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Experimental Investigation of The Granite Subjected to Unloading Confining Pressure Creep Test

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Abstract

Triaxial tests were performed on granite specimens from the dam foundation of the Mengdigou hydropower station by using a triaxial servo rheometer, and the basic mechanical characteristic parameters of the granite were obtained. After that, the triaxial unloading rheology tests of the granite specimens were developed. Based on the unloading rheological test results, granite unloading rheology stress-strain characteristics were analyzed. The rheological properties and the rheology regularity of granite specimens, axial, lateral, and volume were discussed, and the macro and microscopic failure modes of granite specimens were analyzed. The test results demonstrated that the granite behaved with remarkable rheological properties under long-term unloading and existed a typical unloading rheology threshold effect. According to the volume change, the rheological curve was mainly divided into volume compression, volume stability, volume expansion, and the last failure stage after the peak. Throughout unloading rheology tests, the lateral deformation was more observable than that of the axial. The rheological unloading deformation was given priority to the lateral expansion. But the U-shape of the creep rate is constant with the process development. When the confining pressure of unloading at a low level, the failure mode is splitting failure. With the increase of the confining pressure level, the failure mode gradually changes into sheer failure. Still, when the confining pressure reached a high level, it would develop into a "V" shape failure surface on granite specimens. The tests and related analysis results provide a reference for related high arch dam engineering.

Keywords

high arch dam ; unloading rheology ; creep characteristic ; granite ; failure mode; long-term loading

I. INTRODUCTION

The rock of the high dam foundation behaved with remarkable rheological properties under long-term unloading[1]. Scholars at home and abroad carried out the triaxial rheology tests in different stress paths and studied the mechanical properties of different types of rocks relying on different engineering backgrounds [2-11]. The test results provided further proof that the rocks behaved with remarkable rheological properties under long-term unloading. With the increase of crustal stress, the phenomenon of rheology was more remarkable. With the development of high dam engineering, the researchers found that the high dam engineering excavation slope can also make the rock mass-produce intense deformation, which is accomplished mainly by unloading. In recent years, Scholars set out to research the mechanical unloading properties of rocks. Ren[12] completed the real-time CT test of the granite's regularity with a single fracture under the unloading confining pressure. It indicated that the single fracture granite was destroyed with a sudden under conditions of unloading. LÜ[13] carried out the granite's unloading mechanical properties tests under the two different stress paths in high geo-stress conditions. The contrastive analysis of the results and the conventional triaxial compression test results under the same confining pressure revealed that under the condition of high stress, the greater the unloading rate, the higher the strength of the rock specimen. HUANG[14-15] studied the deformation and strength characteristics of the granite and marble, and the results showed that the rock damage possessed obvious tensile fracture characteristics under the condition of unloading, and the greater the unloading rate and initial confining pressure, the more obvious the brittle and tensile fracture characteristics of the rock. ZHANG[16] conducted a test by adding axial compression and unloading confining pressure for hard limestone and found that the specimen's volume produced strong expansion when damaged, caused by an intense expansion in the direction of the unloading.WANG[17] attempted the rheological unloading test at different stress levels. Still, the same initial confining pressure for the argillaceous siltstone analyzed how the joints affected the argillaceous siltstone's unloading rheology. ZHANG[18] carried out the triaxial rheological tests of hard, brittle diabase in different stress paths using a triaxial rheology testing machine and found that the threshold effect existed in both the unloading rheology and the loading rheology. The loading rheology's failure pattern is mainly a shear failure, while the unloading rheology was mainly splitting failure. The strength of rheology damage was less than the conventional strength. Li[19] conducted an experimental study on granite specimens at different unloading rates to determine the relationship between the unloading rate and the rock's mechanical properties. It was indicated that the faster the unloading rate, the more easily broken the sample was.

Although progress has been achieved in many research work, the scholars were mostly devoted to depending on the conventional triaxial test to study the strength, deformation, and failure of several rocks under different stress paths and the unloading effects that would impact the deformation and long-term stability of high dam engineering are not getting enough attention so that the above results have some limitations in the application of practical engineering. The research of rheological, mechanical properties of rock mass of high arch dam foundation under long-term unloading needs to be further developed. The triaxial unloading rheology tests of the granite specimens under different confining pressure levels were developed relying on Mengdigou hydropower station. The characteristics of granite unloading rheology stress-strain were analyzed based on the test results. The change regularity of axial, lateral, and volume of granite specimens and creep rate were summarized, the macro and microscopic failure modes of granite specimens were discussed. The tests and related analysis results laid a solid foundation for studying the unloading rheological, mechanical properties of granite. It also provides a reference for the studies of the long-time stability of high arch dam foundation slope engineering.

