Strength properties of the jointed rock mass medium under dynamic cyclic loading*

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Abstract The dynamic strength properties of the intermittently jointed mediums are studied using model test to investigate the jointed rock mass behavior under dynamic cyclic load. The model test results demonstrate that (i) the dynamic strength of the jointed samples increases with the loading frequency and decreases with the loading loops; (ii) the dynamic residual strength will not be zero like the static residual strength under one-axle loading condition; (iii) the dynamic strength changes greatly with the joint density and joint angle, and it differs from that of the static strength which reaches the lowest at an angle of $45° + \varphi/2$, while in the dynamic case, the lowest strength is at the angle of 45°.

Keywords: **jointed samples, model test, dynamic cyclic loading, dynamic strength.**

Many researchers have studied the mechanical properties of the rock samples[1—5] (usually $\dot{\varepsilon} < 10^{-3}$), including some dynamic strength properties of the rock samples[6—9] and the static mechanical properties of the jointed rock mass samples. But there are some jointed rock mass media permeated by an array of distributed semo-joints or cracks which are neither macro-joints which can be simulated with single joint element nor micro-joints which can be simplified to continuous media. No research on the dynamical strength properties of such a semo-flaw has been reported. In this work, a model test on the intermittently jointed model samples is conducted to study the dynamic strength properties of the jointed rock mass materials under dynamic cyclic loads.

1 Intermittent joint model test

1.1 Model sample

The model sample, with the size of 100 mm × 100 mm × 200 mm, was made of gypsum (water: gypsum = 1.19:1.00) with artificial intermittent joints as shown in Fig. 1. The joint angles (α) were designed at 0°, 30°, 45°, 60°, 90° respectively and the rows of joints were defined to 1, 2, 3 respectively to simulate different joint densities of the jointed rock mass.

1.2 Test scheme

The model test was conducted on an MTS dynamic tri-axial apparatus with a stress-controlled loading system and the dynamic load was designed as harmonious triangular cyclic pressure load

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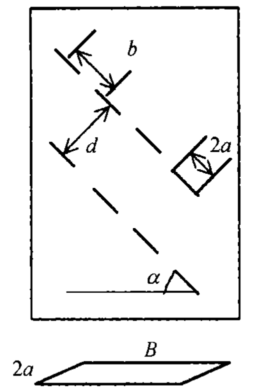


The plane pattern of the joint

Fig. 1 Model of intermittently jointed rock mass. Joint distance d 4.0 cm, joint central distance b 2.5 cm, joint half length a 0.5 cm, joint depth B 10.0 cm.

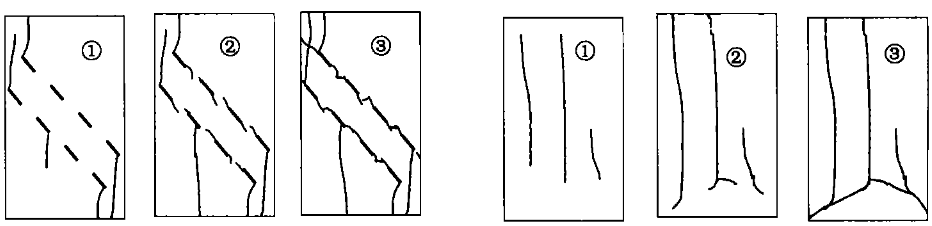
with the loading frequencies of 0.2, 2.0, 21.0 Hz, respectively. The loading level began with $0.2\sigma_c$, $0.3\sigma_c$, $\cdots$, to σ_c, till the collapse of the sample. At each load level, the dynamic loading lasted 15 cycles.

2 Dynamic strength properties of jointed samples

2.1 Failure mode of the jointed samples under dynamic loading

Thirty jointed samples and non-joint samples were tested on the MTS-810 with stress control mode. The failure shape of the whole jointed samples was similar to the static loading, but differed from the non-jointed samples, as shown in Figure 2.

