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Research on initiation stress of jointed rock mass under triaxial compression test

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Abstract. On the basis of the experimental study about the elastic wave propagation characteristics in jointed rock mass under triaxial compression test, Firstly, the initiation stress is determined by the comparison of the experimental results. After that, on the basis of fracture mechanics theory, the fracture development process of rock mass is studied, and the initiation strength equation of fractured rock mass is established. Finally, combined with experimental data, verification and analysis of the initiation strength equation. Research shows:(1) In intact rock mass, the opening and closing of microscopic cracks have less effect on the amplitude of the elastic wave, but in jointed rock mass, that have great effect on the amplitude of the elastic wave. (2) Under different confining pressures of triaxial compression test, as the cracks in the rock mass start breaking, the axial compressive stress is linear with confining pressure. (3) The initiation strength equation of jointed rock mass is in accordance with the experimental results, the research results have some guidance significance to practical engineering.

Keywords. Elastic wave, triaxial compression, initiation stress, confining pressures.

1. Introduction

With the development of our economic construction, human engineering activities gradually go to the deep, at the same time, Engineering problems continue to increase. For example, stress concentration phenomenon occurred on excavating section after the excavation of deep tunnel surrounding rock, and influence on the stability of underground works. For shallow buried rock mass, macroscopic failure will not appear when the axial compressive stress of rock mass is less than uniaxial compressive strength.

For deep rock mass, the strength characteristics is different from shallow buried rock mass because of high ground stress. ZHANG [1] found in the research that fracture and damage will appear in marble under high confining pressure, the fracture and damage often occurs when the stress level is not high during the excavation of deep surrounding rock, the surrounding rock mass is not unstable when the fracture and damage occur Which leads to a large security risk, So, it is very significant to study the mechanism of fracture and damage in deep rock mass.

Brittle failure of rock is a complicated process, Scholars abroad first discovered stress thresholds (the crack initiation stress) for Brittle rock in the failure process, a system of mechanical tests on granite is launched by MARTIN [2], Laboratory tests and field tests is improved to determine the crack initiation stress. Based on the laboratory compression test by Brace [3], the method of acoustic emission and micro electron microscope observation, the initiation stress is determined in the failure process of rock mass. M.CAI [4] gives a method to determine the crack initiation stress in the intact rock mass and the fractured rock mass, the relationship between axial compressive stress and confining pressure is defined in this method. Based on uniaxial compression test and acoustic emission test, Eberhardt [5] found the crack initiation stress of rock is 39% of uniaxial compressive strength. In the field of domestic research, based on the conventional triaxial compression tests at various confining pressures were conducted on the typical hard rock of granite and marble, The physical significance and the calculation methods of the crack initiation stress for rock were summarized by ZHOU [6].ZHANG [7] carried out a uniaxial compression test of schistose rock, analysis of stress thresholds of schistose rock in progressive failure process are firstly applied to schistose rock, stress thresholds under different loading modes for schistose rock are obtained. the characteristic strengths of marble under different confining pressures are determined based on inflection points of crack volume strain and marble volumetric strain by LIU [8]. ZHANG [9] carried out the axial compression and acoustic emission tests on marble samples, and the crack initiation stress is determined.

In conclusion, the crack initiation stress during rock failure process has important practical sense to the failure of the rock and engineering application. Previous studies on the crack initiation stress of rock were mainly focused on uniaxial compression test, while only a few focus on the failure mechanism and triaxial compression tests. Based on this, first of all, this article has carried on elastic wave propagation characteristics in jointed rock mass under triaxial compression tests, and the crack initiation strength of fractured rock mass is determined based on the wave amplitude. Then, based on the fracture mechanics theory, the relationship between the axial compressive stress and confining pressure is studied on the initiation of crack. Finally, the relationship between the axial compressive stress and confining pressure is tested by the experimental data, this research has some academic value and applications.

2. The initiation strength based on elastic wave propagation characteristics test

In order to study the crack initiation strength of fractured rock mass in stress process, In the model test, this paper takes deep-buried marble at Jinping hydropower station as the engineering background, Based on the theory of similarity, the elastic wave propagation characteristics in jointed rock mass under triaxial compression test were carried out on the intact rock mass, single-fractured Rocks, double-fractured Rocks in Figure.1, For the engineering background of this test, the production method of rock mass and test plan, the literature [10] were expounded exhaustively. Because of the limitation of length, no more tautology here.

