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Shear creep characteristics and constitutive model of limestone

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ABSTRACT

The characters of limestone in weak interlayer of a high rocky slope in Xuzhou, China, are studied by shear static test and shear creep test. The results show that limestone specimens have attenuation creep properties and constant rate creep properties, almost have no accelerated creep properties. The exponential type empirical formula is selected to fit creep grading curves by polynomial regression analysis method, and the square sums of the fitting results residual are in the order of 10^{-7}. Then grade creep curves at every shear loads are set up. Combining creep rate-time curve, the creep properties of limestone are analyzed. As the physical meaning of component model is clearer, the Poytin–Thomson model is set up. Through the least square method, the optimal parameters of Poytin–Thomson model are obtained, and the sums of squared residuals belong to 10^{-3} order of magnitude, which can meet the accuracy requirements of engineering calculation. So the Poytin–Thomson model can reflect the shear creep characteristics of limestone very well.

1. Introduction

Shear creeping is an important mechanical property of rock, which has important influence on long-term stability of rock and soil engineering. Especially in high rocky slope of open-pit mines and water conservancy and hydropower projects, interlayer dislocation zones and weak zones are widely distributed. Thus, it is important to study their shear creep properties because of their determination of deformation and failure of rock mass.

In recent years, many scholars got some achievements about rheological property of rock through shear rheology tests [1–23]. Yang et al. made shear rheology test for the shale in Longtan Hydropower Project. The variation tendency of shear rheological rates under different stress states is discussed; and the variation of shear strength of rock with the time is discussed [1]. Using the shear rheological curves of shale, a viscoelastoplastic shear rheological model of rock was established and the parameters were identified. Shen et al. made shear creep test for the marble samples with greenschist discontinuities [2]. Results show that the creep curves have obvious three stages. On this basis, the improved Burger model was selected for the analysis of creep test results. Zhang et al. made shear creep experiments for sandstone with weak plane of Xiangjiaba Hydropower Station [3]. The normal stress enhances the ductility of rock. At a constant normal stress, the creep rate and time required for creep stability of rock increase with the increasing of shear stress. Xu et al. made a deep review of the existing test methods and the modeling theory for shear behavior of interlayer staggered zone, which showed that the elasto-viscoplastic model is the fundamental constitutive model for describing its mechanical behavior [4]. Chen et al. studied shear creep mechanic characteristics of interlayer shear belt based on the shear creep mechanic test [5]. The long-term shear strength parameters, accelerated creep properties and change rules of shear creep rate were analyzed. Based on the Nishihara creep model and the creep damage evolution equations, a creep damage model was proposed and validated through comparison between calculated results and test results.

In this paper, shear creep test was carried out for limestone in weak interlayer of a high slope in Xuzhou, which got relationship between shear displacement of limestone and the time, i.e. creep curves. On this basis, the exponential type empirical formula and Poytin–Thomson creep model of limestone are established and the model parameters are identified. Thus the creep properties of limestone of weak interlayer are studied.

2. Test material, equipment and test plan

2.1. Test specimen

Test specimens are obtained from weak interlayer of a limestone slope. Representative rock masses out of the field are cut into samples sized by 10 cm × 10 cm × 10 cm in laboratory.

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The specimens are light grey or taupe, banded structure, relatively uniform distribution, and have no obvious cracks or joints. X-ray diffraction test tells us the main mineral compositions are calcite, dolomite, a small amount of feldspar and quartz. The dolomite content in the taupe part is slightly higher than that of the light gray part, and contains a little of clay minerals.

2.2. Test equipment

The TAJW-2000 (1500) rock shear & triaxial test machine produced by Changchun Chaoyang Test Instrument Co., Ltd. is adopted. It is characterized by microcomputer controlling and electro hydraulic servo. The shear test loading schematic diagram is shown in Fig. 1. Specimen can be applied vertical compression load and horizontal shearing load simultaneously, whose maximum are 2000 and 300 kN respectively. In order to eliminate friction force, a ball plate is applied between the equipment top surface and the vertical pressure indenter. The loading diagrammatic sketch of test is shown in Fig. 2. The shear load is balanced in the horizontal direction, but it forms an anticlockwise moment. Under the action of this moment, the specimen has a small rotation, and contacts of the equipment top surface and bottom surface with the heel blocks are not uniform. The distribution of small deformation is linear, so the normal stresses of the equipment on top and bottom surfaces are linear distribution. Normal stresses and shear loads make the sample in a state of equilibrium. σ_0 means the average normal stress.

