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THEORETICAL AND EXPERIMENTAL STUDY ON DISTURBANCE EFFECTS ON ROCK CREEP(VOLUME Ⅱ)

—MESO-DAMAGE CHARACTERISTICS OF DISTURBANCE EFFECTS ON ROCK CREEP

岩石蠕变扰动效应理论及试验研究(Ⅱ)

——岩石蠕变扰动效应细观损伤力学特征

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Forward

At present, mining depth in China is over 800 meters, the maximum depth is over 1,200 meters . Roadways stability is poor because they is influenced easily by mining and excavation, and produce larger deformation. For weak rock masses, compressive strength is lower, which have characteristics of obvious ground pressure and strong rheological property. The amount of creep deformation is large enough to cause failure of support, costs of soft rock roadway are increased sharply, expense reach 20,000 Yuan per meter. Key technology of deep soft rock supporting is coupling support. To achieve coupling support, the core problem is to forecast accurately deformation of soft rock tunnels or roadways. Stress state of surrounding rock around roadways is in strength limit neighborhood, creep is the main part deformation, which can be caused by random disturbance loads(mining, rock burst, blasting). Previous many experimental studies of creep include uniaxial compression, uniaxial tension, triaxial compression, weak plane shear and relaxation. Most of the theoretical researches in the past were focused on element combinations, empirical, endochronic model, etc. The studies mentioned above were all conducted under the condition of static load. So far, however, only a few empirical researches have been done to investigate rock disturbance. The results of research indicated that damage model can simulate damage characteristics of rock materials under impact load and provide theoretical evidences for analysis of rock stability under disturbance load in geotechnical engineering. The research on creep

characteristics under disturbance condition is very significant not only for the stability of the geotechnical engineering, but for the development of rheology theory and the supporting of deep soft rock.

The stability of roadways or caverns is related to mining depth (or excavation depth). When deep roadways or caverns are subjected to larger stresses, the stress level is closer to critical state, small disturbance may cause rock cracks to extend dynamically at instantaneous time, and finally roadways or caverns will collapse. Hence, it is of great importance for supporting of soft rock and deep mining to study creep characteristics and damages of rock under disturbance load and to establish a theory of creep disturbance effects. This book is centered on the rock creep and its disturbance effects. When the load is approaching its ultimate strength , the disturbance effects on rock creep is one of the main topics of the book. Tests of triaxial compression creep and its disturbance effects, rock beam bending creep, MTS and CT scanning were carried out in laboratory. Achievements of the book are included as following:

Compared with axial creep, lateral creep is sensitive to confining pressure. Confining pressure has different effects on strength, elastic modulus and damage mode obviously.

On the basis of triaxial creep test under static loading, tests of triaxial disturbance creep effects were performed. It can be found that rock creep damages have a relationship with disturbance impacting energy under same confining pressure.

According to rock creep characteristics under continuous disturbance impact, further study on creep damages characteristics of rock was made. Damages of continuous disturbance impact have a relationship with load impulse and impact times under same confining pressure;

Damages of continuous disturbed impact are related to impact times and confining pressure under same load impulse. Confining pressure increase rock strength and decrease damages rate of rock creep.

Meso-mechanisms of disturbance damages were studied by CT scanning tests under step-wise loading conditions. Results show that creep damage is a process of plastic turning into brittle under low confining pressure conditions.

Analysis of median surface creep for grey sand stone, red sand stone and oil shale were made, fracture departs from median surface on rock beam by bending test.

Contents

1 Introduction

Distributions of stress fields and strain in underground geotechnical engineering have time-dependent effects. After canvers excavation, the surrounding rock deformation increases over time progressively. Creep is rock deformation growth with the passage of time when rock is subjected to constant external force; it is a form of rheology. With the increase of mining depth, deep rock mass are in the complex environment with high temperature and pressure, making it increasingly difficult to support mine roadways. Among them, roadway rheological deformation caused by the high stress is one of the main factors leading to instability of roadways damage. On the one hand, with the increase of mining depth, rock engineering is in a more complex environmental field (stress field, temperature field, seepage field); on the other hand, the characteristics of deep and shallow rock mass show a lager difference, stress states of surrounding rock in roadways are close to or in the strength limit state. To study large rheological deformation of surrounding rock, it should explain the nature of rock creep by lots of rock creep tests. This book is to establish the function relationship of disturbance effects on rock creep by bending creep tests, CT scan, conventional triaxial disturbance creep test and triaxial creep tests, under low confining pressure and high-stress state.

