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Original article

Numerical analysis on the crack propagation and failure characteristics of rocks with double fissures under the uniaxial compression

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A B S T R A C T

The fissures and rock bridges with different dips had different contributions to crack's initiation, propagation, convergence and penetration. In this paper, based on the rock fracture theory, the crack's propagation and evolution process on rock specimen with double fissures under uniaxial compression was simulated. As a result, the crack propagation and evolution law of rocks with different fissure dips ($\alpha = 0°$, $15°$, $30°$, $45°$, $60°$, $75°$, $90°$; $\beta = 45°$) and different rock bridge dips ($\beta = 0°$, $30°$, $45°$, $60°$, $90°$; $\alpha = 45°$) was obtained by numerical tests. Meanwhile, the fissure and rock bridge dips influence on the macro mechanical properties of rock was analyzed. Besides, the paper investigated the influences of different fissure dips and different rock bridge dips on the bridge transfixion. The study is of great significance to reveal the impact of different dips on the mechanical mechanism of multiple-fissures rock under specific conditions, and it also has important theoretical significance for the research on multiple-fissure rock.

1. Introduction

Under the effect of complex geological structure and after a long geological evolution, initial structure defects such as fissures, joints usually exist within the rock. In the actual projects, the rock with those defects is one of the most common engineering medium. Many studies showed [1–7] that the geometrical morphology of fissures and joints contained in engineering rock mass had significantly impacts on its mechanical properties and the evolution feature of fissures under the effect of the external load. Therefore, further research in this field had important theoretical and practical significance to ensure the stability and safety of rock engineering.

Many scholars at home and abroad had carried out a lot of experimental studies on the mechanics properties of rock mass with initial defects. For example, Sagong, Bobet, Shen et al. [1,4,8] investigated the initiation, propagation and transfixion process of cracks under compression loading on the gypsum specimens which contained two inclined fissures. They analyzed the transfixion mode between the fissures, as well as the characteristics of breaking load. Germanovich, Dyskin, Sahouryeh, Jewell et al. [9–11] studied the extension law of three dimensional crack under the conditions of uniaxial compression by experiment. Changa, Li Yin-Ping, Backers, Yang et al. [12–15] researched crack growth law in the rock specimens and the damage characteristics of rock mass by acoustic emission method. Wong, Tang et al. [2,3,6,16,17] conducted compression experiment on the specimens with lots of fissures. They analyzed the transfixion mode of the friction-type fissures and the law of the peak intensity of the specimens. Liyun Li et al. [18,19] carried out large amount of multiple-crack experiments by using of gypsum and white cement. They investigated the macroscopic mechanical properties of rock and the relationship between the fissures. Peng Lin, Shimin Wang et al. [7,20] conducted uniaxial compression test and numerical simulation on granite materials

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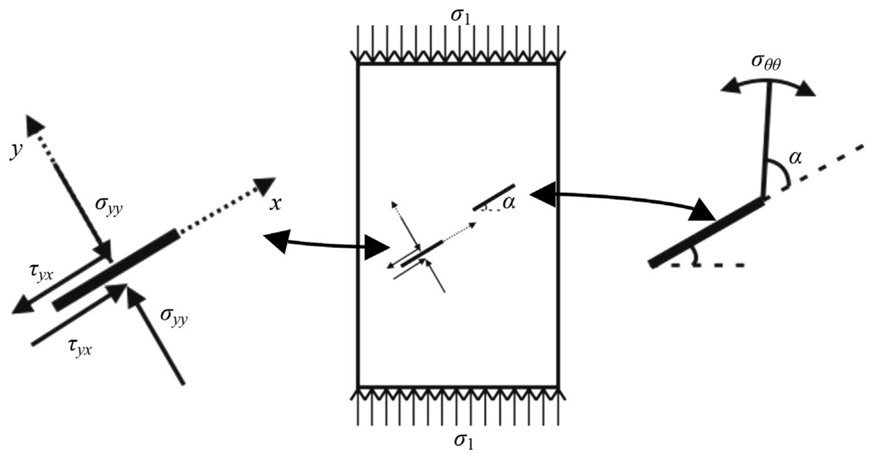

Fig. 1. Fracture mechanical analysis under the uniaxial compression.

with different size of the fissures. They found that the fissure angle and length are the important factors that affect cracks propagation and damage forms of the rock. Bohu Zhang etal [21].analyzed the propagation mode of single "I" crack under the action of the pore pressure. Leyong Chen et al. [22] investigated the strength characteristics of sandstone samples failure with single fissure under the uniaxial compression. At present, most of the studies are indoor experimental research, and the specimens are mainly artificial samples. The study period is long and the cost is high, and sometimes the results may differ with the actual. With the improvement of computer level, the targeted engineering software are developed, the numerical simulations are widely used for the lower cost and the moderate accuracy of the results.

From the above results of previous scholars' studies, the authors know that the geometry morphology of fissure is one of the main factors influencing the crack propagation and evolution. In this paper, we take prefabricated double-fissure rock as the object of the research, for a given value of fissure length and rock bridge length, simulation and analysis of crack propagation were performed on the rock with different fissure or rock bridge inclination and its influence on the mechanical characteristics of the rock mass. The results help to reveal the effects of different inclined fissures on rock mass mechanical mechanism under certain conditions, and this research is of great theoretical significance for the study of multiple-fissure rock.

2. Fracture theory

For the rock material with prefabricated fissures, as shown in Fig. 1, the author establish a Cartesian coordinate system, assuming that the x-axis is parallel to the direction of fissure and the y-axis is parallel to the normal direction of fissure [23]. Based on the coordinate changes of stress component, it can be known that:

$$\begin{cases} \sigma_{yy} = C_n \sigma_1 \cos^2\alpha \\ \tau_{yx} = C_\tau \sigma_1 \sin\alpha\cos\alpha \end{cases} \tag{1}$$

In the formula: σ_1 represents the maximum principal stress; α is the dip of prefabricated fissures; C_n represents the normal stress transmission coefficient of fissure surface; C_τ is the shear stress transmission coefficient of fissure surface; and:

$$C_n = \frac{\pi a}{\pi a + \frac{E_0}{(1-\nu^2)K_n}}, \quad C_\tau = \frac{\pi a}{\pi a + \frac{E_0}{(1-\nu^2)K_s}},$$

K_n and K_s is the normal stiffness and tangential stiffness of fracture surface; a represents the half length of prefabricated fracture; ν is the poisson's ration; E_0 is the elasticity modulus of rock mass.

Assuming that the angle between the direction of crack propagation in crack tips and prefabricated fissures direction is θ, as shown in the enlarged portion of fissure in Fig. 1, it can be drawn that:

$$\sigma_{\theta\theta} = \frac{3}{2}\sqrt{\frac{a}{2r}}\tau \sin\theta\cos\frac{\theta}{2} \tag{2}$$

In the formula: τ represents the driving force of the rock shearing slip; $\tau = \tau_{yx} - f\sigma_{yy}$, and f is the friction coefficient.

Table 1
Simulation table.

Rock sample	Coefficient of homogeneity m	Fissure length $2a$/mm	Length of rock bridge $2b$/mm	Dips of fissure α/°	Dip of rock bridge β/°
1#	2	10	10	0	45
2#	2	10	10	15	45
3#	2	10	10	30	45
4#	2	10	10	45	45
5#	2	10	10	60	45
6#	2	10	10	75	45
7#	2	10	10	90	45
8#	2	10	10	45	0
9#	2	10	10	45	30
10#	2	10	10	45	60
11#	2	10	10	45	90