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Impacts of bench blasting vibration on the stability of the surrounding rock masses of roadways

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A R T I C L E I N F O

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A B S T R A C T

In the process of open-pit and underground mining, the seismic wave generated by open-pit blasting can influence the stability of the surrounding rock masses on a roadway. It is easy to destabilize the surrounding rock, which seriously affects the stability of the roadway and the safety of the underground mining operation. The effects of the blasting vibration on the surrounding rock of the roadway are difficult to obtain with field data and pure theoretical research is relatively difficult to conduct. In this study, we used China's Anjialing Coal Mine and its combined open-underground mining as the research site and used numerical simulations and field observations to analyze the roadway lining, the surrounding loose rock, the anchor, and the stability of the surrounding loose rock before and after blasting to evaluate the effects of the blasting vibration. In addition, the stress transfer of the anchor and lining before and after blasting is analyzed and the performance and safety of the anchor and lining are evaluated in order to determine the mode of propagation of the seismic wave in open-pit blasting. The results show that the vibration velocity at each measuring point is less than 15 cm/s and that the vibration peak of each measuring point is attenuated with an increase in the distance from the point to the explosion source. The blasting vibration can affect the surrounding rock to various degrees in a specific range and the redistribution of the surrounding rock does not result in an increase in the surrounding loose rock. The influence of blasting on the stress of the anchor decreases with the distance from the blasting source. The results of this study can predict and control the abrupt structural and local failure caused by blasting to ensure the stability of the underground structure and the surrounding rock and to maintain the safety of the construction process.

1. Introduction

As the demand for coal resources has reached an unprecedented height, shallow coal mine resources are decreasing constantly, coal mining has gradually transferred to deep mining, and many domestic coal mines are focusing on open-pit and underground mining models. Such is the case for China's Anjialing open-pit mine, the Antaibao open-pit mine, the Pingzhuang West open-pit mine, and other open-pit and non-ferrous metal mines. When the two mining methods co-occur in the same area, open-pit and underground mining processes affect each other. On the one hand, the safety of an open-pit slope is threatened by underground mining; on the other hand, the stability of the mine roadway is influenced by the blasting vibration of open-pit mining. Strata movement, stress changes, and formation of the mining of space caused by open pit and underground mining will affect each other. The mutual influences are mainly manifested in the blasting vibration wave. The seismic wave generated by the open-pit blasting changes the existing roadway lining, the anchor, and surrounding loose rock. The effects of the blasting vibration on the surrounding rock of the roadway involve detonation theory, rock dynamics, stress wave propagation, and many other disciplines, and it is very difficult to solve the blasting problem entirely in theory.

The impact of the blasting vibration on existing roadways is a multidisciplinary problem and involves many aspects, such as the dynamic response of rock mechanics, the blasting vibration, the propagation of the stress wave, the loose zone of the surrounding rock, and the lining of the tunnel. Research methods have included theoretical analyses, numerical simulations, field tests, and synthesis methods. Viktorov et al. (2014) discussed the transfer and redistribution of blasting energy in rocks under complex geological conditions. Attwell et al. (1965, 1967) presented an empirical formula for the maximum velocity of the vibrating waves. Baron (1962) deduced the expressions of the radial and tangential components of displacement and velocity and presented the numerical results of these quantities in the cavity