In order to investigate the influence of the joints on the irreversible strain of the sample at different stress levels, both jointed and non-jointed samples were tested and compared under the stress levels of 0.6, 1.0, 1.2 (Fig. 3). The test results showed that (i) all the samples produced obviously irreversible strains even at very low stress level; (ii) the irreversible strains increased greatly with an increase in loading loops when the stress reached a "threshold value"; (iii) for the jointed samples, the damage (irreversible strain) was 2 to 3 times as large as that of the non-jointed samples at low stress levels; (iv) the damage threshold value of the non-jointed samples was 1.2 times that of the jointed samples.



(a) (b)

Fig. 2 Dynamic failure shape of the joined (a) and non-jointed (b) samples.

2.2 Dynamic stress-strain and the dynamic strength properties

The dynamic stress-strain relations of the samples with joints (30°, 90°) and without joints at the failure stress level under different loading frequencies (0.2, 2 0, 21.0 Hz) are shown in Figs. 4 and 5. There was not any residual strength in both jointed and non-jointed samples under the slow loading (frequency = 0.2 Hz), whereas more loops were needed to make the samples collapse, and higher residual strength occurred when the high frequency (21.0 Hz) load was applied. Table 1 gives the detailed results of the tests.

The dynamic stresses of the samples in Figs. 4 and 5 show that the dynamic strength of the jointed materials increases with the dynamic loading frequency because higher loading frequency induces slower damage evolution inside the samples.

2.3 Dynamic strength properties versus the geometric configuration of the joints

The dynamic strength of the jointed samples increased first with the joint angle till 30°, de-

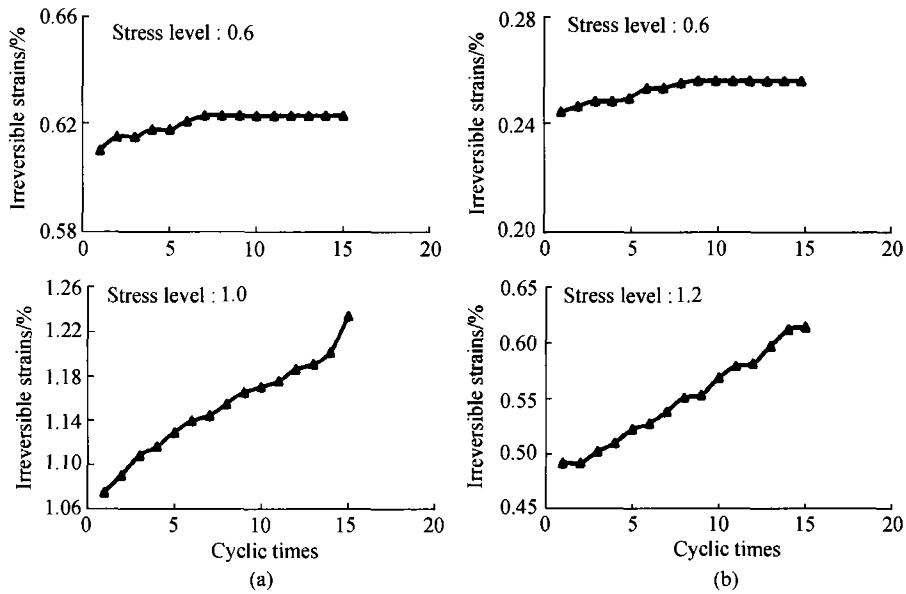


Fig. 3 Influence of joints on the irreversible strains at different stress levels. (a) Jointed samples; (b) non-jointed samples.

creased from 30° to 45°, and reached the lowest at 45°. The strength increased monotonously from 45° to 90° regardless of the loading frequency, as shown in Table 2. Such strength characteristics were different from the strength properties under the static loading conditions, of which the lowest strength was at $45° + \varphi/2$.

