Mechanical Properties and Energy Analysis of Rock under Different Unloading Confining Pressures

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Abstract: In order to study the mechanical properties and energy characteristics of rock under different unloading confining pressures, the triaxial unloading confining pressure of granite was studied by MTS815 rock mechanics test system; and the curve deformation characteristics of whole process of rock stress-strain under different unloading conditions and the energy dissipation law of the rock specimen in unloading and confining failure process were analyzed. The results show that the granite fracture is dominated by shear failure under the conventional triaxial path and the macroscopic cracks generated by rock specimen failure under low confining pressure are significantly more than the high confining stress state; the circumferential hazard and volumetric strain of rock during unloading confining pressure has a linear relationship with the confining pressure in the initial stage, and then changes into a significant nonlinear relationship; Under the unloading confining pressure condition, the rock also has strain softening characteristics and fracture expansion characteristics after yield failure; the elastic modulus hardly changes in the initial stage and is greatly reduced after the break point; the elastic strain energy that can be released increases slowly in the initial stage, and increases sharply when the confining pressure decreases to a certain extent; the initial confining pressure on the axial strain energy, the circumferential expansion capacity and the degree of influence of elastic strain energy is significantly greater than that of the unloading path, and both increase approximately linearly with the increase of initial confining pressure. The study results of this paper provide a reference for further research on rock mechanics and energy properties under unloading confining pressure.

1. Introduction

The rock mass is usually under complex stress state and is subjected to the three-direction stress. Due to the excavation of the underground engineering, the stress in one direction of the rock mass is released, thereby destroying the initial stress balance state of the original rock mass, causing the stress redistribution of the rock mass and the deformation and destruction of the rock mass. Due to the excavation unloading, the elastic strain energy accumulated inside the rock mass can be suddenly released, and the released energy leads to the expansion of the joint crack of the rock mass. When the rock mass releases the strain energy stored internally and the rock mass are too late to release, it will inevitably cause instability of the surrounding rock mass structure. For example, geological disasters such as rock burst, collapse, fracture and slippage have brought serious threats to the stability of surrounding rock and the safety of personnel equipment [1, 2]. Therefore, it is of great theoretical and practical significance to study the mechanics and energy properties of rock under different unloading confining pressures.

In recent years, with the development of rock mechanics and the needs of engineering construction, research on the mechanical properties of rock unloading has also made some progress, such as the study of rock triaxial compression and unloading confining pressure; complex loading and unloading of marble the stress path failure mechanism is analyzed; the relationship between rock deformation parameters and confining pressure under unloading conditions is studied; the results of the first classical rock uniaxial and triaxial tests show that the elastic modulus of marble does not follow the change of pressure changes with the same elastic modulus as that of uniaxial compression; the experimental results of the samples, sandy mudstone and compact rock samples

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show that the elastic modulus of the rock increases with the increase of confining pressure and has a nonlinear relationship [3]; the relationship between energy dissipation, energy release and rock strength loss and overall damage during rock deformation is studied, and the strength loss criterion based on energy dissipation and the overall failure criterion based on energy release are derived. The above results enrich the study of rock unloading mechanical properties, but there is still a lack of systematic analysis of the hoop deformation and expansion of the rock unloading damage. The real-time unloading confining pressure effect is not considered, and the unloading is not considered comprehensively. The influence of initial confining pressure and confining pressure unloading degree on rock deformation parameters also lacks comparative analysis of rock strength parameters and strength criteria under different stress paths [4].

In order to study the mechanical properties and energy characteristics of rock under different unloading confining pressures, the triaxial unloading confining pressure of granite was studied by MTS815 rock mechanics test system; and the curve deformation characteristics of whole process of rock stress-strain under different unloading conditions and the energy dissipation law of the rock specimen in unloading and confining failure process were analyzed. The detailed chapters are arranged as follows: Section 2 introduces the experiment design scheme from the aspects of rock samples, instruments and solutions, and analyzes the mechanical properties of the rock samples under different unloading confining pressure conditions; Section 3 performs the energy analysis of rock samples under different unloading confining pressure conditions; Section 4 is conclusion.