II. ENGINEERING BACKGROUND AND TEST DESCRIPTION

A. Engineering Background

Mengdi-gou hydropower station is the fifth step in seven development plans of Yalong river middle reaches, located in the boundary between the jiulong county town of Ganzi province of China and Muli county town of Liangshan province of China, and the upstream and downstream connect with Lengu and Yangfanggou step respectively. The southwest mountainous area, a close neighbor, with a high altitude of 3700-5300 m, is geomorphologically the Western Sichuan Plateau. The dam site was built on the triangle site where the Litang-Wude fault zone and Yunongxi fault zone were crossed. Light color granite (vein) and calcite-quartzite (vein) were developed partial argillation, and sporadic melanosome can be observed on the surface of light color granite. The reservoir region's normal water level is 2254m, and the installed capacity is 2.2 million KW. Dam type is a concrete double curvature arch dam with a maximum height of 240m.

B. Test Objective

Tests of unloading rheology are the main means to know the rocks' unloading mechanics characteristics under long-term load. Using the RLW-1000 automatic triaxial servo rheometer, the triaxial unloading creep tests of the granite from the Mengdigou hydropower station dam were completed in the constant temperature rheological laboratory with no disturbance. The unloading rheological, mechanical properties and fracture mechanism of granite under the complex stress were analyzed based on the test results.

C. Description of Specimen

The granite specimens used in the tests are hard, brittle rock, a cylinder of Φ 50×100mm, made from Mengdigou hydropower station dam foundation without water operation. Fig.1 shows some rock specimens.

Fig 1: Some rock specimens

D. Test Conditions

Mengdigou hydropower station dam foundation lies in a high-stress field. To study the rheological unloading effect of granite under high stress and the rheological response characteristics of granite, the scope of confining pressure in the unloading rheology tests were limited to 10 MPa to 40 MPa based on the in-situ stress data and related engineering content. The test's stress path is unloading rheology, maintaining the total stress σ_1 unchanged, and unloading confining pressure step by step until the rock damage. Four test conditions were designed as follows:(1) the initial confining pressure σ_3=10 MPa, the total stress σ_1=90MPa, unloading the confining pressure step by step until the rock damage;(2) the initial confining pressure σ_3=20 MPa, the total stress σ_1=85MPa, unloading the confining pressure step by step until the rock damage; (3) the initial confining pressure σ_3=40 MPa, the total stress σ_1=80MPa, unloading the confining pressure step by step until the rock damage. Specific test conditions of unloading rheology tests are as shown in Table 1.

TABLE 1

Unloading Rheology Testing Program

Test conditions	***Different initial confining pressure, constant σ_1, unloading step by step, until the rock damage***		
Specific description	σ_3=40Mpa,σ_1=80Mpa, 7 steps, rock damage	σ_3=20MPa,σ_1=85Mpa, 5 steps, rock failure	σ_3=10Mpa,σ_1=90Mpa, 3 steps, rock failure

E. Triaxial Tests

The granite's conventional triaxial tests were performed before unloading rheology tests to obtain basic mechanical parameters of the granite of Mengdigou hydropower station dam foundation. And the axial compressive strength is 76 MPa, the cohesive force of 20.44 MPa, and the friction Angle is 55.2°. Fig.2 shows the stress-strain curves of granite specimens under different confining pressure.

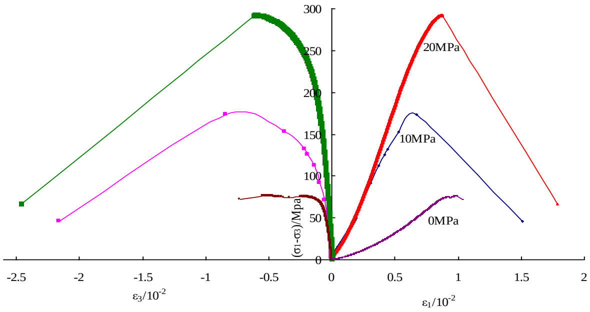


Fig 2: Stress-strain curves of granite specimens under different confining pressure

Fig.2 shows that the uniaxial compression stress-strain curves have mutations on certain points that make the curves bumpy. Why there are mutations? It is mainly due to the serious local damage that occurs in compression when the rock surface is broken, and small pieces are peeled, resulting in discontinuous data collection of the deformation at some point. The effect of the local fracture on lateral deformation is more obvious.

When the rock is subjected to the confining pressure and deviatoric stress, the small openings of the internal part are closed, the void ratio is decreased, and the stress-strain curve is concave upward. With the increase of axial load, the deformation is proportional to the stress increase and obvious linear elasticity. With the continuous increase of stress, the existing cracks began to extend and generate new cracks, and the quantity and dimension of cracks are increasing. Then, the interpenetration of a large number of cracks makes the structural plane emerge shear slip. At this moment, the rock specimen enters to stage of unsteady crack growth. When it reaches the peak, the specimen happens sudden destruction and loses carrying capacity.