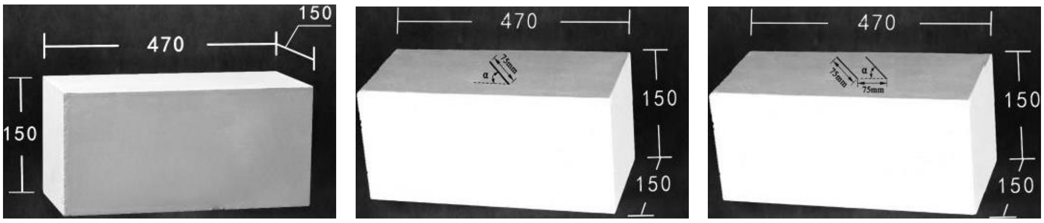


Figure 1. Jointed rock mass model (unit:mm)

Researchers often considered the original fracture in rock mass as the initial damage of rock mass at this stage. The initiation, propagation, through in rock is regarded as the damage evolution of rock, The research of literature [10] shows: the change of elastic wave velocity and amplitude is related to the fracture in rock mass directly, and under the same loading mode, the variation law of elastic wave velocity and amplitude is basically the same, so the change of elastic wave velocity or amplitude can be used to reflect the damage characteristics of rock mass. Finally, the initiation strength of fractured rock mass is obtained.

Taking the relationship between the elastic wave amplitude and the axial compressive stress in rock mass as an example, Figure.2 is elastic wave propagation characteristics in intact (single-fractured) rock mass under triaxial compression test. It can be seen from the Figure.2, In OA segment, The elastic wave amplitude increases first and then decreases, but the amplitude is very small. In AB segment, the elastic wave amplitude decreased rapidly, and the amplitude of the wave decreased greatly, the macroscopic fracture in rock mass is beginning to appear. $\sigma_i = 0.75\sigma_c$ is defined as the critical point of macroscopic cracks began to occur in the rock mass.

It can be seen from the Figure.2 ,the elastic wave amplitude grew rapidly in the OA_1 segment, When the axial compressive stress value $\sigma_i = 0.4\sigma_{1c}$,amplitude reaches a maximum which increased 40% than initial amplitude, micro fracture and macro fracture in rock mass are started to close, And corresponding to the process in intact rock mass, the change of elastic wave amplitude is small, Therefore, it can be considered that the main reason for the increase of the elastic wave amplitude in the fractured rock mass is the macro fracture closure, In the process, the damage is not developed in order for easy analysis. Elastic wave amplitude decreased rapidly in the AB_1 segment ($\sigma_i > 0.4\sigma_{1c}$), the main reason is the expansion of the original macro cracks and the joint effect of the new macro cracks. damage starts to develop in the process. Defining the A point in Figure.2 as the crack initiation strength of the fractured rock mass, When the axial compressive stress of the fractured rock mass reaches initiation strength, the damage of fractured rock mass began to develop.

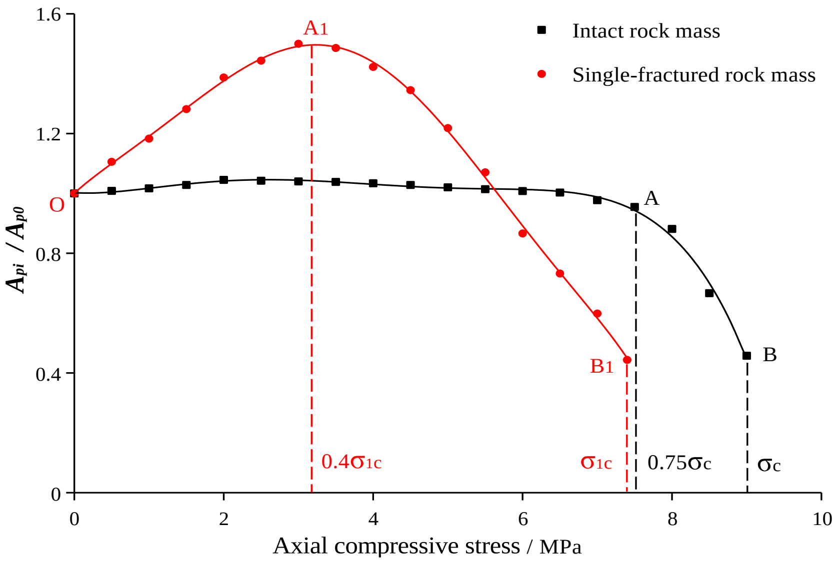


Figure 2. Relation between amplitude ratio and stress of intact and fractured rock mass

3. Initiation strength equation of fractured rock mass under triaxial compression test

The essence of the macroscopic damage evolution of the fractured rock mass is the process of the continuous expansion of the macro fissures in the rock mass under three axial compressions, The macroscopic damage of fractured rock mass began to develop as the macro cracks began to crack. the shear stress on rock mass failure surface causes the damage of rock mass in coulomb navier criterion. According to this feature, the crack initiation equation of fractured rock mass will be established under three axial compressions, Thus the crack initiation strength of fractured rock mass is obtained.

