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Anisotropic characteristics of jointed rock mass: A case study at Shirengou iron ore mine in China

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ABSTRACT

Rock mass is characterized by the existence of distributed joints whose properties and geometry strongly affect the mechanical behavior of jointed rock masses. A finite element model considering the anisotropic characteristics of fractured rock mass was proposed which could deal with a wide variety of joint distribution in rock mass and then applied in Shirengou iron ore mine in Tangshan, China. First, the scale effects and anisotropy were investigated by using multi-scale discrete fracture network models under uniaxial compression tests. Then, the principal direction of elasticity was found and used in the constitutive law of the equivalent continuum model. Finally, the deformation and failure behavior were studied and verified through site-specific microseismic data. It is found that the stress and damage zone are influenced by joint orientation. This proposed model can efficiently study the effects of rock joints on rock mass behavior and thus contribute to a more reasonable explanation on the dominant effect of the joint sets on deformation and failure of rock mass.

1. Introduction

Rock mass is a geological body consisting of large scales of discontinuities, making it heterogeneous, discontinuous and anisotropic. The native discontinuities have an important role in characterization of jointed rock mass. They have extraordinary properties, like low strength and stiffness which are usually the key factors that control the overall strength. Methods that can efficiently model the effects of rock joints on rock mass behavior is beneficial in stability analysis as well as safe design in rock engineering. The traditional classification methods of engineering rock mass, for example the Q system method (Barton, 2002), rock mass rating (RMR) method (Bieniawski, 1973), geological strength index (GSI) method (Hoek et al., 2002), are empirical techniques to relate geometrical properties of rock mass to its mechanical properties. Numerical models based on these methods have been applied to assess the rock mass stabilities (Benardos and Kaliampakos, 2005), however, the distributions of the joint sets are usually neglected in these methods. Moreover, these methods rely on the engineers' experience in the qualitative description of rock and joints. Therefore, differences of parameters may exist when different engineers study the mechanical properties.

Among the jointed rock mass, a special kind of rock mass, which is layered like sandstone, schist or shale, etc, can be easily modeled and studied by assuming to be transversely isotropic materials (Amadei, 1996; Gatelier et al., 2002; Nasseri et al., 1996, 2003; Pietruszczak et al., 2002; Gholami and Rasouli, 2014). Extensive efforts have been made to investigate the influence of transversely isotropy on compressive, shear or tensile strength. Tien and Tsao (2000) performed a series of mechanical tests on artificial interlayered and stratified rock materials. Liang et al. (2005) studied the mechanical behavior of stratified rocks using numerical code RFPA. The mechanical properties as well as the failure process were described and they find that the rock layer orientation has a great influence on the failure process, such as peak strength, failure modes and deformation characteristics. Ghazvinian et al. (2013) studied the shear strength response of inherently anisotropic rocks. He also pointed it out that the anisotropic effect of weak planes orientation was a significant occurrence that must be noted in the analysis and failure mechanism studies. Some researchers performed the Brazilian test to study the mechanical behavior and the influence of transversely isotropic rocks. Chen et al. (1998) tested four types of layered sandstones and determined the independent elastic constants in the constitutive relation. They concluded that the tensile strength was dependent on the

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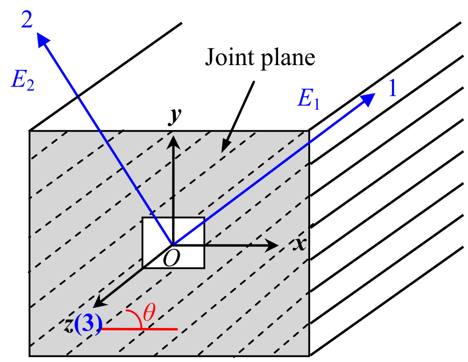

Fig. 1. The relationship between joints plane and the principal stress or permeability direction.

angle between the apparent planes of rock anisotropy and the direction of diametral loading. Claesson and Bohloli (2002) studied the principal tensile stress of layered rock, and proposed a proper formula to calculate the tensile strength. Cai and Kaiser (2004) simulated the fracture process in Brazilian tests on layered rocks. The anisotropy was also found playing an important role in the mechanical behavior of rocks. Tavallali and Vervoort (2010) also conducted an experiment research on the effect of the layer orientation on failure strength and fractures of sandstone. For the layered rock, the layer orientation determined both the strength and failure modes. The influence of strength anisotropy was also investigated on the rock samples by Dinh et al. (2013). A numerical simulation was conducted in parallel to the experimental studies. They also concluded that that the degree of anisotropy has a strong influence on the tensile strength.