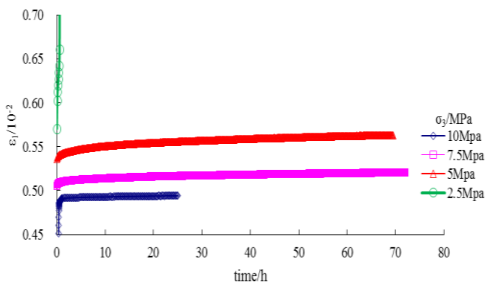
III. TEST RESULTS OF UNLOADING RHEOLOGY

A. *The Axial Rheological Test Results*

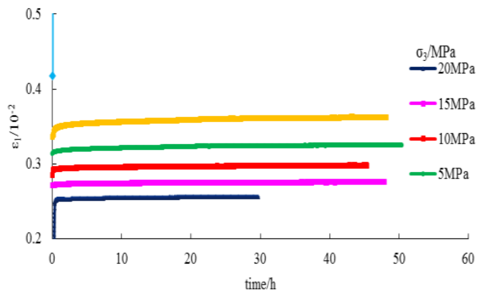
In the process of creep, the axial deformation shows compression. In the early unloading, the axial creep deformation is small, and the rheological phenomenon is not obvious. With the decreasing of confining pressure, the rheological deformation increases at a steady rate. And the rheological deformation increases continuously afterward, then the rheological rate accelerated growth, and finally leads to rapid creep failure.

Fig.3 shows the axial creep curves under various unloading confining pressure, taking confining pressure 20Mpa as an example. The initial stress level: σ_3 =20MPa, $\sigma_1 - \sigma_3$ =85Mpa, after 5 steps of unloading, took 222.12 hours, rock failure.

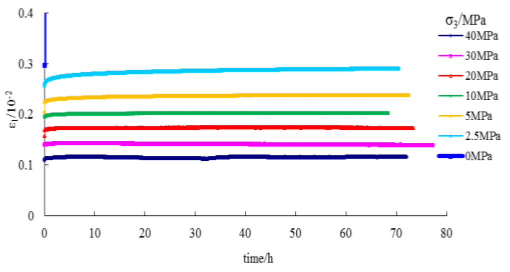
The first step is to decrease confining pressure to 15MPa, and axial instantaneous dependent variable increases by 0.01554ε (here, ε stands for 10^{-2}, and the same as below), after 48 hours' steady rheology, the axial strain increases 0.00464ε; The second step is to decrease confining pressure to 10MPa, and axial instantaneous dependent variable increases by 0.00986ε, after 48 hours' steady rheology, the axial strain increases 0.01246ε; The third step is to decrease confining pressure to 5MPa, and axial instantaneous dependent variable increases by 0.01508ε, after 48 hours' steady rheology, the axial strain increases 0.01166ε; The fourth step is to decrease confining pressure to 2.5MPa, and axial instantaneous dependent variable increases by 0.01160ε, after 48 hours' steady rheology, the axial strain increases 0.02615ε; The last step of decreasing confining pressure, and axial instantaneous dependent variable increases by 0.05521ε, and rock happens to rapid creep failure only lasts for 5 minutes, at that moment, the axial strain instantaneously increases 0.86958ε, and the final compression deformation of axial direction is 0.92449ε.



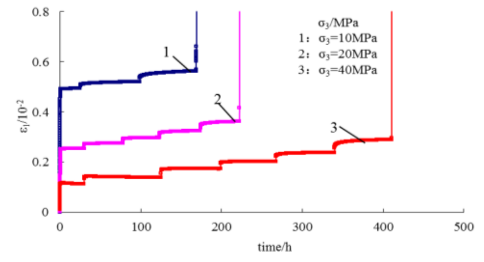
(a)10Mpa



(b)20MPa



(c)40Mpa



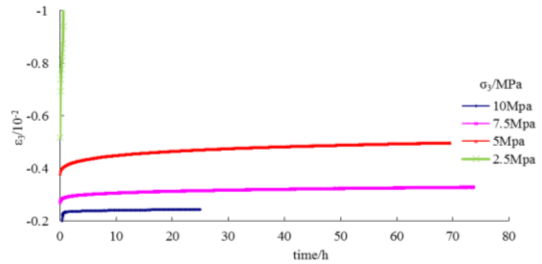
(d) Complete creep curves

Fig 3: Axial creep curves under various initial unloading confining pressure

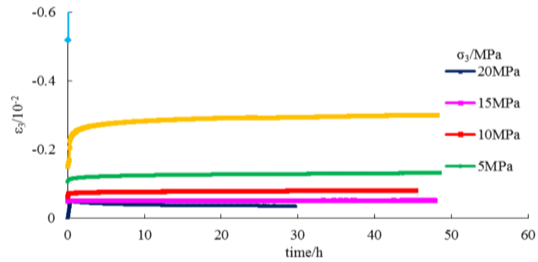
B. The Lateral Rheological Test Results

In the creep process, the lateral deformation appears to have a characteristic of dilatation at the beginning of unloading. The threshold value of the lateral creep is more obvious than that of the axial. It is not hard to find three stages present in the creep curves, described as the initial attenuation creep, steady-state creep, and accelerated creep. Fig.4 shows the lateral creep curves of the unloading rheology under different confining pressure levels. It is observed that when the confining pressure level reaches the threshold, the instantaneous deformation and creep deformation of the lateral is increased rapidly because of the unloading effect.

