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Prediction of blast-induced flyrock in Indian limestone mines using neural networks

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A B S T R A C T

Frequency and scale of the blasting events are increasing to boost limestone production. Mines are approaching close to inhabited areas due to growing population and limited availability of land resources which has challenged the management to go for safe blasts with special reference to opencast mining. The study aims to predict the distance covered by the flyrock induced by blasting using artificial neural network (ANN) and multi-variate regression analysis (MVRA) for better assessment. Blast design and geotechnical parameters, such as linear charge concentration, burden, stemming length, specific charge, unconfined compressive strength (UCS), and rock quality designation (RQD), have been selected as input parameters and flyrock distance used as output parameter. ANN has been trained using 95 datasets of experimental blasts conducted in 4 opencast limestone mines in India. Thirty datasets have been used for testing and validation of trained neural network. Flyrock distances have been predicted by ANN, MVRA, as well as further calculated using motion analysis of flyrock projectiles and compared with the observed data. Back propagation neural network (BPNN) has been proven to be a superior predictive tool when compared with MVRA.

1. Introduction

Due to the explosive force, rock fragments are propelled and thrust high into the air and beyond the safety limit of blast area, thus termed as “flyrock”. This is mainly due to the flaws presented in the blast design and also due to the mis-interpretation of rock mass behavior. The phenomena of flyrock are always uncontrolled and can never be brought down to zero. But beyond safe permissible limits, flyrock can cause some serious damage to the property and can inflict serious to fatal injury to the personnel, thus making it be one of the main causes of accidents and deaths in opencast mines. Number of accidents as well as number of deaths and injuries due to blasting in Indian mines has been shown in Figs. 1 and 2 (DGMS, 2013, 2014). Flyrock is one of the intriguing problems in opencast mining.

By blasting, we obtain a fixed and/or constant size of rock due to fragmentation, which can help in optimizing the further production economics. During explosion, a part of energy is used in breaking and displacing the rock, while the rest of energy (a major portion) is used up in ground vibrations, air blasts, noises, back breaks, flyrocks, dusts, etc., thus posing a thrust to the nearby life and property (Pal Roy, 1995). Flyrock occurrence can be explained with the help of three basic mechanisms, i.e. cratering, rifling and face burst, as described in Fig. 3 (Moore and Richards, 2005).

Inadequate burden, inadequate stemming length, faulty drilling, back breaks, loose rock on top of the bench due to poor previous blast, very high explosive concentration, inappropriate delay timing, and their sequence, and inaccuracy of delays are the prominent blast design parameters responsible for flyrock problems (Workman and Calder, 1994; Siskind and Kopp, 1995; Adhikari, 1999; Rehak et al., 2001). Unfavorable geological conditions, such as open joints, weak seams, and cavities, have been identified as the major causes of flyrock hazards in opencast mines (Persson et al., 1984; Fletcher and D’Andrea, 1986; Bhandari, 1997; Shea and Clark, 1998).

Blast performance is basically governed by geological and geotechnical data, such as rock quality designation (RQD), unconfined compressive strength (UCS), and joint setting. Joints have an important role to play in any blasting operation as they determine both the safety and performance. Joints are the natural planes of weakness that offer practically no resistance to split. Joints are the zones of discontinuity and weakness and thus during blasting they get affected first, rather than the stable homogenous

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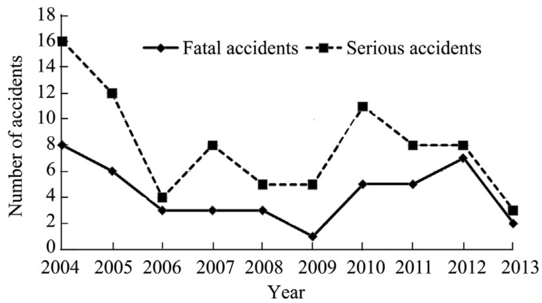

Fig. 1. Number of fatal and serious accidents due to blasting in Indian mines (DGMS, 2013).

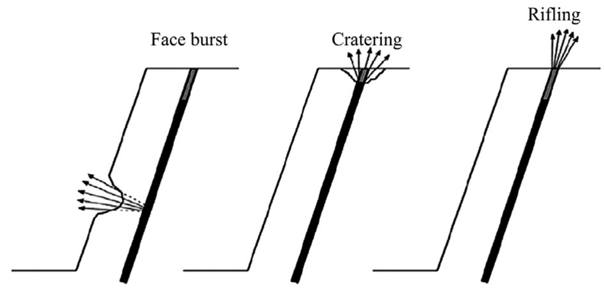

Fig. 3. Mechanisms of blast-induced flyrock in opencast mines.

regions. Therefore, they control the rock breakage process by determining which area gets affected first. Rock fragmentation and over break are influenced by the joint sets. The blast design can be improved by review and analysis of past data of the blasts conducted in the mines (Bhandari, 2011; Parihar and Bhandari, 2012).