The measuring accuracy of the inbuilt displacement sensor is 0.01 mm. For measuring creep deformation, it is improved as 0.001 mm by external dial gauge. For automatic controlling of the whole test process, its measurement and control system are comprised of EDC digital servo controller, sensors and computer, which can acquire and display test data real-timely. During test process, stress and strain data of rock are accurately recorded. For avoiding environmental disturbance, constant temperature and humidity are kept in lab while experimenting.

2.3. Test plan

Shear creep test of single limestone sample is carried out by multi-stage loading. Beforehand, shear static test of same batch limestone sample was carried out for getting its shear strength under the condition of different normal stresses. Accordingly multi-stage loading of normal stress and shear stress of shear creep test are determined.

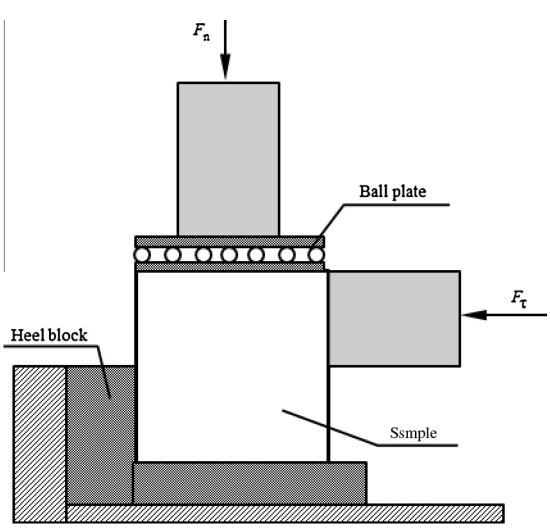

Fig. 1. Schematic diagram of shear test of rock.

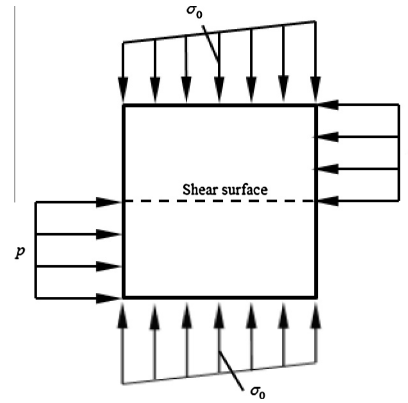

Fig. 2. Shear test specimen.

Creep test procedure is as follows: (1) normal stress is applied to sample until its normal deformation is stable. Then maintaining the same normal loading and first stage of shear stress is applied; (2) shear stress of 5–8 level are loaded into sample gradually. At each level of load computer, real-time record includes instantaneous displacement and creep displacement. In the early stage of each level, load deformation is collected more frequently. After the deformation is stable, the recording frequency of displacement is adjusted to 20 min every time; (3) next level load could be applied as the shear displacement rate is less than or equal to 1×10^{-3} mm/d, which means stabilization of rock creep deformation; (4) shear stress is applied to sample by the low to high order. At the last stage of shear stress, if the shear creep displacement tends to increase rapidly, the sampling frequency of displacement should be raised in order to reflect the final creep damage characteristics; and (5) when the test is carried out, the temperature and humidity of lab should be kept stable, avoiding vibration and disturbing of the surrounding environment.

3. Test result

3.1. Static test of direct shear

Before the shear creep test, it needs to determinate limestone strength of direct shear test under static load. Test is made on a certain number of limestone samples. Firstly normal compressive stress is put on samples till normal deformation tends to be stable. Then shear stress is put on it in displacement control mode till shear failure of samples happens. Shear strength of the test is shown in Table 1.

In the experiment, limestone sample appears some characteristics of brittle failure apparently. Shear stress increasing is linearly proportional to shear displacement increasing approximately. Brittle fracture of rock happens when peak stress is coming, accompanied with rapid displacement increasing and sharp stress decreasing. According to the existing data, the uniaxial

Table 1
Direct shear strength of limestone specimens.

Sample number	Normal stress (MPa)	Shear strength (MPa)	Average value (MPa)
ZJ1-1	4.0	8.65	9.45
ZJ1-2		10.52	
ZJ1-3		9.19	
ZJ2-1	6.0	12.21	10.86
ZJ2-2		9.63	
ZJ2-3		10.75	