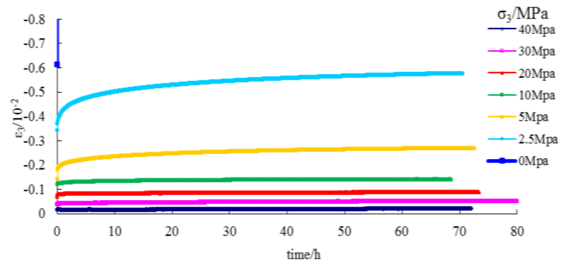
We still take the 20 MPa unloading test as a sample. In the early unloading, the lateral deformation increment is small, which is only 0.00234 ε at the first step, 0.01920 ε at the second step, and 0.02480 ε at the third step. The deformation is relatively stable. When at the fourth step, the increment becomes 0.14882 , which is 6.0 times the previous step. At the final step, a sharper rise appears, and the increment soars to 2.08803 ε , 6.0 times that of the axial deformation. And the rock specimen appeared to be accelerating in its expansion and destroyed rapidly. Generally, the lateral deformation is more apparent than that of the axial when long-term unloading rheology proceeds, so it can truly reflect the influence of stress on rheological deformation and is significant in the Study of unloading rheology characteristics and its long-term stability.



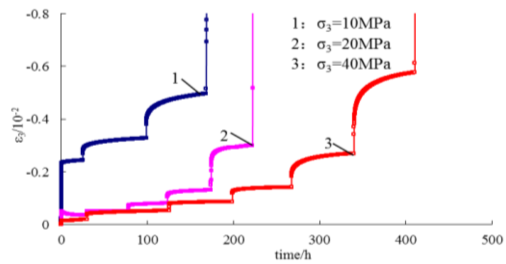
(a)10Mpa



(b)20MPa



(c)40Mpa

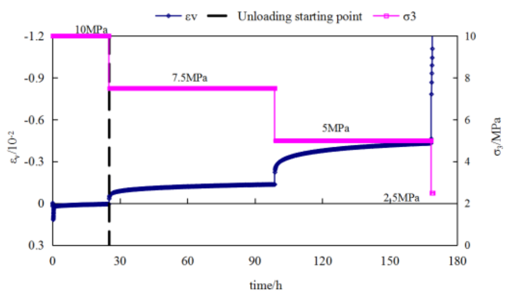


(d) Complete creep curves

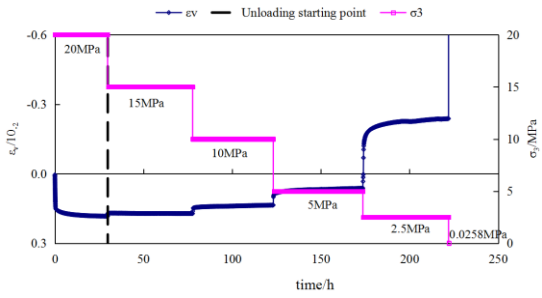
Fig 4: Lateral creep curves under various unloading confining pressure

C. The Volume Rheological Test Results

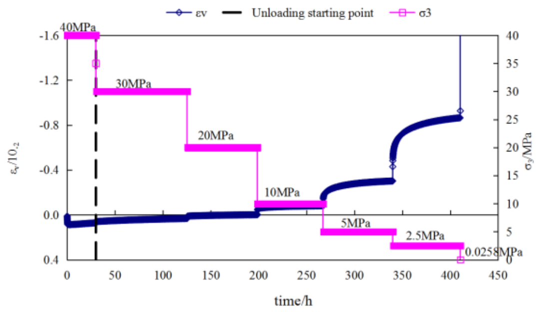
Volume deformation consists of compression and expansion. As shown in Fig.5, the volume deformation transforms from compression to expansion during the whole process of unloading rheology. We take the 40 MPa unloading test as a sample. When the confining pressure unloading rheology lasted 198.79 h, the confining pressure unloading decreases to 10 MPa while the deviatoric stress increases to 70 MPa, the volume strain is zero. This point was considered a cut-off point, from which the deformation converts compression to expansion, and the rock specimen appears volume expansion. Since then, the deformation is given priority to expansion, and the rock specimen is subjected to severe failure after lasting 211.91 h. In the whole process of unloading rheology, when expansion begins, the lateral expansion increases 0.12 ε, accounting for 98.4% of the total expansion, while the expansion time accounts for 52% of the total time. When the rock specimen is subjected to failure, the lateral's total creeps strain is 4.56 times that of the axial. The total instantaneous strain ratio and the total creep strain in terms of the axial, the lateral, and the volume are 48.24, 15.34, and 11.29. It illustrates that: (1) the compression deformation stage has a long duration, once the expansion occurs, the expansion exceeds the compression within a short time, and the expansion dominates the deformation. (2) The rock specimen's failure mode occurs as volume expansion, mainly dominated by the instantaneous strain.



