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Full Length Article

Effect of rock joint roughness on its cyclic shear behavior

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ABSTRACT

Rock joints are often subjected to dynamic loads induced by earthquake and blasting during mining and rock cutting. Hence, cyclic shear load can be induced along the joints and it is important to evaluate the shear behavior of rock joint under this condition. In the present study, synthetic rock joints were prepared with plaster of Paris (PoP). Regular joints were simulated by keeping regular asperity with asperity angles of 15°–15° and 30°–30°, and irregular rock joints which are closer to natural joints were replicated by keeping the asperity angles of 15°–30° and 15°–45°. The sample size and amplitude of roughness were kept the same for both regular and irregular joints which were 298 mm × 298 mm × 125 mm and 5 mm, respectively. Shear test was performed on these joints using a large-scale direct shear testing machine by keeping the frequency and amplitude of shear load under constant cyclic condition with different normal stress values. As expected, the shear strength of rock joints increased with the increases in the asperity angle and normal load during the first cycle of shearing or static load. With the increase of the number of shear cycles, the shear strength decreased for all the asperity angles but the rate of reduction was more in case of high asperity angles. Test results indicated that shear strength of irregular joints was higher than that of regular joints at different cycles of shearing at low normal stress. Shearing and degradation of joint asperities on regular joints were the same between loading and unloading, but different for irregular joints. Shear strength and joint degradation were more significant on the slope of asperity with higher angles on the irregular joint until two angles of asperities became equal during the cycle of shearing and it started behaving like regular joints for subsequent cycles.

1. Introduction

Rocks often have various sets of joints or fractures and almost all failures are caused due to the presence of these discontinuities. Shear strength and deformation of joints play an important role in design and analysis of underground structures, foundation, slope stability and risk assessment of underground disposal. Many researchers presented the shear behavior of jointed rock, based on peak stress–strain along the joint under unidirectional or monotonic (static) shear loads in the field of rock mechanics and rock engineering. But joints are subjected to dynamic loads due to earthquake, blasting, and vibrations, which can be simulated as shearing along the joint under cyclic loads. Thus load direction is reversed on the shearing plane repeatedly. In the present work, a physical model was prepared in order to examine the shear behavior of a jointed rock mass. In the past, the shear behavior of regular joints under cyclic conditions was studied by researchers such as Hutson and Dowding (1990), Homand et al. (2001), Indraratna et al. (2012) and Niktabar et al. (2016). But joints in the rock mass are often completely irregular and have different roughnesses. Few investigations have been conducted on irregular joints including replicated splitting joint and natural joint. Huang et al. (1993) conducted cyclic shear test on natural rock joints and observed that the first cycle is more pronounced in shear stress and dilation on natural joint as compared to subsequent cycles. Lee et al. (2001) studied cyclic shear behavior of saw cut and tensile splitting joints in two types of rocks: granite and marble. It was observed that the frictional resistance increased gradually during increasing cycles in case of granite joint and saw cut, whereas it did not change

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for marble saw cut joint. It was different in case of splitting joints dilation of forward and backward stages. Jafari et al. (2003) performed shear test at low, medium and high normal stresses on saw tooth and replicas of real joint. It was concluded that shearing mechanism was sliding mainly at low normal stress and the shear strength of joint reached a constant value after a few cycles. Degradation of the first- and second-order asperities continued during cycles but the second-order asperities were not effective after few cycles. At high normal stress, both the first- and second-order asperities were broken during shear displacement without any considerable dilation. Nguyen (2013) studied the behavior of schistose jointed rock under static and dynamic conditions (cyclic shear test with different frequencies). Shear test was conducted using large dynamic direct shear apparatus developed by Konietzky et al. (2012). The results showed that the peak shear stress under dynamic condition was 30% greater than that under static condition. Mirzaghorbanali (2013), Mirzaghorbanali et al. (2014) and Nemcik et al. (2014) studied cyclic shear test on saw tooth and replicas of real joint under constant normal stiffness (CNS) condition. The results indicated that with increasing initial normal stress, the effects of shear rate became less pronounced under CNS condition. In addition, there was no significant influence on shear strengths under higher and lower shear rates with increase in the number of cycles.