Disturbance creep is defined as rock creep deformation, which is caused by external disturbance load (such as blasting tremor) when rock is in the states of certain stress. Disturbance load is one kind of vibration wave. Rock mechanics response to disturbance, creep which gradually came into being in a certain time. Soft rock is a kind of special mechanics medium have the characteristics of nonlinearity, discontinuous hetero-

geneity, large deformations, anisotropy and rheology. In addition to, soft rock deformation shows new characteristics, which are different from linear mechanics medium obviously. The soft rock shows obvious randomness and the sensitivity to initial conditions, soft surrounding rock shows the sensitivity to initial engineering conditions, it is very sensitive to engineering disturbance, blasting construction in the adjacent engineering will cause deformation rate of surrounding rock to increase sharply. For the sake of the problem, circular section roadways can be simplified as (as shown in Figure 1.1), radius is R_0.

Unit A stress state is changed from three dimensions to two dimensions after excavation, unit strength decrease. Stress concentration result from stress transfer, which is caused by increase of unit stress. Unit A stress exceed limit, failure occurred in the unit, bearing capacity lower, stress further transferring to deep area. Unit A is similar to Unit B, what's the difference between them there is a smaller radial stress in the unit. Plastic zone, elastic and fractured zones of surrounding rock of roadways are formed from inner to outer. Rock has good integrity in elastic zone, it has very strong anti-disturbance ability capability, or say is very insensitive to engineering disturbance. For plastic zone of the rock mass, because rock is close to strength limit state, smaller disturbance load make plastic deformation develop into further fracture. For fractured rock, because rock is in post-peak region, mechanical property is very unstable, it is very sensitive to outer disturbance. Under non-supporting condition, rock don't maintain the self stability; radial force provided by supporting is smaller, small disturbance make deformation rate increase, deformation is increasing. The deformation induced by disturbance loads is defined as disturbance deformation.

It is shown from test results that when load is less than a certain limit value(10.10MPa in Figure 1.2), strain will be constant after some

time, keep constant while there is no correlation with duration time, creep is stable. Load is lager than this limit value, creep is unstable, this means creep continue to increase until rock specimen crack. This limit is called rock long-term strength, it is strength limit of stable creep. When load is close to certain neighborhood of strength limit, or when load is within certain neighborhood of strength limit, it is difficult to determine if rock creep time is finite or infinite. Rock creep stability is very sensitive to outer disturbance loads. Thus it can be concluded that a small disturbance can change stable creep into instable creep under unaxial stress state. Creep is very complex under three dimensional stress states.

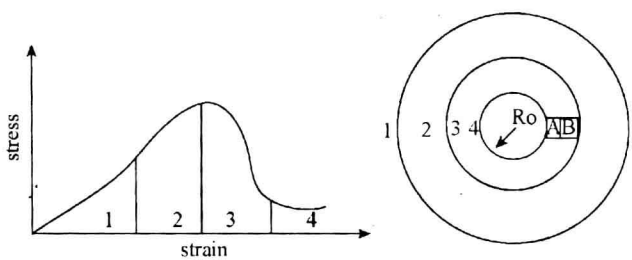

Figure 1.1 Mechanics state of surrounding rock

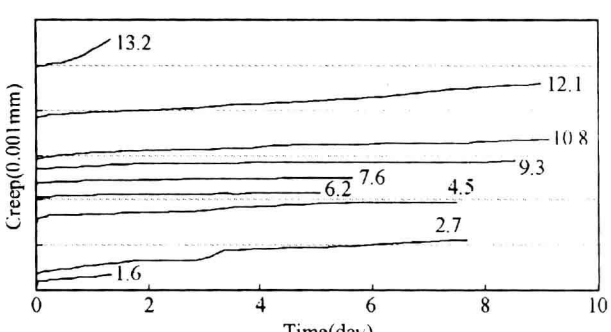

Figure 1.2 Curves of creep test

On the one hand, rock creep stability is related to stress conditions and its change; on the other hand, it is related to rock strength limit neighborhood. The so-called strength limit neighborhood, as to rock stress state, rock is in tension, compression and tension shear state, which has a strength limit σ_0, which $\Delta\sigma$ is given according to certain assumed conditions, that is $\sigma_0 \pm \Delta\sigma$. If rock is in three dimensions stress state, its strength limit neighborhood in stress space is defined as

$$(\Delta\sigma)^2 = (\Delta\sigma_1)^2 + (\Delta\sigma_2)^2 + (\Delta\sigma_3)^2$$

Rock limit strength neighborhood and disturbance sensitivity are determined by test.

