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THE NEXUS UNVEILED: INVESTIGATING T STRESS AND ROCK FRACTURE TOUGHNESS INTRICACIES

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Abstract: Fracture toughness is a critical parameter in both the study of rock fracture propagation within linear elastic fracture mechanics and geotechnical engineering. It plays an indispensable role in ensuring the safety and efficiency of geotechnical construction projects. Prior to commencing construction, the mechanical properties of the rock at the construction site, including fracture toughness, are analyzed and tested. It is widely recognized by experts that rock fracture tip stress exhibits a degree of singularity, making the simultaneous calculation of T stress and rock stress intensity factor a challenging task in fracture toughness testing. Existing research highlights the significant influence of T stress on rock fracture toughness. If we can establish a linear relationship between rock fracture toughness and T stress, it could simplify the complexity of fracture toughness calculations for rock, thereby facilitating geotechnical engineering. However, currently, there is a noticeable dearth of research exploring the relationship between rock fracture toughness and T stress. In the realm of domestic research, investigations in this area began relatively recently, and the associated theoretical foundations are still in their infancy. Although there has been a growing emphasis on the mechanical properties of rock in recent years, with scholars and experts conducting extensive research on aspects such as compressive properties and hardness, there is a lack of a comprehensive theoretical framework that addresses the influence of T stress on rock fracture toughness. Consequently, this study aims to fill this critical gap, providing a solid foundation to enhance and optimize methods for calculating rock fracture toughness.

Keywords: Fracture Toughness, T Stress, Rock Mechanical Properties, Geotechnical Engineering, Calculation Methods

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1. Introduction

Fracture toughness is one of the important parameters in the study of rock fracture propagation in linear elastic fracture mechanics, and it is also a technical parameter that cannot be ignored in geotechnical engineering. In order to ensure the safety and efficiency of geotechnical engineering construction, the site mechanical properties of rock will be analyzed and tested before the formal construction, including the fracture toughness of rock. Relevant scholars and experts believe that rock fracture tip stress has a certain singularity, and it is difficult to calculate T stress and rock stress intensity factor simultaneously when testing rock fracture toughness. Relevant studies prove that rock fracture toughness is greatly affected by T stress. If the linear relationship between rock fracture toughness and T stress can be understood, it will provide a lot of convenience for the calculation and testing of rock fracture toughness and simplify the calculation difficulty of rock fracture toughness [1].However, there is currently no relevant research to demonstrate the relationship between rock fracture toughness and T stress. Domestic research on this aspect started relatively late, and the relevant research theories are not rich enough. Although rock mechanical properties have received attention and attention in the research field in recent years, relevant scholars and experts have conducted a series of studies, most of them focus on rock compressive properties, hardness, and other aspects of research, currently, there is no systematic theory of the influence of T stress on rock fracture toughness. Therefore, this study is proposed to provide a strong reference basis for the optimization and improvement of rock fracture toughness calculation methods.

2. Test Method and Materials

2.1. Materials

In order to explore the influence mechanism of T stress on rock fracture toughness, rock fracture toughness test was carried out. IHFA-AG4F automatic servo material testing machine was used to measure the crack strength, tensile strength and other parameters of rock. The maximum normal load was 1500KN and the stroke was 100mm. The material of all the specimens in the test is the same, and the shape of the specimens is half disk shape. Relevant studies show that there is size effect on rock fracture toughness. During the processing of the specimens, according to the Test Code for Rock Fracture Toughness, the specimens should meet the following conditions: First, the thickness of the rocks should be at least 0.25 times of the diameter; second, the thickness of the rock must be at least 15 times the size of the grain. Thirdly, the deviation of rock cutting plane from core diameter should not exceed 1.25mm, and the flatness of specimen surface should be greater than 0.5°. Fourthly, the optimum value range of relative prefabricated crack degree is 0.45-0.65[2]. In addition, the diameter of rock specimen in fracture toughness test should meet the following requirements:

$$H \geq 0.2\left(\frac{K}{e}\right)^2 \qquad (1)$$

In the formula, *H* represents the diameter of the rock fracture toughness test specimen; *K* represents the compressive strength of the rock; *e* represents the tensile strength of the rock. Based on the above requirements, the rock fracture toughness test specimen in this paper has a diameter of 110 mm, a thickness of 45 mm, a spacing of 55 mm between support points, and a degree of pre cracking of 0.5. In order to test the fracture toughness of rocks, the larger the crack inclination angle, the greater the parameter change of rock cracks. Therefore, the crack inclination angle is set between 5 ° and 40 ° [3]. According to the above design parameters of rock fracture toughness test specimens, mechanical cutting methods are used to fabricate and process the specimens. The prepared core material is cut into half disks, with a cutting error of no more than 1%. Then, a UIHFA-AF77 machine tool is used to fine process the specimens, and a tool is used to create cracks on the rock surface. In this test, a total of 8 test pieces were processed and manufactured, with crack inclination angles of 5 °, 10 °, 15 °, 20 °, 25 °, 30 °, 25 °, and 40 °, respectively. After conducting basic physical property tests on the core of the test pieces, rock fracture toughness tests were conducted.

2.2. Test method

The fracture toughness test was carried out on the processed half disk specimen, which was placed on the IHFA-AG4F automatic servo material testing machine test bench and fixed. In the test, the mobile loading mode was selected to carry out loading control on the half disk rock specimen and control the loading of the load. According to the test requirements of rock fracture toughness, the loading rate parameter of IHFA-AG4F automatic servo material testing machine was set as 0.15mm/min[4]. T stress is constantly applied to the precast crack of rock, and when the rock is loaded and fractured, the loading is stopped. In the test process, KUFR software is used to collect and process the test data of rock fracture toughness [5]. According to the test data, rock fracture toughness is calculated, and its calculation formula is as follows:

$$R = \frac{P\sqrt{\pi q}}{2Zh} Y(y,x) \quad (2)$$

In the formula, R represents rock fracture toughness; P represents the maximum load on the load displacement curve of the rock fracture toughness test; q represents the length of the rock crack;

Z represents the radius of the half disk test piece; h represents the thickness of the half disk test piece; Y represents a non dimensional stress intensity factor for a half disk specimen; y represents the degree of prefabricated cracks; x represents the relative support point spacing [6]. In the calculation of rock fracture toughness, the value of the dimensionless stress intensity factor parameter of the sample is related to the relative support point spacing and the degree of pre cracking, as shown in Table 1.

Table 1: Dimensionless Stress Intensity Factors of Test Pieces

Crack prefabrication degree	Relative support point spacing			
	25	35	45	55
0.1	0.15	0.22	0.41	0.56
0.2	0.85	1.02	1.25	1.41
0.3	1.26	1.58	1.96	2.14
0.4	2.12	2.86	3.59	4.16
0.5	2.86	3.45	5.48	5.28
0.6	3.48	5.25	5.95	6.56
0.7	4.03	5.96	6.35	7.15

In addition, it is also necessary to calculate the T stress value of the rock, and its calculation formula

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is as follows: *P*

L= *X* (*y*,*x*,α) (3) 2*Zh*

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In the formula, *L* represents rock T stress; *X* represents non dimensional T stress of rock; αrepresents the crack inclination angle [7]. Through linear loading until the semicircular disk rock specimen ruptures, after stopping loading, the fracture toughness, T stress, and crack initiation angle of each specimen are counted for subsequent analysis of the impact of T stress on rock fracture toughness.

3. Results and Analysis

Use Formula (2) and Formula (3) to calculate the fracture toughness and T stress of each sample, and record the test data in the spreadsheet, as shown in Table 2.

Test piece serial number	Maximum load/KN	Fracture toughness/MPa	T stress/MPa	Cracking angle/°
1	4.26	1.56	- 0.25	0
2	3.15	1.12	- 0.03	0
3	3.56	1.35	0.15	23
4	5.48	2.56	0.34	35
5	6.25	3.25	0.42	42
6	7.15	4.15	0.56	56
7	8.06	5.25	0.68	59
8	9.41	6.24	0.86	61

Table 2: Test Results of Rock Fracture Toughness

As can be seen from the data in the table above, with the increase of rock crack dip Angle, rock T stress and maximum load increase, and rock fracture toughness also increases with the change of stress, rock fracture toughness ranges from 1.12MPa-6.24MPa, and rock T stress varies from -0.25MPa-0.86MPa. In the testing process, it is found that when the load reaches the maximum, the semi-disk rock specimens with different crack angles will suddenly fracture, accompanied by a part of the rubble collapse, and then the load of the semi-disk rock specimens suddenly drops. In the whole process, the semi-disk rock specimens with different crack angles show obvious brittle failure characteristics, and there is no yield stage in the whole process.