There are limitations for the study of shear test on natural or splitting joints such as lack of the same joints with identical roughness. On the other hand, joints with irregular asperities are more representative and closer to natural joints. In order to study the effect of irregular asperities on shear behavior of rock joints under cyclic conditions, a series of tests has been performed on cast regular and irregular jointed samples using cyclic shear testing machine. In the present study, regular joints with asperity angles of 15°–15° and 30°–30° and irregular joints with asperity angles of 15°–30° and 15°–45° were prepared. Each cycle was divided into four stages as described by Lee et al. (2001) such as forward right (FR), forward left (FL), backward left (BL) and backward right (BR). To represent cyclic movement on the joint, the four stages with load directions are illustrated in Fig. 1. The FR movement at the first shear cycle is similar to static or monotonic shear load.

2. Sample preparation

Joint roughness can be regular or irregular, but in the field it is mostly irregular. In order to simulate joint roughness, triangular asperity is selected to create roughness for the joints. The triangular asperities with the same angle are considered as a regular joint, while those with different angles are considered as an irregular joint. Similar sample preparation methodology was adopted for preparing both regular and irregular joints except for the use of different asperity plates to create different asperity angles as demonstrated in Fig. 2a. A model material is searched in such a way that it could be easily handled and the reproducibility of the sample could be ensured. To achieve this, different brands of plaster of Paris (POP) and dental plasters at different moisture contents and curing periods in isolation or combinations were tried. Finally, POP was selected because of its universal availability and its molding ability into any shape when mixed with water to produce the desired joints and also due to its long-term strength is independent of time once the chemical hydration is completed. The prescribed percentage of water was determined so as to achieve proper workability of the paste and required strength to simulate the weak rock. Different water-POP ratios were tried in order to obtain the desired strength and workability. The ratio finally selected was 0.6. Size of samples and amplitude of asperities were 298 mm × 298 mm × 125 mm and 5 mm, respectively, for all joints based on molds and asperity plates.

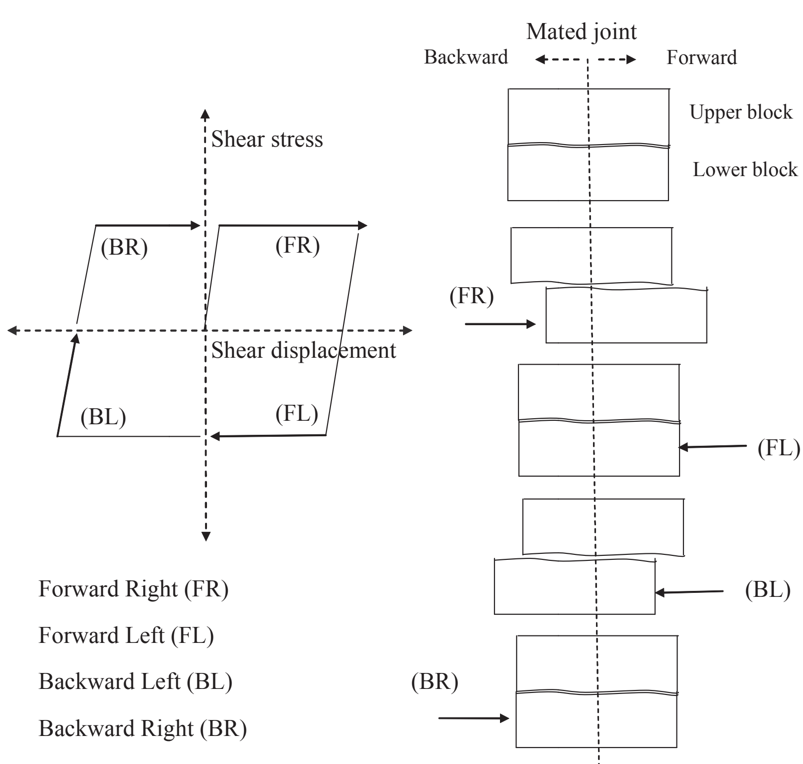

Fig. 1. Load directions and joint movements under shear cyclic condition.