1.1 Research Background and Significance

Creep is one of the most important mechanical properties of rock, creep phenomenon exist in many geotechnical engineerings. For example, surrounding rock of the deep underground tunnels or roadways, its deformation increase over time slowly. Professor Chen Zongji has pointed out that project destruction is often a process of time; the destruction is controlled by the rock creep. A large number of engineering practice also shows that the instability and failure of rock engineering do not occur immediately in many cases after mining or the excavation completion. After the mine roadways excavation, rock mass are stable at the beginning, the continuous development of deformation over time. But after some time, the caverns may be unstable or collapse, caverns deformation increase gradually with time.

The stress concentration results from the self-gravity, tectonic stress and mining excavation work, soft rock mass occurs significant creep deformation over time. The deformation of rock mass would increase over time, corresponding to the rock mass stress field will change, rock de-

formation to be stable or unstable often in a long time.

With the expansion of the underground works, especially the mining activities deepen, the deep original rock stress is much greater than that of the shallow one, rock unloading excavation will inevitably lead to increase stress, and the stress of surrounding rock is close to or at the rock failure strength. There are many underground engineerings at home and abroad, they are either in high earth stress environment or deep bury have encountered serious stability problems. In this case, the rock rheology become very sensitive to external disturbance, rheological questions on surrounding rock are very prominent. On the other hand, geotechnical engineering shows a distinctive feature of longer life service. This is the rock mechanics practitioners raised three chanlleges: (a) Under deep excavation unloading conditions, the rock stress changes have led to the stress state of rock closer to the rock strength limit state. How do surrounding rock show rheology features? (b) Rock stresses close to or at the rock failure strength, how do the sensitivity of the rock rheology response to external disturbance? (c) Modern geotechnical engineering will not only have to consider the safety of the construction period, also to take into account the safety during the operation, how to ensure the long-term stability of geotechnical engineering? These three issues is the task of rock rheology, but have not yet been well resolved.

This book focuses on resolving the following issues:

(1) Rock creep test are performed under the conditions of low confining pressure and triaxial compression, aim to understand rock creep characteristics.

(2) To carry out creep disturbance effects test under the conditions of triaxial compression, to study rock creep disturbance characteristics within the ultimate strength neighborhood.

(3) To make rock beam bending creep tests and disturbance effects

to creep so as to fully understand the characteristics of rock creep and disturbance effects to creep.

(4) CT tests for rock creep meso-damage were made, to create constitutive equation of rock micro-creep disturbance damage.

1.2 History and Present Study

The previous studies on rock rheology include rock creep test, rock creep constitutive model, the analysis of rock creep constitutive equations and rock creep constitutive model for engineering applications. This book focuses on the former two aspects.

1.2.1 Rock creep tests

Rock creep test is one of the most important means to understand the mechanical properties of rock creep. Griggs proposed sandstone, silt sandstone and argillite, when the load reached 12.5% to 80% of failure load, creep occur. H. Ito and S. Sasajima made rock beam bending creep test for the granite and gabbro for a decade and two decades, verified that rock beam bending creep is a volatile process, when the rock beam creep time reach 650 days, the bending deflection reduction occupy 10% of the total bending deflection; Chen Zongji carried out creep tests on the Yichang sandstone for 8,400h, studied creep and dilatancy.

Many of the creep tests have shown that rock occurs more evident creep under the conditions of constant load bending. Even at a lower stress level, it is also easy to show creep behaviors of visco-elastic-plastic fluids. Under the unloading condition, one part of the deformation can be resumed immediately under the higher stress; while the other parts of deformation restore gradually in some time, this is called inverse creep deformation.