Table 1 The dynamic strength (MPa) with different loading frequencies

Frequency of loading / Hz	90°		30°		Non-jointed samples	
	Peak strength	Residual strength	Peak strength	Residual strength	Peak strength	Residual strength
0.2	3.5	0	2.2	0	3.6	0
2.0	4.2	0.5	2.5	0.2	4.2	0
21.0	4.4	1.2	2.9	1.0	4.7	2.0

Table 2 Dynamic peak strength (MPa) versus different joint angles (2-row joints)

Frequency of loading / Hz	Joint angle (°)					Non-jointed samples
	0	30	45	60	90	
0.2	2.30	2.47	2.13	2.84	3.57	3.64
2.0	2.46	2.49	2.13	3.22	4.18	4.23
21.0	2.74	2.90	2.31	3.59	4.52	4.65

Under the same loading condition, the dynamic strength of the jointed samples simply decreased with the joint intensity for all the loading frequencies (Table 3). No matter what the joint intensity or joint angle was, even if no joint existed, the dynamic strength always increased with the loading frequency.

In order to investigate the influence of the loading mode, a strain-controlling mode on the MTS testing machine was designed and used in the tests. The results are shown in Table 4, which gives results of the dynamic strength similar to those in Tables 2 and 3.

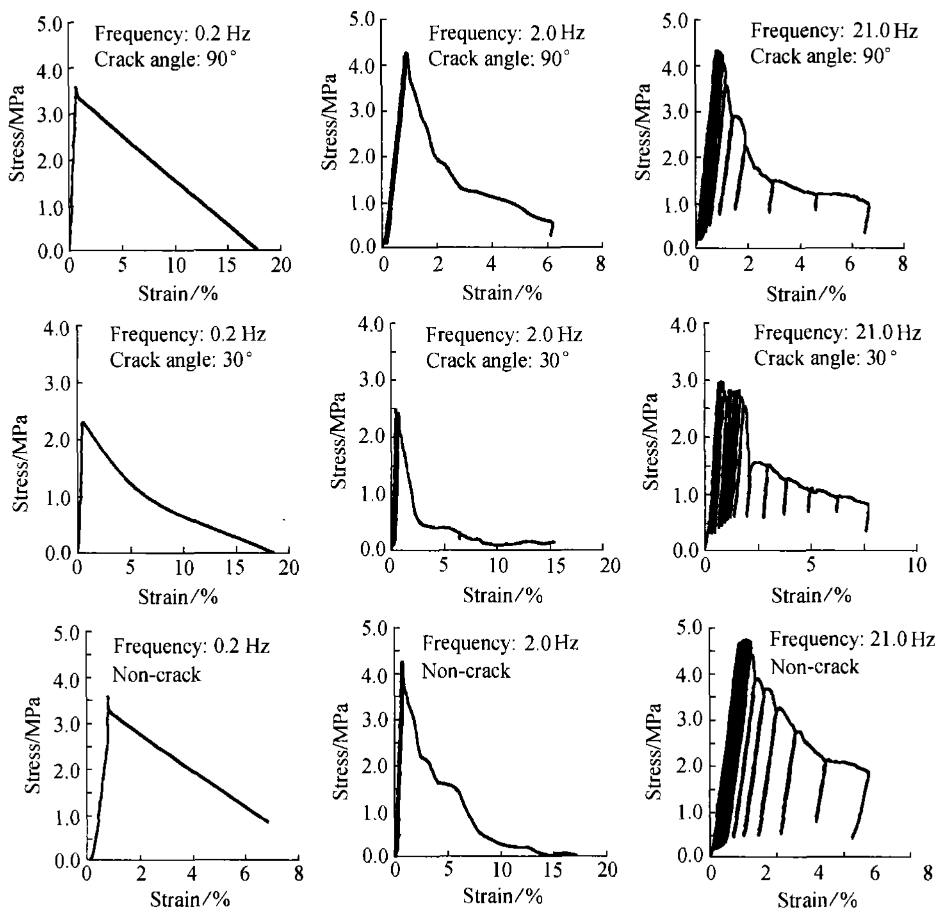


Fig. 4 Dynamic stress-strain relations under the collapse loading level.