(a)10MPa



(b)20MPa

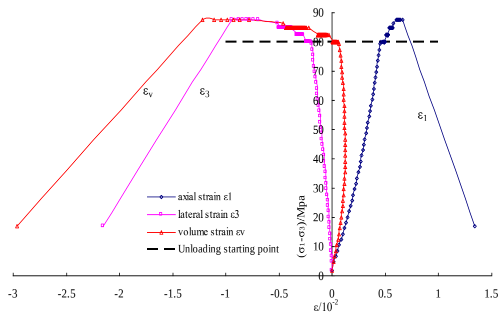


(c)40MPa

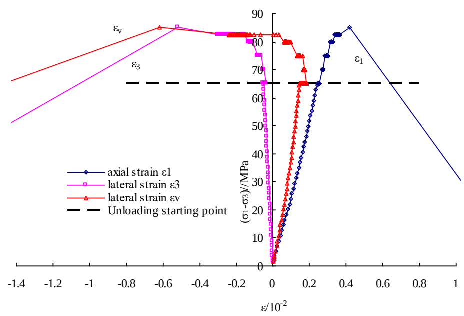
Fig 5: Volume strain curve of unloading rheology test

IV. CHARACTERISTIC ANALYSIS OF STRESS-STRAI

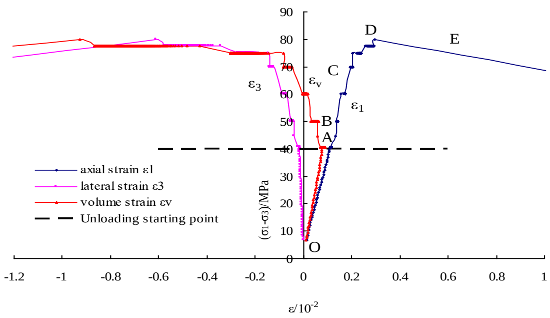
The typical stress-strain curves of granite unloading rheology tests are as shown in Fig.6.



(a)10Mpa



(b)20Mpa



(c)40Mpa

Fig 6: Creep stress-strain curve under various CP

The stress-strain curves of the unloading rheology tests of hard rock are different from the triaxial creep tests[20-21] shown as Fig.7, and mainly it is because when unloading confining pressure happens, it is equivalent to superpose tensile stress on the original stress, and easy to grow tensile cracks in the direction of σ_1. The creep deformation of macro performance is significant. Whatever the expansion generates from the start of unloading confining pressure. The unloading rheological test process is roughly divided into five parts following every part's main feature. And the stress-strain curves also behave five-stage, that is the original state simulation stage, the initial attenuation creeps stage, the steady-state creep stage, the accelerating creep stage, and the failure stage, which is described as OA, AB, BC, CD, and DE, shown as Fig.6(c).

OA: The original state simulation stage that simulates the original crustal stress and cracks of the rock specimen is closed.

AB: The initial attenuation creep stage (volume compression stage). With the unloading step by step, the deviatoric stress increases, and the axial compression rate gradually decreases, while the lateral expansion rate increases gradually. Still, deformation is given priority to compression and tends to be ladder-like at each step. At this stage, the friction between the surface of closed cracks inhibits the damaged surface movement, and the internal cracks of rock material have no expansion. Thus, there are no new microscopic cracks.

BC: The steady-state creep stage (constant volume stage). With decreasing confining pressure and increasing the deviatoric stress, the axial compression deformation tends to slow, while the lateral deformation is gradually obvious. At this stage, the axial and lateral axial rate is approximately the same, and the axial compression is synchronized with the lateral expansion. Moreover, the volume deformation is hardly affected by the rheology, and the deformation rate tends to be zero. At this point, the damaged cracks appear in the rock specimen, but the cracks are not through.

CD: The accelerating creep stage (volume expansion stage). Once entering this stage, the lateral deformation increases significantly, the volume behaves significant expansion, and the lateral expansion rate develops rapidly and exceeds the axial compression rate. The deformation is given priority to the lateral expansion. With the decreasing of unloading confining pressure and increasing the deviator stress, expansion appears even more significant. At this stage, the effect of stress concentration produced in the damage process makes damage cracks through soon, forms tiny cracks, and then fracture surface is generated quickly.

