Propagation and prediction of blasting vibration on slope in an open pit during underground mining

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ARTICLE INFO

ABSTRACT

In order to assess the influence of underground mining blasting on the stability of open pit slopes and control the potential risk, it is crucial to investigate the propagation and attenuation of blasting vibration in rock slopes. In this paper, we aimed to investigate the attenuation of blasting vibration on open pit slopes subjected to underground mining activities using Daye Iron Mine as an example. To this end, we first analyzed the characteristics of blast loadings using the dynamic finite element method. We then established a three dimensional (3D) numerical model for open pit subjected to underground mining and proved its reliability using the field monitoring data. Next, we calculated and analyzed the distribution characteristics of peak particle velocity (PPV) by inputting the obtained blast loadings into the numerical model and discussed the impacts of blasting vibration on open pit slopes subjected to underground mining. To better and more conveniently assess and predict the impacts of blasting vibration, we further established a mathematical model to describe the attenuation of PPV on open pit slopes subjected to underground mining blasting through theoretical analysis and proposed a PPV predicting model for slopes in Daye Iron Mine based on the numerical simulations of underground mining blasting at different elevations.

1. Introduction

With the continuous surface mining of mineral resources, open pit slopes become higher and steeper, potentially leading to instability. In addition, with depletion of near-surface mineral resources, surface mining becomes more costly. Obviously, to ensure mining safety and efficiency, underground mining is an alternative choice. However, in the process of transition from open pit to underground mining, blast-induced seismic wave propagates in open pit slopes. Such a disturbance is often the critical factor triggering the instability of high and steep open pit slopes (Ak et al., 2009; Deb and Jha, 2010). In order to effectively assess the seismic effect of blasting during underground mining on open pit slopes and control the potential risk of instability, it is crucial to investigate the impacts of blasting vibration on slope and understand the propagation and attenuation of blasting vibration in rock slope.

At present, although many scholars have extensively studied the impact of blasting vibration on rock slopes, most of them focused on the influence of open pit excavation and mining blasting on rock slopes (Guo et al., 2004; Li and Zhang, 2007; Afeni and Osasan, 2009; Baczynski, 2010; Deb et al., 2011; Choi et al., 2013; Hu et al., 2014;

Saadat et al., 2014). For example, Kesinal et al. discussed the influence of blast-induced acceleration on slope stability at a limestone quarry by field monitoring and theoretical analysis (Kesimal et al., 2008); Thote and Venkat experimentally investigated the slope damages due to blast loadings of different frequencies and vibration velocities (Thote and Ramana, 2013). In recent years, with the development of computer technology, numerical simulations are frequently adopted to study the influence of blast on rock mass and rock slopes (Zhong et al., 2010; Sangroya and Choudhury, 2013; Zhang et al., 2011; Deng et al., 2015). Yan et al. analyzed the variation law of slope stability coefficient influenced by blasting vibration using the software GEO-SLOPE (Yan et al., 2014). Yang et al. adopted the software FLAC to analyze the dynamic stability of opencast slopes affected by blast loading (Yang et al., 2011). Zheng et al. and Azizabadi et al. analyzed the vibration of slope subjected to excavation blasting using the software UDEC (Zheng et al., 2014; Azizabadi et al., 2014). Liu et al. conducted discontinuous analysis of the stability of blast-induced slopes based on the DDA numerical method (Liu et al., 2010). Li et al. adopted the software FINAL to analyze the dynamic response of prestressed anchorcables subjected to blast loading on slope (Li et al., 2007). Moreover, many scholars utilized ANSYS/LSDYNA, a nonlinear finite element software, to

analyze the effects and characteristics of blast loading induced by detonation of explosives (Li et al., 2011; Xie et al., 2016; Yi et al., 2017; Xie et al., 2017).

In this paper, we focused on the effects of blast during underground mining on the open pit slopes of Daye Iron Mine in China (Section 2). First, we calculated the characteristics of blast loading in underground mining by employing the dynamic finite element software ANSYS/LS-DYNA (Section 3). Second, we established a 3D numerical model of open pit and verified its reliability using the field monitoring data (Section 4). Third, we used the model to analyze the impacts of blast vibration on pit slopes based on the distribution characteristics of peak particle velocity (PPV) on slopes (Section 5). At last, based on these primary results, we established a mathematical model to describe the attenuation of PPV on slopes subjected to underground mining blast through theoretical analysis and proposed a PPV predicting model for the open pit slopes of Daye Iron Mine during underground mining (Section 6).

2. General information of the open pit to underground mining mine

2.1. General information of the open pit slopes

Daye Iron Mine is located in Tieshan District, Huangshi City, Hubei Province, PR China, about 90 km west to Wuhan City, 25 km east to the downtown of Huangshi City and 15 km southeast to Daye City, as shown in Fig. 1. Throughout 100 years of mining activities, a deep open pit of 2400 m long longitudinally and 1000 m wide latitudinally has been formed, as shown in Fig. 2. The east open pit of Daye Iron Mine was selected as the study area, as shown in Fig. 3. Its north slope is 170 m–270 m above the mean sea level (AMSL) and composed of diorite, and its south slope is 86 m–200 m AMSL and composed of

marble. The slopes' angle is 38°–43°, and the slopes' height is 230 m–430 m. Magnetite distributes in the contact zone between diorite and marble. The pit bottom is filled to ± 0 m AMSL with crushed stones. There are many natural faults in the study area. Among them, Fault F9 and Fault F25 have great effects on the slope stability. A-slope is located in the east of the north slope and its stability is mainly controlled by Fault F9. In history, A-slope was locally destabilized for many times and has become a potential threat. Meanwhile, under the impacts of underground blasting operation and weathering, the partial collapse of surficial rock mass of the open pit slope always happens, destroying the pit slopes' benches (Yao, 2008).

2.2. Underground mining method

Non-pillar sublevel caving method is adopted for the underground mining of Daye Iron Mine. A total of 14 boreholes with diameter of 80mm and various length ranging from 7 m to 17.4 m were distributed in a fan-shape with angle between adjacent boreholes varying between 6° and 9° for blasting (Fig. 4). For each mining blast, the 14 boreholes were detonated simultaneously to create a tunnel of 3.6 m wide and 3 m high with an arch shaped wall using the No.2 rock emulsion explosive of China.

3. Characteristics of blast loading in underground mining

3.1. Numerical model and parameters

In order to obtain the blast loading in underground mining, a 3D numerical model of 30 m high, 16.4 m wide and 4.8 m long in the axial direction of the tunnel was established based on the distribution of boreholes in the tunnel (Fig. 5). These boreholes were distributed on the top of the tunnel within a fan-shaped vertical plane, 1.6 m away

Fig. 1. Location of Daye Iron Mine in Hubei Province, China.