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THEORETICAL AND EXPERIMENTAL STUDY ON DISTURBANCE EFFECTS ON ROCK CREEP

(VOLUME Ⅲ)

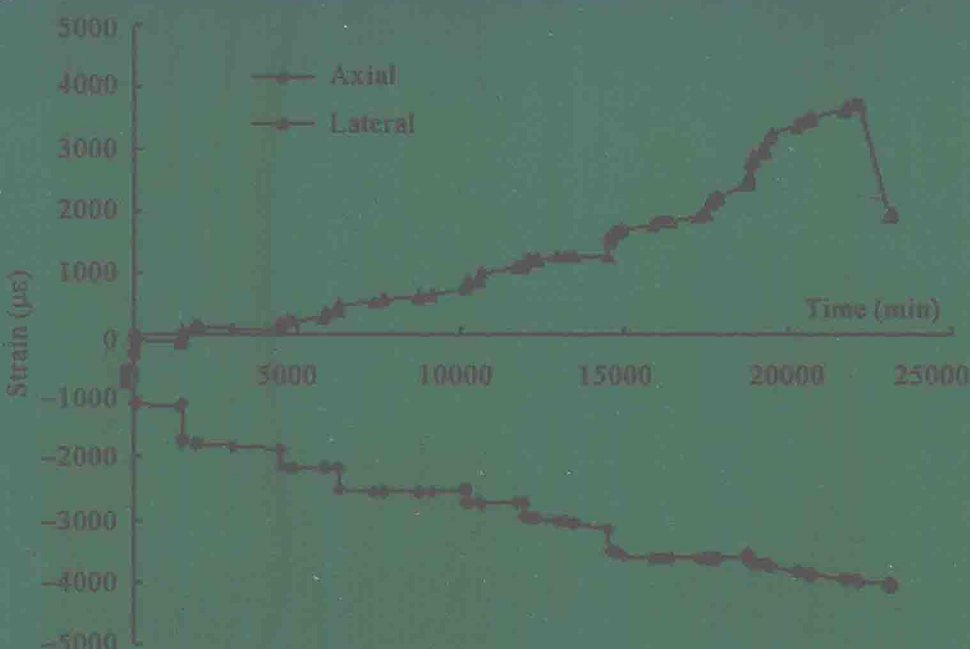
– ROCK RHEOLOGY DISTURBANCE EFFECTS TESTING SYSTEM

Pan Yuan　Fu Zhiliang　Cui Xihai　Gao Yanfa

岩石蠕变扰动效应理论及试验研究（Ⅲ）

——岩石流变扰动效应试验测试系统

潘玉安　付志亮　崔希海　高延法　著



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Preface

When the stress in geotechnical material is close to strength limit state, it is sensitive to external disturbed loads; it is called disturbance effects. The excavation depth of tunnels and mining depth of the ore are buried below 500 m. Although the mining depth of some coal mines is only 250 to 400 m, the surrounding rocks around the roadways are weak; thus they are vulnerable to weathering and hydrolysis. Similarly, in railroad, traffic, water conservancy, we also encounter soft rock. These soft rock caverns or chambers produce greater deformation, and in particular, when affected by the disturbance, may even cause major security incidents. These problems have become major difficulties in mining activities.

Stress state in surrounding rock of roadways is within strength limit neighborhood; creep of surrounding rock is the main deformation, which can be caused by random disturbance loads (mining, excavating and blasting). Surrounding rock of tunnels, roadways, chambers and caverns in deep mining or soft rock will produce large creep deformation when the stress in the rock is close to its ultimate strength. Most of the creep deformation is caused by disturbance loads. Previous studies on creep include uniaxial compression, uniaxial tension, triaxial compression, weak plane shear and relaxation. Most of the theoretical research focused on element combinations, empirical, endochronic model, and they were conducted under the condition of static load. So far, however, little empirical research has been done to investigate rock respose to disturbance. Hence, the testing system can simulate on the creep properties of rock materials and provide theoretical evidences for analysis of rock stability under disturbance loadings in geotechnical engineering.

The book contains the main ideas of the design and manufacturing of a new creep testing system that is set up at Shandong University of Technology and Science (SUTS) and China University of Mining and Technology (Beijing). This testing system includes a creep testing machine, triaxial pressure box, system of disturbance loading and measurement. The testing machine is capable of

performing creep tests under blasting disturbance and gravity impacting, and can evaluate the disturbance effects of the rock creep. Finally, in order to verify the performance of the equipment, a series of creep tests were performed on rock specimens and the axial and lateral deformations were measured using dial gauges and strain gages.

