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Mechanical behavior of red sandstone under cyclic point loading

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Abstract: The mechanical properties of red sandstone subjected to cyclic point loading were investigated. Tests were conducted using MTS servohydraulic landmark test system, under cyclic loadings with constant amplitudes and increasing multi-level amplitudes. The frequencies range from 0.1 to 5 Hz and lower limit load ratios range from 0 to 0.60. Laboratory investigations were performed to find the effect of the frequency and the lower limit load ratio on the fatigue life and hysteresis properties of sandstone. The results show that the fatigue life of sandstone decreases first and then increases with the increase of frequency and lower limit load ratio. Under the same cycle number, the spacing between hysteresis loops increases with rising frequency and decreasing lower limit load ratio. The existence of “training” and “memory” effects in red sandstone under cyclic point loading was proved.

Key words: red sandstone; cyclic point loading; fatigue life; hysteresis loop; penetration; training effect; memory effect

1 Introduction

With more and more mineral exploitations going into deep underground, traditional mining with blasting method tends to trigger rock-burst frequently [1]. Researchers around the world are devoted to finding non-explosive mining method [2]. In the coal mines, various continuous mining machines have been invented and made the production process safer and more efficient. However, for the metal mines with very compact and hard rock mass, these machines are found not to be effective for severe abrasion [3]. Many major mining or machinery companies have invested heavily in developing new equipments. We also paid lots of effort in this field. Recently, our studies have revealed that appropriate combination of static and dynamic loads can increase the rock fragmentation efficiency greatly [4−6]. Based on the findings, we have improved the cantilever excavator by adding an impact device, which can apply low-frequency cyclic impacts behind the cutting head. During excavation, the conical cutting teeth contact the rock mass and apply forces. The loading mode of the cutting teeth can be treated as cyclic point loading, based on the fact that the contact area between the cutting teeth and rock face is very small and the applied force has certain frequencies and amplitudes.

To improve the working performance of excavator for hard rock mines, it is necessary to investigate the rock behavior under such loading conditions. Cyclic loading has been studied by many researchers. For example, GUO et al [7] conducted a systematic study on the fatigue damage and irreversible deformation of salt rock subjected to uniaxial cyclic loading. Their results showed that the fatigue life of rock was mainly determined by its structure, amplitude and upper stress. They also concluded a “three-stage law of axial deformation”. LIU et al [8,9] applied axially cyclic loading to sandstone samples to experimentally determine the effects of confining pressures on their dynamic residual deformation and dynamic mechanical properties, and found that when the confining pressure was larger, the sample failed after fewer cycles, while the axial strain and the number of cycles at failure increased with the increase of frequency. BAGDE and PETROŠ [10,11] studied the fatigue property of intact sandstone under different waveforms, amplitudes and frequencies. They concluded that all these three factors had great effect on its fatigue property, and the most critical damage condition was square wave, low frequency

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and amplitude. TAO and MO et al [12] studied the behavior of rocks under cyclic loading, and found that the loading waveform and the cycle amplitude had important effects on the deformation. In each cycle, the deformation caused by the triangle waveform loading was smaller than that by the sine waveform loading. The fatigue life became shorter when the cycle amplitude was larger. ATTEWELL [13] reported that in cyclic compression tests, the fatigue life of rock increased with decreasing the stress amplitude. He found that, with decreasing the stress amplitude, the number of cycles to failure increased on a logarithmic scale. The results indicated that, the percentage of strain hardening increased with increasing the number of load cycles at a given maximum applied stress, cyclic frequency and stress amplitude. XIAO et al [14,15] revealed that the fatigue life decreased with the increase of the maximum stress, amplitude and fatigue initial damage.

The former researches mainly studied on cyclic tests where specimens were loaded with whole face contact, and few studies focused on rock specimens under cyclic loading with point contact. In this work, tests of rock under different cyclic point loadings were conducted. Some mechanical characteristics were presented, such as the effect of frequency and lower limit load on rock's fatigue life, which may bring insight for the coming invention of new mining machinery.

2 Laboratory testing schemes

Laboratory tests were performed on red sandstone specimens extracted from Yunnan Province of China. The rock was in good geometrical integrity and petrographic uniformity. Rock specimens were cut into cylindrical shape with a diameter of 50 mm and a length/diameter ratio of 0.8. All specimens were naturally dried and had average mass density of 2220 kg/m^3.

2.1 Equipment and loading cone

The MTS servohydraulic landmark test system was used for the tests. In order to apply cyclic point loading to the specimens, a special loading cone (Fig. 1) was installed on the clamping groove of the system. The cone was manufactured according to the suggested method for determining point load strength by ISRM (International Society for Rock Mechanics) [16].

2.2 Cyclic point loading tests

In this study, the following two kinds of cyclic point loading tests were arranged: 1) cyclic loading test with constant amplitude, and 2) increasing multi-level loading test. The former was mainly to study the effect of frequency and lower limit load on penetration (the reduced distance between two loading cones), cyclic modulus and the fatigue life of red sandstone. The latter was designed to find out if training or memory effects also exist in red sandstone under cyclic point loading.

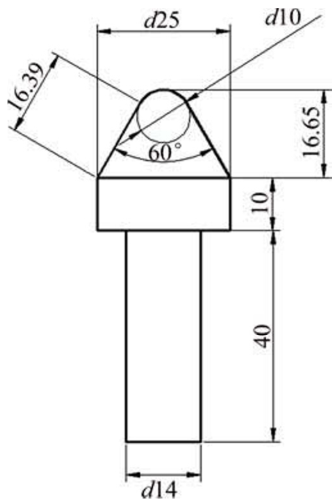

Fig. 1 Geometric parameters of loading cone (unit: mm)

2.2.1 Cyclic loading tests with constant amplitude

In the cyclic loading tests, rock specimens were firstly loaded with static force P_{min}, which was applied by force-controlled model with a speed of 9 kN/min. Then, the dynamic loading with specified frequency and upper limit load P_{max} was applied, as shown in Fig. 2.

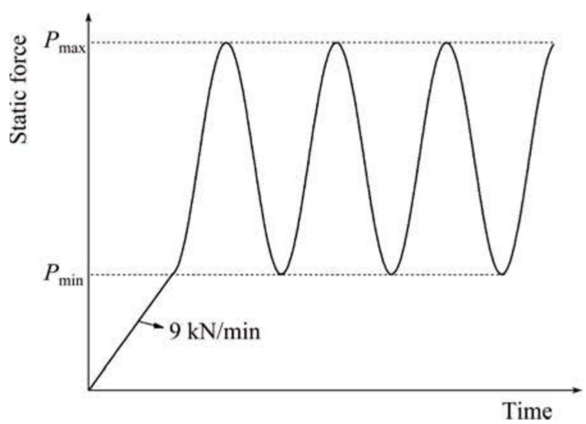

Fig. 2 Cyclic loading with constant amplitude

The dynamic loadings have a sinusoidal waveform. And the wave frequencies varied from 0.1 to 5.0 Hz, which were chosen according to the mining practice. The upper limit loads and lower limit loads were taken according to the average static point load strength of the specimen (P_a), as listed in Table 1. The static test was conducted with an axial displacement-controlled model, and the displacement rate was 1.3 mm/min.

The loading conditions and results of the constant amplitude cyclic point loading tests are given in Table 2, where the loading parameters R_{max} (upper limit load ratio) and R_{min} (lower limit load ratio) were expressed as