The transversely isotropy studies can be used in the engineering problems (Vu et al., 2013; Li, 2013) when the rock (bedded, layered or schistose rocks) is transversely isotropic. However, theories or modeling methods relating to the evaluation of the natural rock mass are still limited because there exist large scale of randomly distributed discontinuities. Thus, the failure mechanisms have not yet been investigated in detail and laboratory results can be hardly used in the engineering problem directly. Until recently, many modeling methods for jointed rock mass have been developed and used in stability analysis of rock mass with higher or lower accuracy. These methods can be divided into two approaches when assessing the mechanical behavior of rock mass: one with visible fractures, and the other with invisible fractures. In the visible fracture approach, the geometrical distribution of fractures in the rock mass is considered (Lu et al., 2009; Wang et al., 2012; Debecker and Vervoort, 2013; Zhou et al., 2014), which are usually used to study the crack initiation and propagation problems. Nevertheless, the computational ability of computers is a serious

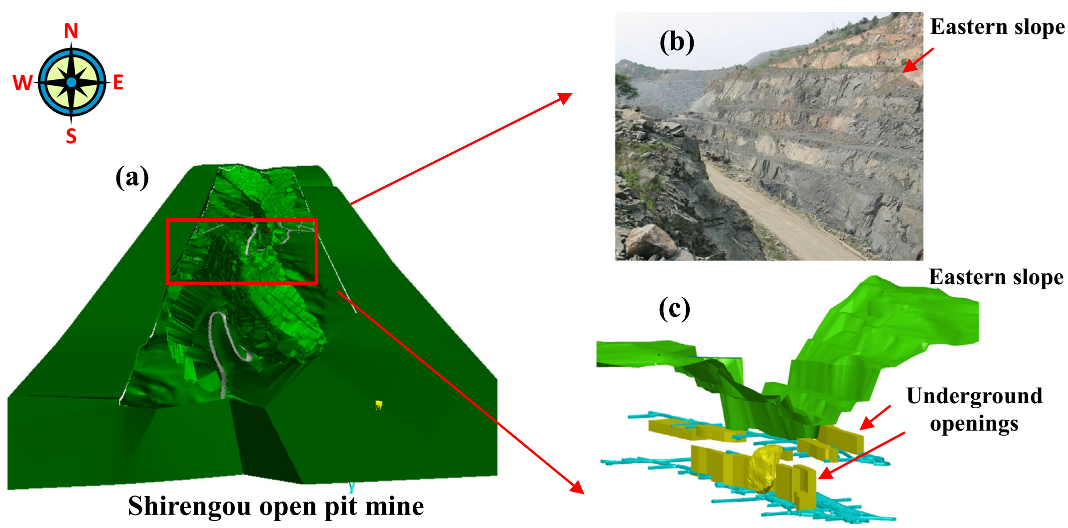

Fig. 2. The open pit and underground openings distribution of Shirengou iron ore mine.

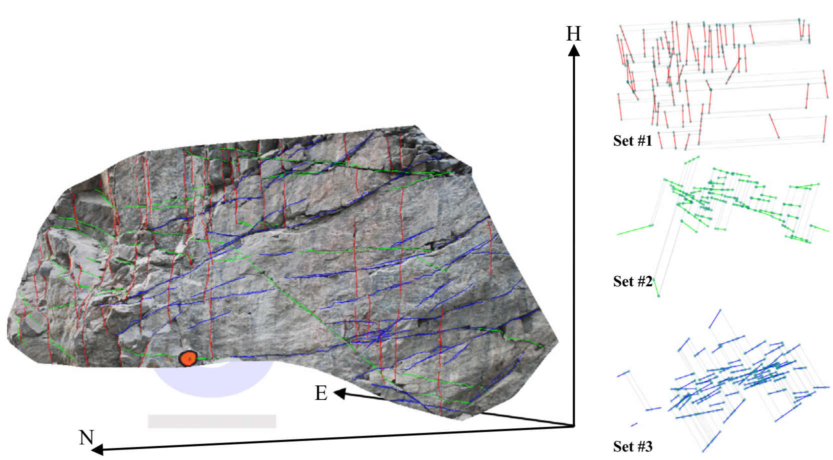

Fig. 3. Geometric measurements of stereoscopic restructuring model.