Flyrock due to blasting in opencast mines is complex in nature as it is a random phenomenon. Raina et al. (2007, 2011) attempted to devise a criterion for prediction of blast-induced flyrock distances and focused on the factors on which the phenomenon of flyrock depends. An effective prediction of a blast in opencast mines can address the flyrock problem (Ladegaard-Pedersen and Holmberg, 1973; Lundborg, 1974; Roth, 1979; Richards and Moore, 2004; Monjezi et al., 2010).

In this paper, an attempt has been made to calculate initial velocity and angle of ejection of flyrock projectile, and maximum horizontal throw of flying fragments. Flyrock distances have been predicted with the help of feed forward back propagation neural network (BPNN), because it is the most versatile and robust technique (Sawmliana et al., 2007; Singh et al., 2008). Predictive problems, such as ground vibrations, air blast, flyrock, fragmentation, and back break, can be solved using back propagation algorithms (Huang and Wfinstedt, 1998; Singh and Singh, 2005; Tawadrous and Katsabanis, 2005; Remennikov and Mendis, 2006; Singh and Verma, 2010; Khandelwal and Monjezi, 2013; Trivedi et al., 2014).

Experimental blasts have been conducted in 4 limestone mines in India. Out of datasets of 125 experimental blasts, 95 datasets have been used to train the neural network; remaining datasets are used for testing and validation of neural network. Flyrock distances for 30 experimental blasts have been predicted by artificial neural network (ANN), multi-variate regression analysis (MVRA), calculated using motion analysis of videos of flyrock projectiles and compared with the observed data.

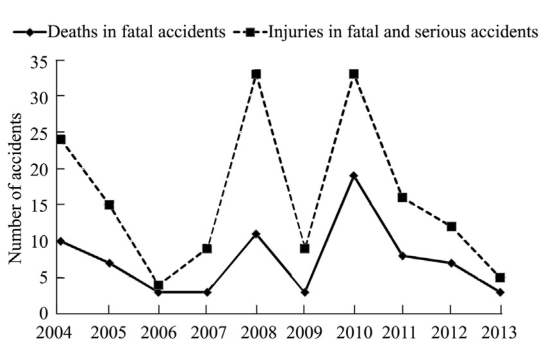

Fig. 2. Number of deaths and injuries due to blasting in Indian mines (DGMS, 2014).

2. Materials and methods

2.1. Field study

Four limestone mines have been selected in this study, i.e. (1) Bamangaon and Mehgaon mines, ACC, Katni, (2) Sheopura-Kesarpura (S-K) mine, shree cement, Beawar, (3) Aditya mine, UltraTech, and (4) Chittorgarh and Kotputli mines, UltraTech, Jaipur. The mining lease of Bamangaon and Mehgaon mines is located at Kymore Village, Vijayraghavgarh Block, Katni District, Madhya Pradesh State of India. It lies between longitude E80°29′ and E80°57′E and latitudes N23°48′ and N24°8′, survey of India toposheet No. 64A/53. The lease area is 51.2022 km^2. The true dip of limestone bed varies between 10° and 20° from west to northwest. However, at some places it is gentle in nature.

The S-K mine is located near Beawar City, Ajmer District, Rajasthan. The mining lease of 856.8 ha lies between longitude E74°22′ and E74°26′ and latitudes N26°1′ and N26°5′, on toposheet No. 45J/8 of survey of India. The planned capacity of the mine is 2.0 million tons of limestone per year. The major portion of area is rocky and there is no vegetation. There occur two parallel ridges of limestone extending along length of area. Between two ridges, there is alluvium/soil. Structurally the area represents a tight isoclinal synclinorium fold where limestone constitutes two limbs of fold, which are separated by a shallow valley. The general strike direction of limestone beds in the area is N30°E. Generally beds are dipping in WNW direction with dip of 45° to as high as 60°.

The Aditya limestone mine is located in Tehsil—Chittorgarh and Nimbahera, Chittorgarh District (Raj). The site is located 18 km Southwest of Chittorgarh Town. The mining lease area of the Aditya limestone mines forms a part of survey of India toposheet Nos. 45L/9 and 45L/10 between latitudes 24°43′ and 24°45′ north and longitudes 74°35′ and 74°37′ east. The leasehold area of mine is 760.692 ha with the planned production capacity of 6.6 million tons of limestone annually with a stripping ratio of 1:0.33. Structurally the area represents a syncline fold. In spite of above folds, study of dip and strike readings indicates N—S trend with maximum of 10° deviation on either side. The dip varies between narrow ranges of 0° and 20°. Dip direction changes from east to west due to folding.

The Kotputli limestone mine (Grasim Cement) is located at Mohapura Jodhapura near Kotputli Town, Jaipur District, Rajasthan. It is situated at a distance of 165 km south from Delhi and 106 km north from Jaipur. The lease area of the mine is 5.4878 km^2. The mine lies between latitude N27°39′ and N27°42′ and longitude E76°6′ and E76°9′, survey of India toposheet No. 54A/2. The production capacity of the captive limestone mine is 6 million tons per year. The limestone formations of this area is light to dark gray in color, low to medium grained crystalline, hard and massive in nature. Color banding was observed at some places. The general strike direction of the rock formation of this area is NE—SW with variable dip ranging from 38° to 80° due east.