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A rock engineering systems based model to predict rock fragmentation by blasting

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ABSTRACT

A new model for prediction of rock fragmentation by blasting is presented based upon the basic concepts of rock engineering systems (RES). The newly proposed approach involves 16 effective parameters on fragmentation by blasting with keeping simplicity as well. The data for 30 blasts, carried out at Sungun copper mine, western Iran, were used to predict fragmentation by the RES based model as well as Kuz–Ram and multiple regression modeling. To validate the new model, the fragmentations of nine production blasts were measured and the results obtained were compared with the predictions carried out by the RES, Kuz–Ram and multiple regression models. Coefficient of determination (R^2) and root mean square error (RMSE) were calculated for the models to compare the results obtained. For the RES, linear, polynomial, power, logarithmic, exponential and Kuz–Ram models, R^2 and RSME are equal to (0.65 and 14.51), (0.58 and 29.73), (0.54 and 21.58), (0.60 and 32.64), (0.61 and 23.80), (0.50 and 184.60) and (0.46 and 22.22) respectively. These indicate that the RES based model predictor with higher R^2 and less RMSE performs better than the other models.

1. Introduction

Rock fragmentation has been the concern of many research works because it is considered as the most important aspect of production blasting, since it affects on the costs of drilling, blasting and the efficiency of all the subsystems such as loading, hauling and crushing in mining operations [1–7]. The parameters affecting on the rock fragmentation can be categorized in two groups: the first group is controllable parameters; such as blasting design parameters and also explosive related parameters; and the second one are uncontrollable parameters, which contains physical and geomechanical properties of intact rock and also rock mass [8–10].

Prediction of the rock fragmentation size is the first step toward optimization of blast design parameters to produce required fragment size [11]. Several studies have been conducted on the prediction of fragmentation by blasting accounting for controllable and uncontrollable parameters. An equation on the basis of the relationship between mean fragment size and specific charge was developed by Kuznetsov [12]. Cunningham [13], based upon the Kuznetsov model and the Rosin & Rammler distribution, introduced a new model, Kuz–Ram model, to predict rock fragmentation by blasting. Kuz–Ram model was further improved by Cunningham [14].

Hjelmberg [15] presented the SveDeFo model to predict X_{50}, considering the rock mass type and the blast pattern. Otterness et al. [16] performed an extensive study to correlate shot design parameters to fragmentation. Kou and Rustan [17] developed an empirical model to predict X_{50}. Lownds [18] used distribution of explosives energy to predict the fragmentation by blasting. Aler et al. [4] carried out a research work to predict blast fragmentation by multivariate analysis procedures. Djordjevic [19] presented the results of blast fragmentation modeling based on two mechanism of failure at JKMRC. Furthermore, Morin and Ficarazzo [20] applied Monte Carlo simulation as a tool for prediction of fragmentation based on Kuz–Ram model. Also, Gheibie et al. [21,22] tried to enhance fragmentation prediction by modification of Kuznetsov model and Kuz–Ram model. In 2010, Ouchterlony proposed a new fragment size distribution function [23].

Some research works were carried out using artificial intelligence methods to predict rock fragmentation. Saavedra et al. [24] conducted a research work to predict fragmentation by blasting, using a neural network model. Monjezi et al. [25] developed a fuzzy logic model for prediction of rock fragmentation by blasting. Kulatilake et al. [10] presented a piece of work, predicting mean particle size in rock blast fragmentation using neural networks. Also, Monjezi et al. [26] used neural networks for prediction of rock blasting fragmentation. Chakraborty et al. and Hudaverdi et al. [27,28] applied multivariate analysis procedures to predict rock fragmentation by blasting.