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Parts of the research were performed with a grant on behalf of the General Program of National Natural Science Foundation of China (No. 50474029). Additional support was given by the China Postdoctoral Science Foundation, Scientific Research Foundation for Doctor Introduction of Jingdezhen Ceramic Institute. We'd also like to acknowledge Dr Fan Qingzhong for the test results on the red sandstone, Dr. Cui Xihai and Prof. Gao Yanfa who developed the rheology device with creep testing system. Useful comments and criticisms from Prof. Chen Zhanqing, Wang Lianguo, Mao Xianbiao, Tang Chunan and Dr. Li Tiezeng were also highly appreciated.

Symbols

σ_0-Limit strength or ultimate stress (MPa)

$\Delta\sigma$-Strength limit neighborhood in stress space

σ_1-Maximum principle stress

σ_2-Intermediate principle stress

σ_3-Minimum principal stress

A-Cross-section area of rock specimen (m^2)

P_0-Limit load of rock specimen

L-Axial length of the specimen

ΔL_{max}-Maximum axial deformation

φ_p-Diameter of pressure cell

l-Length of the connecting rod

e-Eccentricity distance

K-Force amplification ratio

ΔS-Indenter travel

S-Displacement of the indenter

L_2-Lead for screw thread

Φ-Rotation angle of screw

G-Tangential force on disc

Θ-Specimen stress (N)

r-Average radius of screw thread (m)

ψ-Angle of thread Helix

n-Thread Helix number

φ-Friction angle of screw pair

f_1-Friction coefficient for bolt extruded surface

τ-Force arm of friction torque on bearing surface (m)

p-Screw pitch

D-Diameter of disc

K_1-Force amplification ratio of inclined wedge

K_2-Transmission ratio of disc-screw mechanism

$[\tau]$-Allowable shear stress of grade 45 steel

E_r-Accumulated energy of rock specimen

E_m-Accumulated energy of test machine

K_m-Machine rigidity

K_r-Stiffness of the rock specimen

Δu-Displacement increment

n-Component number in testing system

l_i-Component length

r_i-Gyration radius

$A(x_i)$-Sectional area of component

$I(x_i)$-Moment of inertia moments of inertia of the component's cross-section

$J(x_i)$-Moment of polar moments of inertia of the component's cross-section

E_i-Elastic modulus of the component materials

G_i-Shear modulus of the component materials

$F_i(x)$-Axial internal force of each component

$M_i(x)$-Bending moment

$T_i(x)$-Torque (N·m)

Δl_i-Deformations of every component

Δl_m-Total deformation of testing system

Δl_1-Tensile deformation of machine frame

Δl_2-Deflection along F direction results from eccentric axle bending

Δl_3-Compression deformation of connecting rod

Δl_4-Compression deformation of the piston

Δl_5-Increment value of total deformation of testing machine

ε'-Instantaneous strain

t_p-Travel time of longitudinal wave

t_s-Travel time of transverse wave

σ_c-Uniaxial compressive strength for specimen

λ-Creep compliance (is defined as time-dependent strain per unit stress)

λ_t-Deformation compliance

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Part One　Testing System Design

1 Introduction

The deformation behaviour of rocks is time-dependent. Some hard rocks, such as gabbro and granite show a time-dependent strain under high stress whereas the time-dependent strain of other weak rocks such as salt, potash, trona, coal, mudstone greatly exceeds the instantaneous elastic deformation under low stress. An understanding of time-dependent behaviour of rocks is considered essential for further development in the fields of underground mine design, strata control, seismology and in researching many other geological and geophysical phenomena occurring in the earth's crust.

Creep phenomenon in rock engineering plays a key role in the development of underground spaces as they must be stable for a long period of time. The rheology and time-dependent behavior of rocks are fundamental mechanical properties of rock materials, which can be used as an important base in explaining and analyzing the phenomena of geological tectonic movement, as well as predicting the long-term stability for rock engineering. Laboratory tests and in situ rheological observations are the major methods employed to study time-dependent behavior and deformation rules of rock materials. The creep test is frequently carried out for rheological experiments. The creep observation is relatively easier to obtain; therefore, there are many results available in the laboratory.

For underground geotechnical engineering, free surface displacement, deformation and convergence of roadways or caverns, surface subsidence and slope instability are caused by the excavation, all of which are rheological processes. Excavation activities cause stress and strain fields to redistribute; the surrounding rock deformation increases over time progressively. The rock, which is in a certain state of stress, produces a corresponding rheological strain increment after undergoing external disturbance load (such as blasting vibration, blasting tremor, rock burst, etc.); this is called a rheological disturbance effect which is a mechanical phenomena.