DE: The failure stage. After the rock bearing capacity reaches the peak strength, the fracture surface appears obvious slip, forms macro fracture surface, and the internal structure is destroyed, the bearing capacity reduces significantly. The whole process of failure is so brief that the specimen shows the obvious characteristics of brittle failure.

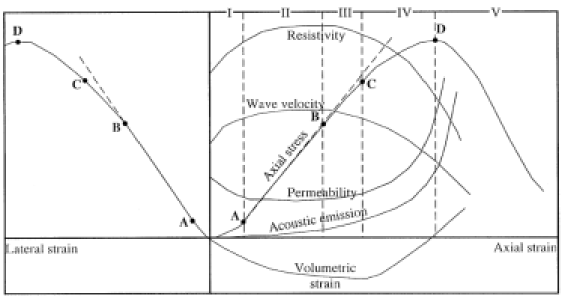
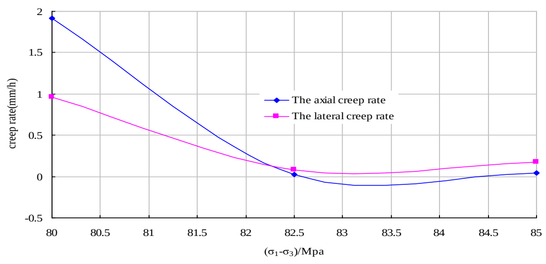


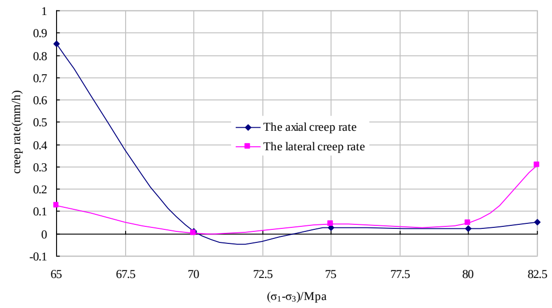
Fig 7: Curves of physical and mechanical characteristics of rock specimens in triaxial compression tests

V. THE INFLUENCE OF THE STRESS TO CREEP RATE

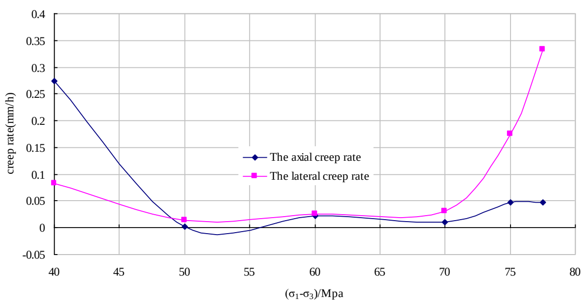
Plot the stress-creep rate curves of the axial and lateral creep under different confining pressure, as shown in Fig.8. By studying the axial and lateral creep rate change rule of unloading rheology, it is found that in the early unloading the axial creep rate is greater than the lateral creep rate, and the deformation is dominated by the axial compression, this stage is regarded as the volume compression stage; With the decreasing of unloading confining pressure and increasing of the deviator stress, the decrease of the axial creep rate and the increase of the lateral creep rate gradually slow down, the value tending to be zero, and volume deformation maintain a constant, this stage is regarded as the volume constant stage; But Soon Afterwards the lateral creep rate increases rapidly, and far more than that of axial creep rate, deformation is gradually dominated by the lateral expansion, and behaves the obvious volume expansion, this stage is regarded as the volume expansion stage; After the last step of unloading, the specimen behaves fast creep, and the instantaneous rate tends to infinity, and destroyed immediately. The creep rate curve is U-shape in the whole process of unloading. It is not hard to find that the lateral creep rate increases dramatically in the final damage step of unloading. With the increase of the initial unloading confining pressure, the lateral creep rate increases significantly. For example, when the initial unloading confining pressure level is 10Mpa, the lateral creep rate of unloading damage is 244.97mm/h; while the lateral creep rate is 2506.64mm/h under 20MPa, and 10.2 times of that of the 10MPa; and the lateral creep rate is 11642.98mm/h under 40MPa, and 47.5 times of that of the 10MPa, 4.6times of that of the 20MPa.