The empirical and neural network models that are based upon the data surveying from different blasting operations, in a certain

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range of rock types, cannot be generalized for various ground conditions. Furthermore, all of above models do not simultaneously consider all the pertinent parameters in the modeling. Under such limitations or constraints, the prediction of rock fragmentation due to blasting needs the new innovative methods such as the RES based model, capable of accounting unlimited parameters in the model. The RES approach has been applied to a number of rock engineering fields, for examples, evaluation of stability of underground excavations [29], hazard and risk assessment of rockfall [30], rock mass characterization for indicating natural slope instability [31], development of an assessment system for blastability of rock masses [32], assessing geotechnical hazards for TBM tunneling [33] and quantitative hazard assessment for tunnel collapses [34].

Fig. 1. A general view of the Sungun copper mine.

The present paper introduces a new RES based model that can be applied to evaluate fragmentation risk (poor fragmentation) and then, predict rock fragmentation in bench blasting, considering all pertinent parameters. To validate the performance of the model proposed, it is applied to Sungun copper mine, Iran. Furthermore, the results obtained are compared with the results of Kuz–Ram model and also statistical modeling, which carry out for the same mine.

2. The field study

2.1. Site description

Sungun copper mine, an open-pit mine, with a mineable reserve of 410 Mt and average grade of 0.6% copper, is located 100 km north east of Tabriz city, Iran. It is planned to produce 7 Mt ore for the initial 7 years with the intention to expand capacity up to 14 Mt of ore. A maximum slope height of 765 m was obtained for the initial design of the final pit. In blasting operation, ANFO is used as explosive and NONEL and detonating cord as initiation systems with staggered pattern. Also, inter-row

Table 1
Properties of intact rock and rock mass in the Sungun copper mine [35].

Sector	Average values of intact rock and rock mass			
	UCS (MPa)	*C* (KPa)	GSI	RMR
RS01	55	538	35	37
RS02	63	630	38	49
RS03	73	662	39	44
RS04	68	710	39	34
RS05	64	655	37	43
RS06	87	794	39	41
RS07	82	789	40	44

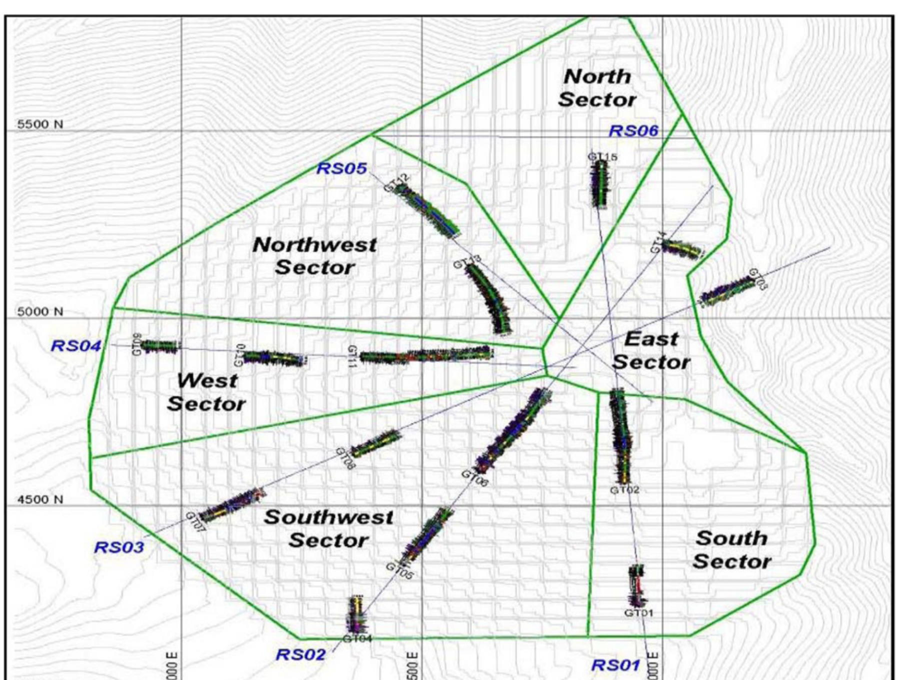

Fig. 2. Different sectors in the Sungun copper mine [35].