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Interval non-probabilistic reliability of surrounding jointed rockmass considering microseismic loads in mining tunnels

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ABSTRACT

The frequent microseismicity affects the stability and reliability of surrounding rock and the safety of supporting structures in deep mining tunnels. The limit state equations of rock blocks under microseismic loads were developed to indicate the stability conditions and sliding characteristics. The scarce field data result in the uncertainty of the physico-mechanical parameters of tunnel surrounding rock. According to the insufficient statistical information for the rockmass, a method of the interval non-probabilistic reliability was proposed to analyze the stability of surrounding jointed rockmass. The method considered both microseismic loads and the uncertainty of rockmass parameters. The solving approach of interval non-probabilistic reliability was optimized, and it can be available when the field data is scarce. To verify the proposed method, the interval non-probabilistic reliability was used to evaluate the stability of the mining tunnel rockmass in the Yongshaba mine (China). The calculated interval non-probabilistic reliability was compared with the safety factor and random reliability. Results show that the interval non-probabilistic reliability model is in agreement with practical situations. It is proved that the proposed method of interval non-probabilistic reliability, considering both the uncertainty of the rockmass parameters and the microseismic loads, is a beneficial complement to the traditional analysis methods of safety factor and random reliability.

1. Introduction

As the mining depth increases with the development of mining process, the increased high stress may cause numerous seismic events with large magnitude, which result in the frequent occurrences of rockburst hazards. Meanwhile, the rockmass of mining tunnels is divided into blocks of different forms by the structural planes. The blocks will lose balance and slide along the structural planes once being disturbed (Wang et al., 2013). The microseismic loads induced by blasting will exacerbate the severity of the hazards. However, most current researches conventionally focus on the stability and reliability analyses based on the probabilistic analysis (Ma et al., 2016; Tiwari et al., 2017; Majumder et al., 2017), without the consideration of microseismic loads existed in the deep mining tunnels. Therefore, it is significant to research the reliability of surrounding jointed rockmass under the effects of microseismic loads.

Deep tunnel excavation has close relationship with engineering construction and human safety, many studies have been performed to discuss the stability and reliability of mining tunnels. Hoek and Marinos (2000) carried out a Monte Carlo analysis to generate the probability distribution of percentage strain, which can estimate of potential tunneling problems. The first-order and the second-order reliability methods were applied to a circular tunnel using the Coulomb failure criterion (Low and Einstein, 2013). Liang et al. (2014) applied a displacement back analysis for a slope, to obtain the mechanical parameters and then evaluate the safety condition. Zhu et al. (2010) established a numerical model to study the dynamic failure process of rock under coupled static geo-stress and dynamic disturbance. Yu et al. (2014) performed numerical simulation on rock failure process based on the characterization of rock heterogeneity using a digital image processing technique. A least square support vector machine method was investigated to analyze the tunnel reliability (Zhao et al., 2014). Dong and Li (2013) proposed comprehensive models for evaluating rockmass stability based on statistical comparisons of multiple classifiers.

Microseismic monitoring is an effective method to provide sufficient information related to tunnel stability. Considering the effects of microseismic damage, Liang et al. (2013a, 2013b) developed an elastic-brittle failure model to simulate the seismic activities in rock failure. Furthermore, the acoustic emission and far infrared techniques were applied to monitor the progressive failure of a mining tunnel model subjected to biaxial stresses. Zhuang et al. (2016) studied the

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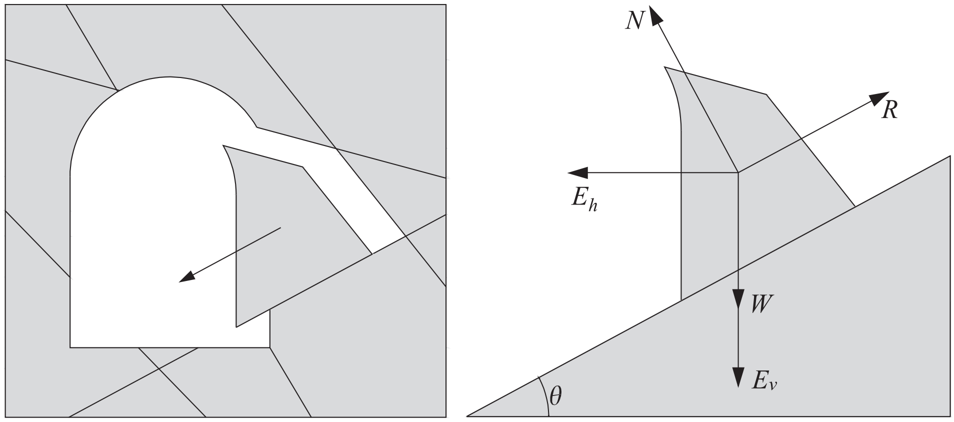

Fig. 1. 2D Figure of a block sliding along a single structural plane: W, N, R, E_h, E_v, and θ indicate the gravity, support force, resistance force, microseismic load along the horizontal direction, microseismic load along the vertical direction, and dip angle of the structural plane, respectively.

microseismic energy evolution of high rock slop during excavation and after reinforcement. Based on the microseismic monitoring technology, Lu et al. (2013, 2015, 2016) revealed the precursory characteristics for multi-parameter, as well as source distribution evolution rules pre-rockburst and post-rockburst. Dong et al. (2016a, 2016b) proposed the discriminant models of blasts and seismic events in mines, which can provide important information about the local state and stress conditions of the rock mass.