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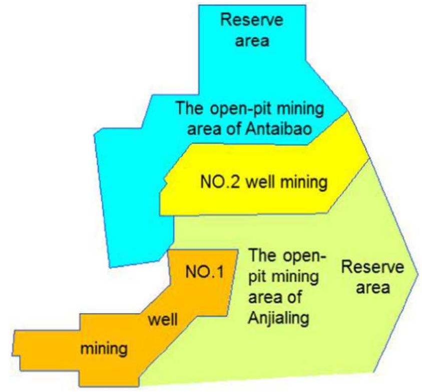
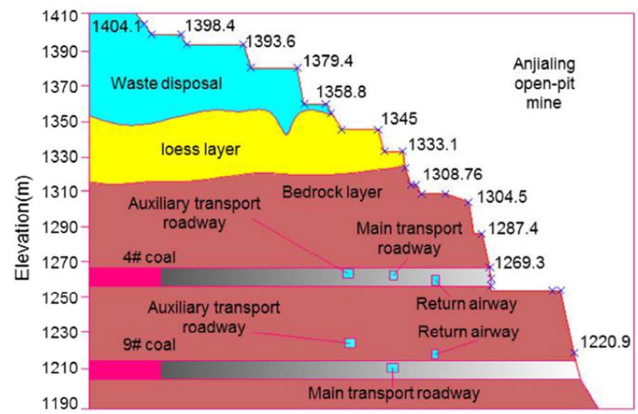
boundary. A numerical simulation analysis by Maihemuti et al. (2016) of the deformation and failure processes of a fractured rock slope showed that the influence of the water level decline on the stability of a reservoir bank slope was greater than the influence of the water level rise. Srikrishnan et al. (2014) studied the influence of earthquakes on mining slopes. Finally, with regard to field tests, Singh (2002), Singh et al. (2005, 2015) conducted a research project at the Rampura Agucha open-pit lead-zinc mine and investigated the vibration response of open-pit blasting on the adjacent roadway and the top and bottom plates of the underground coal mine; the authors concluded that the vibration effect on the roof was large while the vibration effect on the bottom plate was small. Dick et al. (2015) proposed an early-warning method for the instability of open pit slopes by using radar monitoring data of slope stability. Ali and Morteza (2014) conducted a study on the influence of the uncertainty of geomechanics on the slope stability of a metal mine. Roy et al. (2014) studied the influence of controlled blasting on the vibration of a foundation pit. The results showed that the blasting vibration did not affect the stability of the foundation pit wall. Osasan and Stacey (2014) used radar monitoring and an inversion speed method to predict the failure time of a slope to ensure the safety of the construction process. Brich and Pegden (2010) improved the prediction of the ground vibration caused by blasting in a quarry and analyzed the law of the propagation of the vibration waves. Uysal et al. (2007) studied the effects of load width on vibration in opencast mines, under increased load and reduced vibration. Several comprehensive research studies have been conducted using a variety of methods. For example, Jeon et al. (2007), Jeon and Jang (2009) studied the effects of blasting on the stability of the concrete lining of an adjacent tunnel and the rock bolts. A numerical simulation analysis indicated that the stress of the concrete lining and the anchor increased but that the effect was small on the concrete lining and large on the anchor. Shin et al. (2011) reported on the influence of blasting on an existing tunnel in soft rock using numerical simulations and field methods. Khakestar et al. (2016a, 2016b) discussed the application of a multi-criteria decision method for the analysis of slope stability in an open-pit mine. In this study, the risk of slope collapse was predicted by using the statistics of various geotechnical parameters. The results showed a discontinuity between the low values of the parameters for the rock and soil around the foundation pit.

Although much research has been conducted to date on this topic using theoretical analysis, numerical simulations, and field tests, research on the effects of seismic waves on existing roadways due to blasting in open-pit and underground mining is lacking. In addition, because field measurements and numerical simulations are scarce, most of the research results can only be used as reference data for blasting in tunnel engineering. Moreover, many studies are restricted due to geographical environmental, and construction conditions and the data are not suitable to solve this problem.

The research goal of this paper is to conduct numerical simulations and field observations to investigate the influence of blasting vibration on the stability of the roadway and surrounding rock at the combined open-underground Anjialing Coal Mine in China. First, an analysis of the roadway lining, surrounding rock loosening rings, and the bolts is carried out. In addition, the stability of the surrounding loose rock before and after blasting is observed. Second, the stress transfer of the bolts and the lining before and after the blasting is analyzed, the performance and safety of the bolts and lining are evaluated, and the propagation mode of the open-air blasting seismic wave is determined. Finally, the interaction between the blasting seismic wave and the underground cavern is analyzed to predict and control the integral and local damages caused by the surrounding rock and the structure of the underground cavern. This paper provides a theoretical basis for ensuring the stability of the underground structures and the surrounding rock.



(a) The open pit and underground mining layou of Anjialing No.2 well mining



(b) The relative position of No.2 well mining monitoring roadway and anjialing open-pit mine

Fig. 1. Engineering situation of Anjialing.

2. Materials and methods

2.1. Engineering survey

The research object of this paper is the Anjialing Coal Mine. It is located in the Pinglu District in Shuozhou City, Shanxi Province and is China's first open-pit and underground mining operation, and has a highest coal-recovery rate. The Anjialing No. 2 well mining operation represents a typical open-pit and underground mine. Its surface is the outer dumping area of the open pit mine (Fig. 1(a)). The main mining objective is mining of the #4 coal and #9 coal. The relative position of the No. 2 well mining monitoring roadway and the Anjialing open-pit mine is shown in Fig. 1(b).

Deep hole bench blasting was used in the Anjialing open-pit mine, using an hole-outside non-electric millisecond detonator, a single hole ring, and single hole blasting of once each location. The EXEL high precision non-electric detonators of Orica company were used, which can easily and accurately realize the single hole blasting. Maximum single blow blasting charge is 149–500 kg. Aperture of bench blasting is generally Φ165 mm or Φ250 mm. Hole distance is 7.0–8.0 m. Distance between two rows is 6.0–8.0 m.

2.2. Blasting vibration monitoring of roadway lining in mine

2.2.1. Measuring point arrangement

According to the safety monitoring characteristics of Anjialing open-pit mine bench blasting, Optimization of the Minimate Plus model (Instantel company, origin, Canada) micro-type blasting testing system. The system is the most advanced micro-type blasting vibration testing system in the world, the minimum precision is 0.127 mm/s. At the same