Table 3 Dynamic peak strength (MPa) versus different joint densities (joint angle 30°)

Loading frequency / Hz	Joint density / rows			Non-jointed sample
	1	2	3	
0.2	2.50	2.47	1.74	3.64
2.0	2.82	2.49	2.14	4.23
21.0	3.12	2.90	2.77	4.65

Table 4 Dynamic peak strength with different strain velocities (2-row joints)

Strain velocity / s^{-1}	1×10^{-3}	1×10^{-2}	1×10^{-1}
Joint angle /(°)	60	60	60
Dynamic peak strength / MPa	1.90	2.02	2.21

3 Conclusions

Under the condition of the dynamic loading mode used in this study for the gypsum samples with artificial intermittent joints, several conclusions can be drawn as follows: (i) the dynamic strength of the jointed samples decreases with an increase in loading loops and increases with the

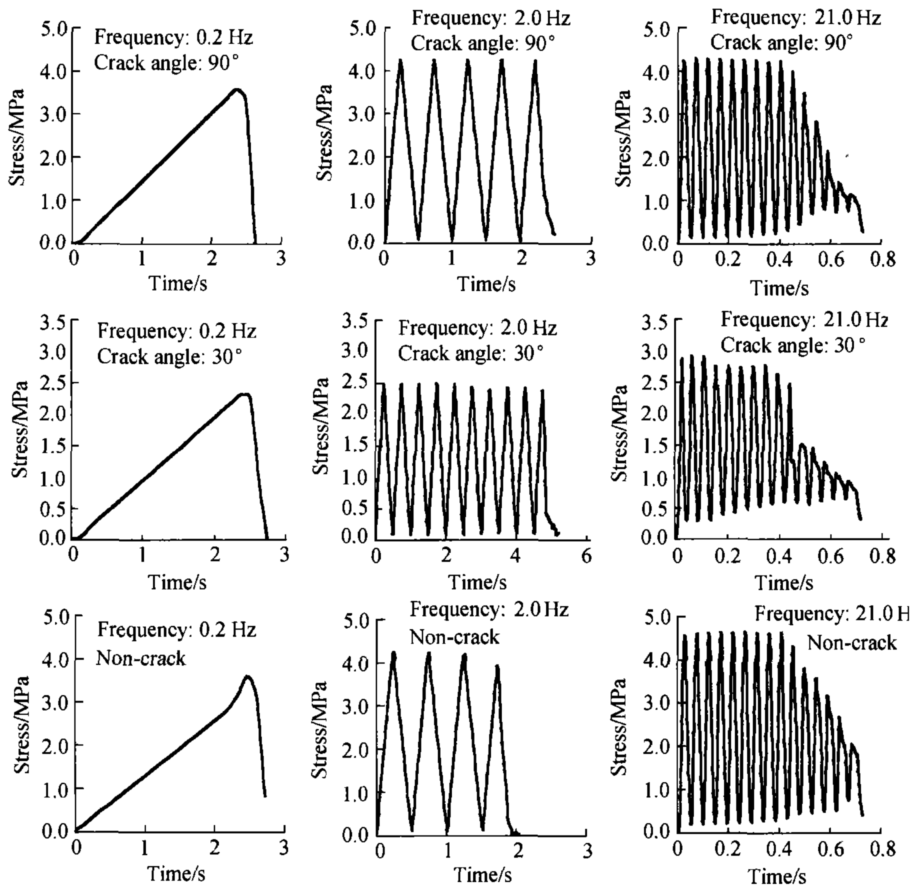


Fig. 5 Dynamic stresses at the collapse loading level with different loading frequencies.

loading frequency; (ii) the dynamic residual strength should not be zero as in the static situation under the one-axle loading condition; (iii) the dynamic strength changes greatly with the joint angle in the same way as the static strength does, and decreases obviously with the increase in joint density.

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