Rock deformations in the vicinity of deep and weak rock roadways exhibit the following common characteristics:

1) The rock closes to the ultimate strength in the high stress state; rock deformation of the shallow surrounding often exceeds the ultimate strength of the peak corresponding to the limit deformation, which shows that the deformation is in a very unstable state.

2) Creep convergence magnitudes of these roadways are large, and the deformations speed up. For example, the convergence rate of cross-section of weak rock roadways at Liuhai coal mines, Shandong, comes up to dozens to 200 mm/d; the amount of floor heave is 700 mm/d.

3) Roadway deformations are extremely sensitive to the disturbance load. Two parallel roadways are under construction at Liangjia mine by Longkou Mining Group. The shotcrete support for the first roadway has been completed; when the second roadway is being developed, the first roadway produces large deformation and failure under the load disturbance of the second roadway, therefore the first roadway has to be re-constructed through a second support and maintenance.

Because of the above-mentioned deformation characteristics, deep roadway and soft rock roadway supporting become very difficult; support costs and expenses are considerably high, which has become one of essential technical difficulties of mining production. Deep weak rock roadway is sensitive to disturbance; rocks become very sensitive to external disturbances, when the stress state in rocks is close to the strength limit. Therefore, the rock rheological disturbance effect concept is put forward.

In order to study about the disturbance effects on rock rheology, it is necessary to carry out a rock rheology test; we must design the appropriate testing instrument.

Rock creep stability is related to both rock stress conditions and rock strength limit neighborhood. The so-called extreme strength neighborhood, that is, the rock has an extreme value at strength when it is in tension, compression, and tension shear states. $\Delta\sigma$ is given according to certain assumed conditions. If the rock is in a 3D 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 can be determined by the tests.

The creep deformations are produceed; it is prerequisite that a constant stress is applied to rock specimen. The investigation of time-dependent strain has many experimental difficulties as it must be conducted under controlled conditions for temperature and humidity. Also, the sustained load should be applied throughout the experiment and the strain measuring system must be sensitive enough to show small strain in the samples.

Over the past several decades, many scholars have developed different types of triaxial rheological experiment apparatuses and have performed extensive laboratory investigations by using hydraulic, pneumatic or mechanical loading systems (including springs, weights, and levers). Because of their higher loading capacity, Servo-Hydraulic units are best fitted for such tests. However, long-term testing of materials can be very expensive using these machines while, mechanical instruments, in relatively lower cost and loading capacity can be more preferable for soft materials such as salt and coal. Springs and levers are widely used in mechanical loading instruments to ensure constant loading in longer time intervals. However, the loading capacity of springs will decrease when lengthened; so, levers are more appropriate to be used in mechanical loading equipments, especially in creep tests.

Lever arm testing machines and wheel-axle testing machines provide a more satisfactory condition for constant load, but are limited by their loading capacity. For mechanical spring testing machines, the applied load level will decrease as the sample deforms. To study the creep behavior of salt rocks, this study conducted uniaxial compression creep tests using a newly developed testing machine. Required facility for studying time-dependent deformation was manufactured by the research team at Shandong University of Technology and Science (SUTS) and China University of Mining and Technology (Beijing).

The facility is developed to perform creep tests by applying different loading scenarios to one or more cylindrical rock samples and measuring their deformation response. It works in combination of two second-type lever arms and dead weights as shown. In the second-type levers the load is applied on one side of the resistance and the fulcrum is located on the other side. Based on the law of the lever, the power into the lever equals the power out, and the ratio of output to input force is given by the ratio of the distances from the fulcrum to the points of application of these forces.

The ideal mechanical efficiency of the whole system can be multiplied by increasing the number of lever arms but, the moving intervals of the upper loading plate will be decreased dramatically as a result. Currently the mechanical advantage of the system is ideally equal to 25.

To apply load on samples, at first, weights are placed at the end of the first lever. The mechanical advantage of the first lever (approximately equal to 12.6) will enhance the applied force and transmit it through vertical connector between levers. Next, the mechanical advantage of the second lever (approximately equal to 2) will increase the applied force by 2 times and transmit it to the sample with the aid of loading axis. Weights should be kept unchanged during each experiment. Also, humidity and temperature should be carefully monitored. Finally, to unload the sample, weights can be easily removed. The equipment facilitates repeating similar experiments by using different loading. The only thing that needs to be changed is weight.

To measure strain in rock samples, a number of methods such as optical systems, strain gauges and dial gauges have been frequently used. Dial gauges were preferred due to their simplicity and economy. The dial gauges used were of 30 mm range and read to 0.01 mm. The dial gauges were installed on the system to collect axial and lateral deformation data.

At present, two loading modes (stepwise loading and variable load) were adopted to study the rock creep behavior.

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