In order to further analyze the mechanism of the influence of T stress on rock fracture toughness, the rock crack propagation criterion is used as a theoretical basis to analyze it. Under the assumption of plane linear elasticity, the circumferential stress distribution at the rock crack tip can be expressed by the formula:

1 α

ε= cos ^{2} □□*R*(1 cosα)□□ *L*+sinα$\sqrt{Qu+}$ (4) $^{2\ 2\pi Z}$

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Where, ε represents the circumferential stress of rock crack tip; *O* represents the critical value of circumferential stress at the crack tip; *u* represents the critical value of the radius of rock crack growth zone. Under the rock fracture mode, the solution of rock initiation Angle can be obtained, and its calculation formula is as follows:

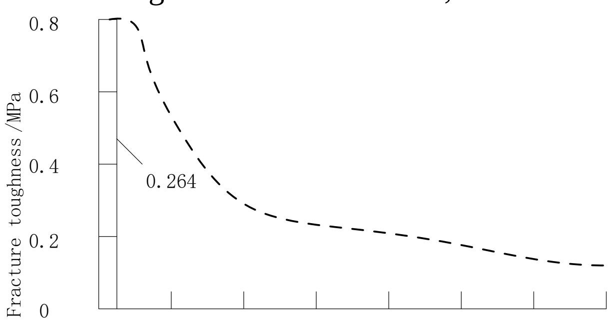
$$\beta = 2\cos^{2} \quad \frac{3R}{32L\sqrt{2\pi Z}} + 1 \quad \sqrt{ - \frac{3R}{2\,32L\sqrt{2\pi Z}} } \qquad (5)$$

In the formula, β represents the rock fracture initiation angle. In order to facilitate analysis, two parameters are introduced in this study, and the parameters are expressed as follows:

$$U = \frac{T\sqrt{2\pi Z}}{L}$$

$$G = \frac{\sqrt{2\beta}}{\alpha} \qquad (6)$$

Where, *U* and *G* represent two parameters. According to the above formula, the influence of T stress on rock fracture toughness can be obtained, as shown in Figure 1.



0 1 2 3 4 5 6 7

UG

Figure 1: Changing Law of Rock Fracture Toughness

As can be seen from the above figure, when and only when the multiplication of the two parameters is less than 0.264, the fracture toughness is the same as considering only the singularity of T stress; When the multiplication of the two parameters is greater than 0.264, the rock fracture toughness after T stress *L* is not ignored, and the ratio of the two parameters is not 1. According to the above criteria for determining the propagation of rock cracks and the data from this rock fracture toughness test, the variation trend of the impact of T stress *L* on rock fracture toughness can be obtained. If the impact of T stress *L* on rock is not considered, under the action of external forces, rock cracks will expand and extend along the angle and direction of the prefabricated cracks. When the rock fractures, the rock cracks are penetrating cracks; After considering T stress *L* , when the product of the two parameters

U and *G* is less than 0.264, the rock fracture toughness is equal to the rock fracture toughness that only considers stress singularity. That is, when calculating the rock fracture toughness, it is only necessary to calculate the rock fracture toughness that considers stress singularity. When the product of the two parameters *U* and *G* is greater than 0.264, the rock crack does not extend and expand along the direction and angle of the prefabricated crack, and the crack direction changes. During the extension and expansion process, the crack deflects, and the axial direction of the crack tends to the direction of rock load loading.

To sum up, T stress has a great influence on rock fracture toughness, and the two are positively correlated, that is, with the increase of T stress, rock fracture toughness of different crack angles will increase. When only T stress is considered, the direction of rock crack propagation and extension under the influence of T stress gradually tends to the loading position of rock, and the crack will not extend and change along the direction of prefabricated crack. Therefore, in practice, the crack propagation direction can be controlled by controlling the circumferential stress of rock crack tip.

4. Conclusion

This time, based on relevant literature and data, through rock fracture toughness tests, we explore the impact of T stress on rock fracture toughness. This study has important theoretical and engineering significance, which can effectively prevent rock fracture problems and avoid huge disasters and accidents. At the same time, it also provides a reference basis for rock fracture toughness analysis and research. However, due to the limited time available for this study, rock classification was not included in the study. In the future, in-depth exploration will be conducted in this area to deepen the study of the impact of T stress on composite fracture toughness of rocks and enrich the theory in this area.

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