} \tag{1}$$

Subsequently, the stress field in the surrounding rock of the cave chamber can be calculated according to the formula for calculating the stress in a hole in a thin plate under bidirectional stresses. As shown in equation 2:

$$\begin{cases} \sigma_r = \left(\dfrac{p_v + p_h}{2}\right)\left(1 - \dfrac{r_0^2}{r^2}\right) - \left(\dfrac{p_v - p_h}{2}\right)\left(1 - \dfrac{4r_0^2}{r^2} + \dfrac{3r_0^4}{r^4}\right)\cos 2\theta \\ \sigma_\theta = \left(\dfrac{p_v + p_h}{2}\right)\left(1 + \dfrac{r_0^2}{r^2}\right) + \left(\dfrac{p_v - p_h}{2}\right)\left(1 + \dfrac{3r_0^4}{r^4}\right)\cos 2\theta \\ \tau_{r\theta} = \left(\dfrac{p_v - p_h}{2}\right)\left(1 + \dfrac{2r_0^2}{r^2} - \dfrac{3r_0^4}{r^4}\right)\sin 2\theta \end{cases} \tag{2}$$

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Let $r = r_0$, then there is a computational expression for the stress distribution of the cave wall. As shown in equation 3:

$$\begin{cases} \sigma_r = 0 \\ \sigma_\theta = \left(p_v + p_h\right) + 2\left(p_v - p_h\right)\cos 2\theta \\ \tau_{r\theta} = 0 \end{cases} \tag{3}$$

This indicates that the forces are unidirectional at the sidewalls, with significant stress concentrations. However, the corresponding numerical simulation experiments and similar modeling experiments do not solve the specific crack extension mechanism of a particular local section. As shown in Fig. 2.

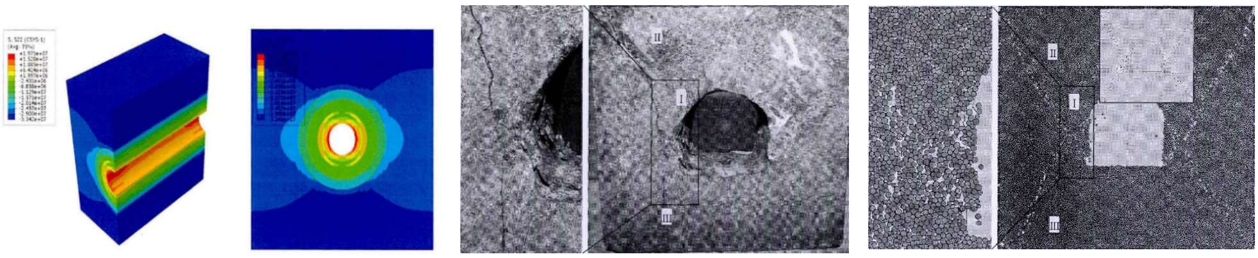

Fig. 2 The specific expansion mechanism of the sidewall cracks can not be clearly shown [1,5]

In this study, the stress and displacement models of the tunnel surrounding rock were first constructed using PFC. As shown in Fig. 3. The results are consistent with existing numerical simulation studies [1,6].

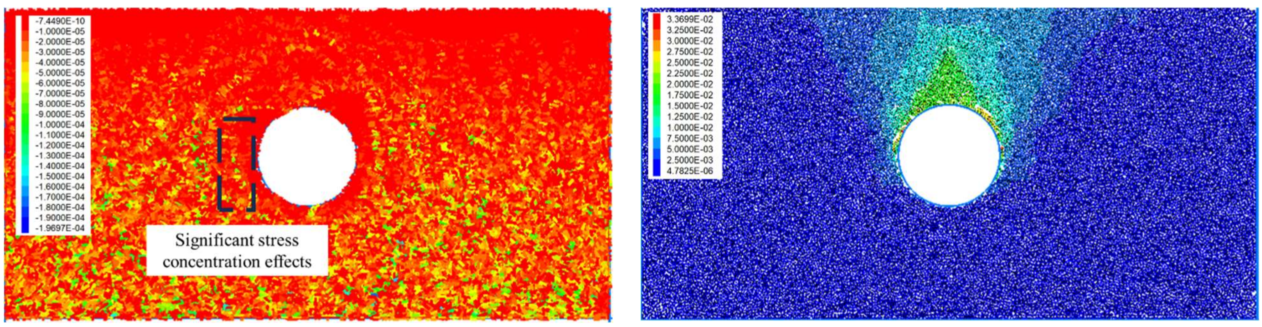

Fig. 3 Stress (left) and displacement (right) maps of tunnel surrounding rock

Based on the research idea summarized above, this paper samples and models the tunnel sidewalls. Due to the unidirectional force on the tunnel sidewalls, in order to study its deformation and failure, it can be considered that its axial pressure gradually increases, thus generating corresponding loosening, spalling and failure. As shown in Fig. 4.

Based on Fig. 4, the crack direction and block damage inside the specimen can be seen more clearly and can better simulate the wedge-shaped failure fragments generated from both sides of the tunnel. In addition, the successful refinement of the tunnel sidewall area into the specimens made it possible to analyze the cracking mechanism of the rock surrounding the roadway. This also shows that the research ideas presented in this paper have some legitimacy.

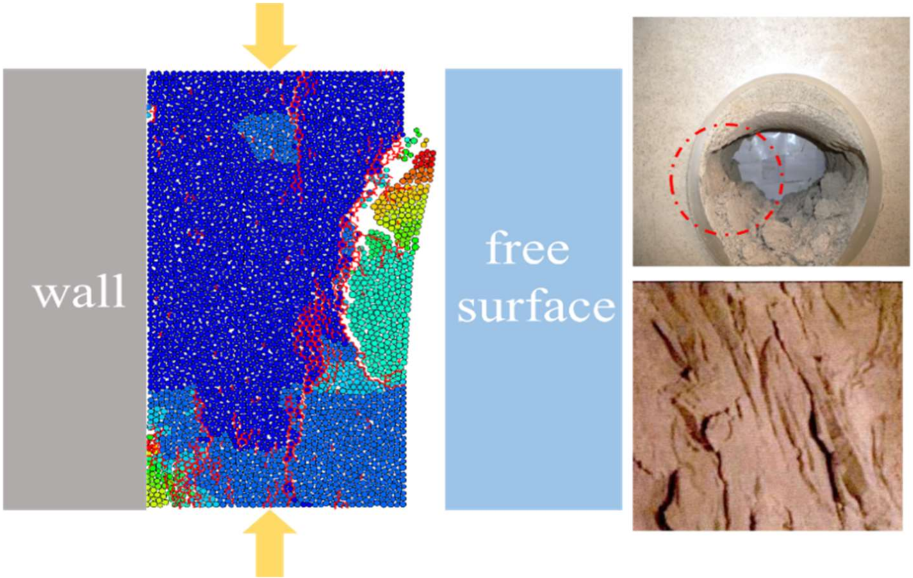

Fig. 4 Comparison of actual sidewall failure [1,7] and specimen failure

4. Conclusion

This paper analyzes the current situation in which there is less linkage between the cracking mechanism of specimens under pressure and the failure of actual tunnel conditions and proposes a research idea that applies a similar stress path or stress condition to the rock specimen as the corresponding tunnel location to achieve the purpose of studying a specific localized area of the tunnel in detail. This paper also uses the stress conditions of the tunnel sides to verify the research idea, the numerical simulation shows that it can better simulate wedge crushing of the sides in actual tunnel conditions. The results show that the idea proposed in this paper has certain rationality.

Acknowledgments

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