(a)10MPa



(b)20MPa

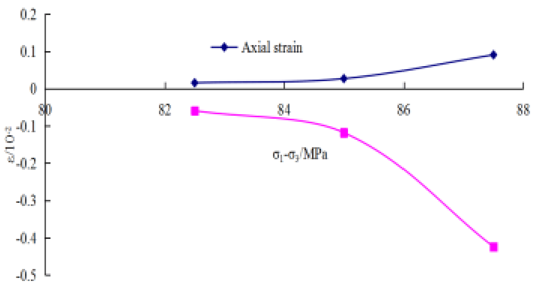


(c)40MPa

Fig 8: Stress and velocity curves

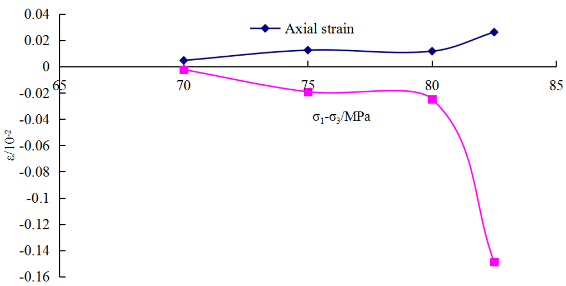
VI. THE INFLUENCE OF THE STRESS TO CREEP

Fig.9 shows the axial and lateral creep curves under different unloading confining pressure level; it is easy to discover that the unloading rheological creep tendency of the granite conform to the same direction roughly, that is, keeping the total stress unchanged and unloading confining pressure step by step, creep deformation increases with the decrease of confining pressure or, you might say, creep deformation increases with the increase of deviatoric stressed. Creep deformation increases rapidly at the last step, and the rock is destroyed in a short time. For example, in the last step of unloading under confining pressure 40Mpa, the axial strain has a sudden increase from 0.03466ε to 0.04097ε, which corresponding to the increase of confining pressure from 77.5 MPa to 80MPa, and the increment rate is 18.2%; Lateral strain has a sudden increase from 0.12748 ε to 0.23430 ε , which corresponding to the increase of confining pressure from 77.5 MPa to 80MPa, and the increment rate is 83.8%, and then entering the stage of accelerated creep, at last, it is led to macro expansion damage.

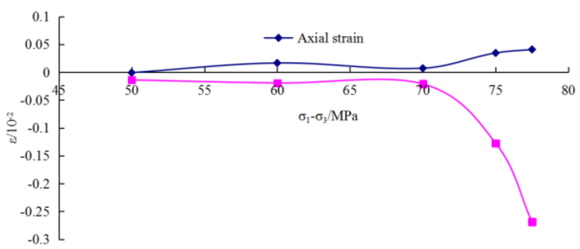


(a

)10MPa



(b)20MPa



(c)40MPa

Fig 9: Creep strain increment curve under various confining pressure

VII. CREEP FAILURE MODE AND MICROSCOPIC ANALYSIS

A. Triaxial Compression Failure Mode

Fig.10 shows the triaxial compression failure mode. We can see that the axial compression failure mode of granite specimen is the typical tensile fracture, some small debris peels when the specimen was damaged, and there is no unified failure surface. It is relatively broken as a whole and shows the obvious brittleness. Under the effect of confining pressure and deviatoric stress, the failure mode of rock specimen gradually changes from splitting failure to shear failure with the increase of confining pressure. There is an obvious shear failure surface when the confining pressure is high.

(a) 0MPa

(b) 10Mpa

(c) 20MPa

Fig 10: Failure modes of specimens under multi-stage axial loading with constant confining pressure

B. Unloading Rheological Failure Mode

Fig.11 shows the unloading rheological failure mode under different original levels of confining pressure. It can be seen that the unloading rheological failure mode is different from the conventional triaxial loading failure mode. The failure mode is splitting failure when the original confining pressure is 10MPa. Simultaneously, the obvious macroscopic shear fracture surface with fine powder appears when the original confining pressure is 20MPa. There are obvious slip traces between the fracture surface, and small pieces fall off occasionally. When the original confining pressure is 40MPa, the specimen's failure mode forms V-shape conjugate shear failure surface. The specimen shows a clear conjugate shear failure surface. The V-shape conjugate shear failure surface slips apparently when the original confining pressure is 40MPa. The internal structure is destroyed. The specimen no longer maintains integrity but is broken into three parts along the V-shape surface. The broken surface has a large number of fine powder, and the bearing capacity is significantly reduced.

In general, when the initial unloading confining pressure is low, the failure mode of rock specimen is mainly splitting tensile failure along the axial direction with small chippings on the appearance, and there is no unified macro fracture surface; When the confining pressure is high, the failure mode gradually changes from splitting failure to shear failure, and generates dominant fracture surface with obvious slip traces; with the increase of confining pressure, the dominant surface shows V-shape shear fracture, and the broken surface has a large number of fine powder. Rock specimens are quickly damaged with a loud sound at the final step of unloading and show the obvious brittleness characteristic.