2. Mechanical properties of rock under different unloading confining pressures

The test specimens were taken from the granite in the deep buried section of the tunnel. In order to reduce the discreteness of the test results, rock specimens were obtained by intensive drilling from a large rock block and processed into cylindrical specimens with a height of about 100 mm and a diameter of about 50 mm [5]. The test was carried out on the MTS815 rock test machine, which can measure the axial and hoop strain of the sample and can record high-speed data. It is one of the most complete and technically advanced rock mechanics test equipment. The axial deformation of the rock sample during the test was measured by an axial extensometer. The hoop deformation of the rock sample was measured by a chain-oriented ring-elongation meter, and the chain was placed in the middle of the sample [2].

The stress-strain curve of rock under unloading test is shown in Figure 1. The axial load of the test is controlled by strain, and the loading rate is 0.15 mm/min. The unloading pressure is controlled by stress, and the rate is 0.025 MPa/s. The test procedure is as follows: the axial pressure and the confining pressure are gradually applied to the predetermined values of 4 MPa, 8 MPa and 12 MPa according to the hydrostatic pressure conditions; the confining pressure σ3 is kept unchanged, and the axial stress σ_1 is gradually increased to the rock sample. 70% of the peak strength; keep the axial deformation unchanged, gradually reduce the confining pressure σ_3 until the rock sample is destroyed [6]; the unloading test adopts the load control, which is automatically controlled by the test aid software system program, and the axial pressure before unloading the confining pressure The loading rate is 1.5 kN/s, the unloading pressure is 0.05 MPa/s, and the unloading pressure is 0.05 MPa/s. It can be seen that the triaxial strength has a good linear relationship with the confining pressure. Under the condition of unloading confining pressure, the triaxial strength of the specimen is affected by the confining pressure and has the same law under the loading condition [7].

Under unloading conditions, the cohesive force of the rock is reduced and the reduction is large, while the friction angle is increased. During the unloading process, the deformation of the rock is mainly caused by the deformation caused by the expansion and expansion of the main direction of the unloading. In the compression test, the failure of the test piece is mainly caused by the deformation of the compression shear, and it is obvious that the rock is shearing. When it is destroyed, its cohesive force value is lower than that of the compression shear failure; in general, the fracture surface formed by tensile shear failure has higher roughness than the compression-shear fracture surface and strong anti-friction ability. Therefore, the friction value is relatively higher [8].

When the confining pressure is 1.45, 2.58, 9.37 MPa, the elastic modulus of the granite hardly changes with the decrease of the confining pressure, and only slightly decreases in the smaller range before the confining pressure, that is, the failure point. When the confining pressure is further lowered beyond the failure point, the elastic modulus of the granite is sharply reduced, showing a distinct brittle failure characteristic [6].