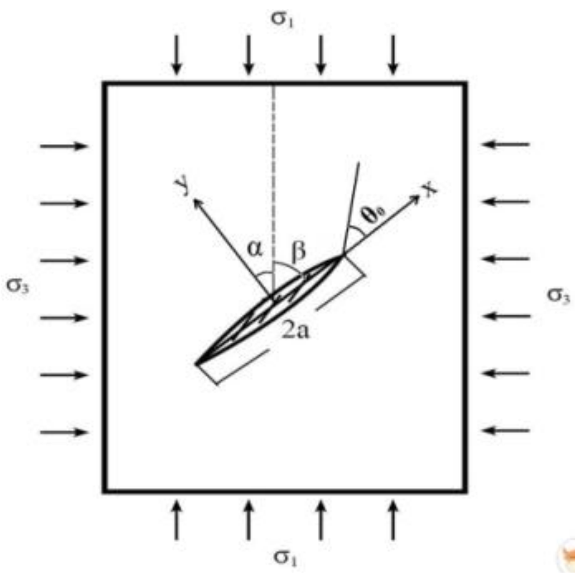


Figure 3. The I-II Mixed-mode crack under triaxial compression test

As shown in Figure 3,The length of the crack in the single-fractured Rock is 2a, σ_1 is the axial compression stress in the single-fractured Rock, $\sigma_2 = \sigma_3$ is the confining pressure on the single fracture rock mass. β is Crack inclination angle, θ_0 is crack initiation angle, f is equivalent to friction coefficient on the fracture face. τ_c is shearing strength on the fracture face, so the normal stress σ_N and equivalent shears τ_f are:

$$\begin{cases} \sigma_N = \dfrac{\sigma_1 + \sigma_3}{2} - \dfrac{\sigma_1 - \sigma_3}{2}\cos 2\beta \\ \tau_f = \dfrac{\sigma_1 - \sigma_3}{2}\sin 2\beta - f\sigma_N \end{cases} \tag{1}$$

(1)If $\tau_f < \tau_c$,The fracture surface will not slip: $\tau_f = 0$,In this case, the crack is mode I fracture , $K_I \neq 0$, $K_{II} = K_{III} = 0$, the Stress intensity factor K_I is:

$$K_I = -\sigma\left(\sin^2\beta + \lambda\cos^2\beta\right)\sqrt{\pi a} \tag{2}$$

In the formula, $\sigma_1 = \sigma$, $\sigma_3 = \lambda\sigma$, $K_I < 0$,Obviously, $K_I < 0$ does not have any meaning in physics because of the non-intrusive between the fracture surfaces, the fracture surface is closed at the moment, there is no substantial effect on the stress field around the crack.

(2) If $\tau_f \geq \tau_c$,The fracture surface will slip, in this case, the crack is mode II fracture, the stress component of the crack front is:

$$\begin{cases} \sigma_{xx} = -\dfrac{K_{II}}{\sqrt{2\pi r}}\sin\dfrac{\theta}{2}\left(2 + \cos\dfrac{\theta}{2}\cos\dfrac{3\theta}{2}\right) \\ \sigma_{yy} = \dfrac{K_{II}}{\sqrt{2\pi r}}\sin\dfrac{\theta}{2}\cos\dfrac{\theta}{2}\cos\dfrac{3\theta}{2} \\ \tau_{xy} = \dfrac{K_{II}}{\sqrt{2\pi r}}\cos\dfrac{\theta}{2}\left(1 - \sin\dfrac{\theta}{2}\sin\dfrac{3\theta}{2}\right) \end{cases} \tag{3}$$

The stress intensity factor II is:

$$K_{II} = -\sigma\left[(1-\lambda)\sin\beta\cos\beta - f\left(\sin^2\beta + \lambda\cos^2\beta\right)\right]\sqrt{\pi a} \tag{4}$$

The initiation condition of Stress intensity factor II under three axial compression is:

$$\sigma_1 = a\sigma_3 + b \tag{5}$$

In the formula, K_{IIc} Is constant, $a=\dfrac{\sin 2\beta+f\left(1+\cos 2\beta\right)}{\sin 2\beta-f\left(1-\cos 2\beta\right)}$, $b=\dfrac{2K_{IIc}}{\left[f\left(1-\cos 2\beta\right)-\sin 2\beta\right]\sqrt{\pi a}}$ .strength of fractured rock mass is σ_1 in formula (5).