(a)10MPa

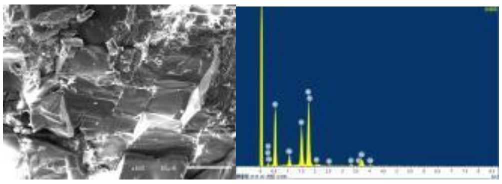
(b)20MPa

(c)40 MPa

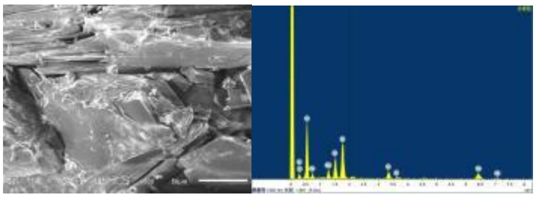
Fig 11: Failure modes of granite specimens under different levels of confining pressure in the unloading rheology test

C. Microscopic Analysis Of The Rheological Damage

We take the 40MPa unloading test as a sample. The microscopic structure and mineral element content from different points of the same damaged surface were analyzed by Scanning Electron Microscope(SEM). Fig. 12 shows the analysis results of the microscopic fracture. In contrast, Table 2 shows the results of the microscopic fracture component analysis.



(a) Spectrum A



(b) Spectrum B

Fig 12: The microscopic fracture cross-section analysis of granite specimens in the rheological unloading test by keeping σ_1 in constant（σ_3=20MPa）

TABLE 2

The Microscopic Fracture Component Analysis

Position	Spectrum A		Spectrum B	
Element	Weight (%)	Atom (%)	Weight (%)	Atom (%)
C	0.81	1.36	0.71	1.28
O	51.64	65.49	49.20	66.95
Na	3.98	3.52	/	/
Mg	/	/	3.71	3.32
Al	11.67	8.77	7.80	6.29
Si	23.94	17.29	15.96	12.37
K	0.89	0.46	5.79	3.22
Ca	5.42	2.74	/	/
Fe	/	/	16.83	6.56
Zr	1.66	0.37	/	/
total	100	100	100	100

With the above analysis, the microstructure of granite is mainly characterized by two features: 1. the mineral composition of some parts with low intensity is relatively complicated, which possess the characteristic of a typical gneissic structure, the high degree of metamorphism, poor crystallization degree, multiple metallic elements especially the high content of Mg, K and Fe, and is supposed to be chlorite which is transformed from the altered intrusive rocks, and mainly distributed in the fractured zone; 2. Also, the mineral composition of some other parts with high strength is relatively simple, which possess the characteristic of compact structure, uniform particle, good crystallization degree, metallic elements of Mg, K, Fe, and other rare metals.

The material consists of various kinds of components and is supposed to be a mineral aggregate. The macroscopic strength of the specimen mainly depends on the fastness degree and cementation degree of the inlaid combination of internal mineral grain. Rock is highly fractured in the two minerals' intersectional place: low cementation degree or the place of mineral grains that is Poor crystallization. So the mineral with poor crystallization degree and multiple metallic elements is supposed to be low strength and is easy to be broken earlier. The initial crack propagation of rock is extremely easy to have occurred in these weak positions with creep development under constant stress. The mesoscopic fracture is an important factor affecting the long-term macroscopic strength of the rock.

VIII. CONCLUSIONS

Based on the research of the granite's basic mechanical properties from the mengdigou hydropower station dam, the triaxial unloading rheological tests were performed on granite specimens under the condition of constant total stress, and the unloading rheological, mechanical properties, and rheological regularity of the granite were analyzed. The influence of mesoscopic fracture mechanism on long-time macroscopic strength was studied combined with the results of SEM, and the methods to determine the long-term strength of unloading rheology were discussed. The main conclusions of this research are as follows:

(1)Granite is characterized by high strength; when the unloading effect occurs, lateral deformation is more apparent than that of the axial. Though unloading rheological compression deformation lasts long, once expansion begins, the deformation of expansion is far greater than the compression in a short time, and the expansion dominates all the creep deformation. Rock specimen is easy to expand.

(2) The granite's unloading rheological process consists of three important stages: volume compression stage, constant volume stage, and volume expansion stage. In the initial, the axial compression is dominant. The axial creep rate is far greater than the lateral creep rate. The axial creep rate gradually decreases while the lateral creep rate gradually increases, soon it steps into a new stage and tended to be steady-it changed more and more slowly; With the continuous increase of deviatoric stress, the internal injury of the rock specimen increases, the lateral creep rate increased rapidly, and is far more than the increase of axial creep rate, the deformation is given priority to lateral expansion little by little. At the last step of stress, the creep rate increases quickly and rapidly enter the accelerated creep stage. When the strength reaches its peak strength, the rock specimen bursts to be destroyed, and the bearing capacity reduces significantly shows the obvious characteristics of brittle failure. The creep rate curve shows a U-shape in the whole process of unloading.

(3) The failure modes of granite differ between the rheological unloading test and the triaxial test. EMS founds on the fracture surface that when the initial unloading confining pressure is low, the rock specimen's failure mode is mainly splitting tensile failure. In contrast, when the initial unloading confining pressure is high, it is easy to be a shear failure, and the rock specimen shows a V-shape shear fracture with even higher confining pressure. The inlaid combination fastness degree of internal mineral grain and cementation degree among the mineral determines the long-term strength of rock.

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