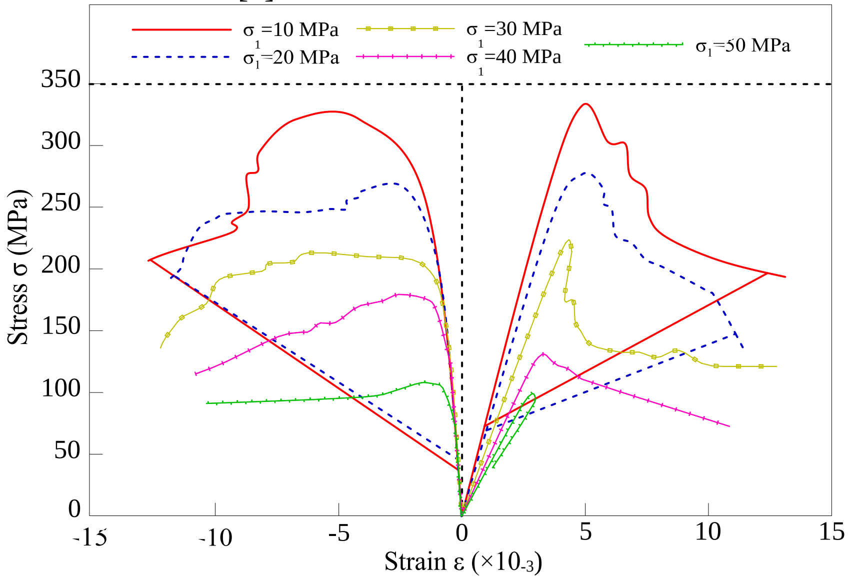

Figure 1 Stress-strain curve of rock under unloading test

The unloading pressure rate has a certain influence on the deformation and failure characteristics of the rock sample: the smaller the confining pressure reduction rate, the larger the final expansion strain of the rock sample, which indicates the propagation and stress of the crack in the rock mass when the unloading confining pressure rate is low. The transfer has sufficient time to complete, and the initial damage and proliferated cracks in the material have sufficient time to further evolve and develop. Therefore, the lower the unloading rate, the greater the ultimate strain at which the specimen is broken. At a slow unloading rate, the acoustic emission phenomenon is frequent due to the sufficient expansion of the crack, and the slower the unloading rate, the greater the energy emission rate of the acoustic emission. Conversely, when the unloading pressure is faster, the propagation of cracks and the transfer of stress are insufficient. The final bearing capacity is greater. When the unloading speed is fast, the sample can only produce a few rupture surfaces along the initial rupture direction. The greater the energy released [9]. From the initial unloading pressure to the end of the test, the principal stress difference decreases as the lateral deformation increases. It shows that in the process of fixed axial strain unloading pressure, it is also a plastic strain softening process with plastic strain softening characteristics.

3. Energy analysis of rock under different unloading confining pressures

In the conventional triaxial loading test of rock, the test machine performs positive work on the rock in the axial direction, and the lateral direction pressurizes the work on the rock. It is assumed that the physical process has no heat exchange with the outside world, that is, a closed system. Therefore, according to the first law of thermodynamics, the strain energy U of the rock during the whole test can be expressed as [10]:

$$U = U_1 + U_3 \tag{1}$$

$$U = U_e + U_d \tag{2}$$

Both U_1 and U_3 can be obtained from the stress-strain curve integration:

$$U_1 = \int_0^{\varepsilon_1^t} \sigma_1 d\varepsilon_1 \tag{3}$$

$$U_1 = \int_0^{\varepsilon_3^t} \sigma_3 d\varepsilon_3 \tag{4}$$

Where: ε_1^t is the axial strain at time t; ε_3^t is the lateral strain at time t. Under the conventional triaxial test, the elastic strain energy U_e at time t during the test can be solved according to the following formula:

$$U_e = \frac{1}{2E_u^t}\left[\sigma_1^2 + 2\sigma_3^2 - 2\mu_u^t(2\sigma_1\sigma_3 + \sigma_3^2)\right] \tag{5}$$

Where: E_u^t and μ_u^t are the three-axis unloading elastic modulus and Poisson's ratio at time t, respectively.

At the stage before the predetermined confining pressure is reached, the stress conditions of the constant axial pressure unloading confining pressure test and the corresponding conventional triaxial test rock samples are completely consistent with the stress path, so the energy evolution law is consistent with conventional triaxial test. At this stage, the energy growth is slow, and proportion of energy in the whole process is small. When the energy storage limit is reached, the elastic strain energy of the conventional triaxial test is 0.45 MJ/m^3, and the elastic strain energy of the constant axial pressure unloading confining pressure test is 0.55 MJ/m^3. This shows that at the same confining pressure level, the absorption energy can be converted into a larger elastic energy than the conventional triaxial stress path. In the whole failure process of the two rock tests, the total energy absorbed by the conventional triaxial test was 1.95 MJ/m^3, and the constant axis pressure unloading confining pressure test was 1.35 MJ/m^3. This shows that under the same level, the stress conditions of conventional triaxial test have more safety reserves in actual engineering (Figure 2) [11].