It can be seen from the development of fracture in literature [11], for the multi fractured rock mass which is subjected to compression-shear effect. All fissures in the multi fractured rock mass are cracked and expanded in the same way. Therefore, reference type (4) form, the stress intensity factor II of multi fractured rock mass under three axial compression is:

$$K_{II}^{'}=-Y\sigma\left[\left(1-\lambda\right)\sin\beta\cos\beta-f\left(\sin^2\beta+\lambda\cos^2\beta\right)\right]\sqrt{\pi a} \tag{6}$$

The stress intensity factor II is:

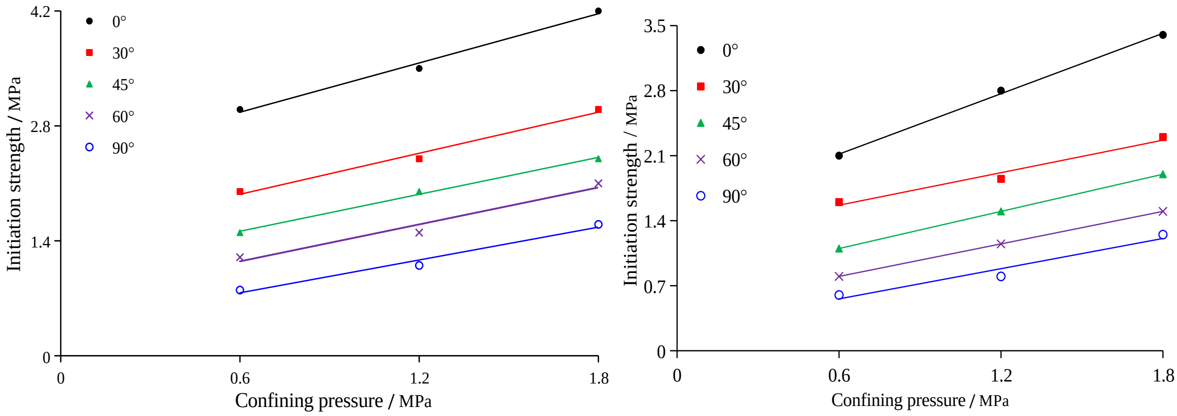
$$\sigma_1=a\sigma_3+c \tag{7}$$

In the formula, $K_{IIc}^{'}$ Is constant, $a=\dfrac{\sin 2\beta+f\left(1+\cos 2\beta\right)}{\sin 2\beta-f\left(1-\cos 2\beta\right)}$, $b=\dfrac{2K_{IIc}^{'}}{Y\left[f\left(1-\cos 2\beta\right)-\sin 2\beta\right]\sqrt{\pi a}}$ the initiation strength of multi fractured rock mass is σ_1 in formula (7).

4. Validation test on the initiation strength of fractured rock under triaxial compression test

For the elastic wave propagation characteristics in fractured rock mass under triaxial compression test, When the axial compressive stress of the fractured rock mass reaches the initiation strength, elastic wave began to reduce significantly, the damage of fractured rock mass began to develop. On this basis, the test curves of fractured rock mass with different fracture angles (0 degrees, 30 degrees, 45 degrees, 60 degrees, 90 degrees) are selected to verify the formula (5) and formula (7).

The initiation strength-confining pressure curves of fractured rock mass with different fracture angles is in figure 4.



(a) Single-Fractured rock (b) Multi-Fractured rock

Figure 4. The initiation strength-confining pressure curves of fractured rock mass

From Figure 4 it appears that: (1) When the fracture angle is certain, the confining pressure is increased, the initiation strength of the single fractured rock mass and the multi fractured rock mass increases continuously there is a highly linear relationship between initiation strength and confining pressure, This feature is in full compliance with the formula (5),(7),The above analysis shows the accuracy of the crack initiation equation in the fractured rock mass.(2) When the confining pressure certain, the fracture angle is increased, the initiation strength of fractured rock mass decreases continuously. This is due to the greater the fracture angle, the weaker the bearing capacity of rock mass on the normal plane of the axial compressive stress, which leads to the decrease of the initiation strength with the increase of the crack angle. This characteristic can be reflected by the specific expression of a, b and c in the formula (5) and formula (7). On the other hand, it shows the accuracy of the crack initiation equation in the fractured rock mass.

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