In complex stress state of the biaxial and triaxial compression, rock or rock mass will occur creep, creep behaviors are affected by stress magnitude in all directions and loading path. Under constant axial pressure and confining pressure, axial creep deformation increases with time significantly; the confining pressure is constant while the axial load increases, characteristics of the time-strain curves are similar to those under uniaxial compression. In short, rock or rock mass in the complex stress state, the rheological properties are closely related to stress difference, when stress difference is smaller, deformation transform from the decay creep deformation phase to the stable creep stage; stress difference is larger, result in accelerating creep and damage.

In recent years, the rock rheology tests have been further developed, and obtained some new achievements. Géraldine Fabre found that three kinds of sedimentary rocks exists stress difference threshold in the second and tertiary phases of the creep, and their values are lower than threshold values of stress difference in the first creep phase through the static and quasi-static rheological tests.

Li Yongsheng and Xia Caichu made uniaxial compression creep and relaxation tests on silt sandstone, marble, red sandstone and mudstone by the servo-rigid machine, pointed out that under a certain regular stress, creep rate for the rock material have three phases generally, decrease, stability, and increase, but whether or not every phase occur, which depends on the rock nature and stress level; relaxation curve for the rock have continuous type and ladder type; the former is continuous, and is closer to the continuous medium, while the latter has a non-continuity and mutability characteristics.

Literature used self-gravity lever-type rock creep test machines to make mudstone triaxial creep test, found that triaxial creep of weak rock have non-linear relationship, its creep deformation is more 3 times than

that of the instantaneous deformation. JIN Feng-nian first proposed similar theory on rock mechanical characteristics of tension and compression through the rock creep in uniaxial tension, uniaxial compression, and effects of the load rate. Literature described the creep fatigue testing and failure process of rock in convectional uniaxial compression, and the correlation between convetional uniaxial compression test and creep damage test. Literature made uniaxial and triaxial compression creep test on Pietra Leccese limestone, indicated that the main mechanism of creep include crack propagation under the low confining pressure and pores collapse under high stress.

During the rock excavation process, the rock produce tension damage, rheological effect is very significant. In 1969, Kubetsky, Ukhov and Eristov concluded that E and the creep parameters are different in the loading and unloading conditions by the layered rock creep test. In 1974, Langer proposed rheological models apply to different rocks, that is, parallel model of Hooke body and a series of Kelvin body.

Wu Gang verified damage of the red sandstone samples under unloading. Literature performed splitting tensile creep test for the Three Gorges granite, indicated that creep tensile strength is related to loading rate, also studied the water act on the tensile creep characteristics. Literature showed that when the tensile stress is 30% of rock tensile strength, the rheological deformation sustained for more than 6 months. Literature established that the rock elastic parameters and the creep parameters are not fixed values, but rather a function of time; strength and elastic modulus of soft rock decrease with time, and their changes are similar, this phenomenon can be using damage mechanics to describe. Literature made a number of rock rheology tests, and found that the viscosity increase with the loading stress and load duration.

Geotechnical engineering practice and tests have proved that the

rock failure is a gradual process. Rock macro-damage is crack initiation, expansion and connection in medium, the rock rheological damage and fracture with the aging property. Deng Guangzhe, Zhu Weishen used testing means to get the basic relationship between the fracture propagation and jointed rock mass strength weakening, illustrated that the crack emergence and extension are one of important factors for rock mass weakening, the main cracks and aging extension are internal mechanisms discontinuous fractured rock mass creep, creep crack extension and fractured rock mass exist phase threshold, the two have certain inherent correlation.

Literature introduced the aging characteristics based on the conventional fracture mechanics, and proposed rheological fracture criteria of rock crack initiation and crack aging extension mechanism, analyzed the microcrack zone of crack tip impact on the fracture toughness and used non-equidistant gray theory to predict fracture time for rock creep. Literature studied rheological fracture properties of stratified rock by the three-point bending test method and rheological fracture criterion for rock was obtained by theoretical analysis. Literature shown that the mechanism of crack initiation and expansion on the creep crack red sandstone by tests and theoretical analysis, the creep fracture toughness is one of important parameters for the geotechnical engineering design and calculation. Literature reviewed rock crack (defect) evolution and mechanical properties, indicated the softening of the rock properties in deep mine.

Computer tomography recognition technology, the CT (computerized topography) technology, with the advantages of its non-disturbance and multi-dimensional analysis paid by the rock and soil mechanics research community's attention to. Can CT not only identify the rock damage without disturbance, and more importantly, through quantitative the CT images, CT number relate to the rock damage variables and damage propaga-