Although much effort has been made to study the stability and reliability of mining tunnels, general analysis methods still lead to a result with low accuracy, even an incorrect one. Currently, the reliability analysis methods widely used are mainly based on the probability theory, of which the random parameters are assumed to obey a certain distribution. In addition, the data used to conduct analysis are too scarce to accurately characterize the variables. The reliability indexes are different according to different distribution forms, which means that a certain assumed distribution form cannot be applied in all conditions (Chowdhury and Xu, 1995; Zhang and Goh, 2012). Moreover, the probabilistic reliability analysis model is highly sensitive to the values of parameters, that is, minor errors caused by the censored data from the distribution forms will lead to unacceptable results (Zhang and Goh, 2012). The microseismic loads induced by blasting operation also significantly affect the reliability of mining tunnels. The unacceptable errors may mix into the results of stability and reliability analysis when the microseismic loads are not considered.

The interval non-probabilistic reliability analysis methods for structures (Guo and Lu, 2015; Chowdhury et al., 2016; Guo et al., 2001; Ben-Haim et al., 1998; Jiang et al., 2007; Alefeld and Mayer, 2000) provide a useful approach to evaluate the uncertainties of the structures parameters. It is better for interval values to reflect the uncertainty of the parameters and reduce the demand for data information. In an actual project, it is much easier to estimate the value range of parameters, compared to the determination for both the exact values and probability distribution of parameters. Therefore, the interval non-probabilistic reliability analysis methods are better for the application in rock mechanics and rock engineering.

As mentioned in the beginning, the mining tunnels rockmass is divided by the structural planes. To analyze the stability of the formed blocks, the block theory (Goodman and Shi, 1985; Shi, 1978) is widely discussed and used, which is proved to be one of the most effective methods. Taking advantages of interval non-probabilistic reliability analysis methods and the block theory, Dong et al. (2017a, 2017b) adopted the interval rock strength to the stability analysis and then established interval non-probabilistic reliability analysis models for underground jointed rockmass and tailing dam. However, the microseismic loads are not considered.

Given all that, this paper focuses on the evaluation of jointed rockmass stability under microseismic loads in mining tunnels. The interval non-probabilistic reliability analysis method was used to analyze the stability of the underground jointed rockmass in Kaiyang mine, Guizhou, China. The interval values were selected to characterize the uncertainty of the random parameters. The proposed method can easily calculate the reliability index without the need of exact values or the probability distribution forms. It can be served as a useful complement to the traditional probabilistic reliability method when the data describing the uncertainty parameters are scarce. As a result, the calculated reliability index can provide guidance to the design of mining tunnels and the support of the jointed rockmass under seismic loads in actual projects.

2. Limit state equation and sliding characteristics of rock blocks

The rockmass of an underground mining tunnel is divided into blocks owing to the existence of structural blocks. With frequent blasting operations, the induced seismic load may lead to the unbalanced state of the blocks and chain disasters. Through the analysis of stress conditions and contact area, the sliding mode of a key block can be classified into two conditions, which are sliding along a single structural plane and sliding along two structural planes, respectively. In this paper, the sliding modes and limit state equations of key blocks in tunnels are analyzed under the effect of microseismic load.

Fig. 1 shows the strained condition of a block that slides along a single structural plane i under the microseismic load. To analyze the state condition of the block, the forces are resolved into the sliding direction and the direction normal to the structural plane.

In the direction normal to the structural plane, the total normal force N can be expressed as

$$N = (W + E_v)\cos\theta - E_h\sin\theta, \tag{1}$$

Along the sliding direction, the active force S and resistance R are shown in Eqs. (2) and (3), respectively.

$$S = (W + E_v)\sin\theta + E_h\cos\theta, \tag{2}$$

$$R = N\tan\varphi + cs, \tag{3}$$

where φ, c, and s indicate the internal friction angle, cohesion, and area of the structural plane, respectively.

The seismic loads along the vertical and horizontal directions can be defined as Eqs. (4) and (5), respectively.

$$E_v = W\cdot a_v/g, \tag{4}$$

$$E_h = W\cdot a_h/g, \tag{5}$$

where a_v and a_h are the component of the PGA along the vertical and horizontal direction, PGA represents the peak ground acceleration.