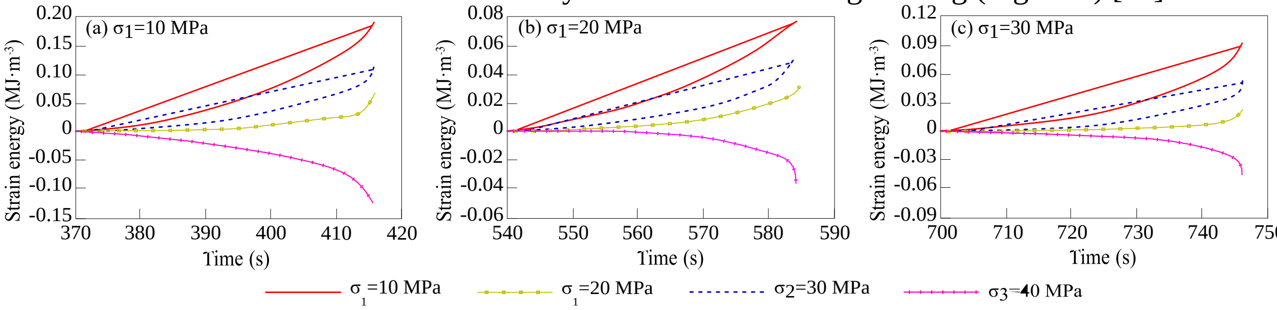

Figure 2 Strain energy conversion curve of rock under unloading test

When the confining pressure is gradually increased, the increase of the damage degree of the rock sample becomes slower with the increase of the cumulative specific energy absorption value, that is, the higher the confining pressure, the more energy is required to be dissipated when the test piece reaches the same damage degree. Other areas inside the rock sample will gradually yield, and then new cracks will be generated, which will cause multiple sections to yield, plastic deformation will continue to increase, so that the rock sample will yield a platform during axial compression, and the rock sample will need to be dissipated more [12]. The axial absorption strain energy in the initial stage of unloading confining pressure increases linearly. The strain energy in the hoop direction decreases linearly, and the elastic strain energy and dissipated energy remain basically unchanged. The axial absorption strain energy of the rock sample, the strain energy consumed by the hoop expansion, the elastic strain energy and the dissipated energy all increase with the increase of the initial confining pressure. The dissipative energy of the damage dominates, and the rock gradually undergoes macroscopic damage [10].

The lower the confining pressure of the rock sample during unloading, the greater the energy released during the failure process, and the less energy the rock material actually absorbs in the rock sample. That is, the larger the stress difference, the larger the unloading amount is, the more energy is released, and the higher the energy release rate is. As the energy is released, the rock damage is worsened and the bearing capacity is gradually reduced. To a certain extent, the test piece suddenly broke [8]. During the unloading process of granite, the elastic strain energy stored in the early stage is gradually released, which promotes the cracking and expansion of the internal micro-cracks until it penetrates. As the confining pressure decreases, the granite will suddenly break down when the elastic strain released by the granite accumulates to the surface energy required for the failure of the rock sample.

4. Conclusions

In order to study the mechanical properties and energy characteristics of rock under different unloading confining pressures, the triaxial unloading confining pressure of granite was studied by MTS815 rock mechanics test system; and the curve deformation characteristics of whole process of rock stress-strain under different unloading conditions and the energy dissipation law of the rock specimen in unloading and confining failure process were analyzed. The results show that when the unloading pressure is 1.45 MPa, 2.58 MPa, 9.37 MPa, the elastic modulus of the granite hardly changes with the decrease of the confining pressure, and only slightly decreases in the small range before the confining pressure; the fracture of granite under the path is mainly shear failure; the elastic modulus hardly changes in the initial stage, and it decreases greatly after crossing the failure point; the smaller the confining pressure reduction rate, the larger the final expansion strain of the rock sample, which indicates the unloading pressure rate; at lower times, the propagation of cracks in the rock and the transfer of stress have sufficient time to complete, and the initial damage and proliferated cracks in the material have sufficient time to further evolve and develop; the elastic strain energy of the conventional triaxial test is 0.45 MJ/m^3, the elastic strain energy of the constant axial compression and unloading confining pressure test is 0.55 MJ/m^3, which indicates that the initial confining pressure has a greater influence on the axial strain energy, the circumferential expansion capacity and the elastic strain energy than the unloading path, and both The increase in initial confining pressure increases approximately linearly.

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