Journal of African Earth Sciences 133 (2017) 36–45

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Optimization of a nonlinear model for predicting the ground vibration using the combinational particle swarm optimization-genetic algorithm

Hossein Samareh [a, b], Seyed Hassan Khoshrou [c], Kourosh Shahriar [c, *], Mohammad Mehdi Ebadzadeh [d], Mohammad Eslami [e]

[a] *Department of Mining Engineering, Science and Research branch, Islamic Azad University, Tehran, Iran*
[b] *Azad Islamic University, Hejrat Ave, 78185-187, Sirjan, Iran*
[c] *Department of Mining and Metallurgical Engineering, Amirkabir University of Technology, Hafez Ave, No, 424, 15875-4413, Tehran, Iran*
[d] *Department of Computer Engineering and Information Technology, Amirkabir University of Technology, Hafez Ave, No, 424, 15875-4413, Tehran, Iran*
[e] *Senior of Project in Sarcheshmeh Copper Mine, Kerman, Rafsanjan, Iran*

ARTICLE INFO

Article history:
Received 2 October 2016
Received in revised form
4 April 2017
Accepted 26 April 2017

Keywords:
Ground vibration
Geo-mechanics properties of rock mass
Artificial neural network
Genetic algorithm
Particle swarm optimization
Blasting

ABSTRACT

When particle's wave velocity resulting from mining blasts exceeds a certain level, then the intensity of produced vibrations incur damages to the structures around the blasting regions. Development of mathematical models for predicting the peak particle velocity (PPV) based on the properties of the wave emission environment is an appropriate method for better designing of blasting parameters, since the probability of incurred damages can considerably be mitigated by controlling the intensity of vibrations at the building sites. In this research, first out of 11 blasting and geo-mechanical parameters of rock masses, four parameters which had the greatest influence on the vibrational wave velocities were specified using regression analysis. Thereafter, some models were developed for predicting the PPV by nonlinear regression analysis (NLRA) and artificial neural network (ANN) with correlation coefficients of 0.854 and 0.662, respectively. Afterward, the coefficients associated with the parameters in the NLRA model were optimized using optimization particle swarm-genetic algorithm. The values of PPV were estimated for 18 testing dataset in order to evaluate the accuracy of the prediction and performance of the developed models. By calculating statistical indices for the test recorded maps, it was found that the optimized model can predict the PPV with a lower error than the other two models. Furthermore, considering the correlation coefficient (0.75) between the values of the PPV measured and predicted by the optimized nonlinear model, it was found that this model possesses a more desirable performance for predicting the PPV than the other two models.

1. Introduction

Currently, in open pit mines, application of explosives and blasting operation is the only way for extracting ores and containing rocks. When the seismic waves resulting from the blast of a certain weight of explosives inside excavated holes pass through the rock masses in the emission environment, they can lead to instabilities and damages to the structures surrounding the blasting region such as the final pit walls of the mine or facilities especially at low frequencies (Singh et al., 2015; Yugo and Shin, 2015; Zaka Emad et al., 2012; Singh and Roy, 2010; Monjezi et al., 2010). In some cases, these damages are irrecoverable or at best their recovery incurs enormous costs to the mining activity, to such an extent that it can also result in the closure of the mine. Under such circumstances, the best remedy for reducing the intensity of vibrations is proper designing of the geometry of blasting holes based on the extent of influence of the emission environment conditions of the vibrational waves on the wave characteristics. In this respect, it is possible to attain a suitable blasting design model, whose intensity of vibrations does not cause any damage to the structure but predict the characteristics of blasting waves such as the PPV and

* Corresponding author. Tel.: +98 9125046009.
E-mail addresses: hossainsamareh@yahoo.com (H. Samareh), dr.khoshrou@aut.ac.ir (S.H. Khoshrou), k.shahriar@aut.ac.ir (K. Shahriar), ebadzadeh@aut.ac.ir (M.M. Ebadzadeh), eslami_m@nicico.com (M. Eslami).

http://dx.doi.org/10.1016/j.jafrearsci.2017.04.029
1464-343X/

frequency at the site of every structure by changing controllable influential parameters affecting the transitional vibrational energy (Blair, 2014; Yan et al., 2013; JHA and DEB, 2010; Ozer et al., 2008).

Various researchers have presented different models for predicting the attenuation degree of seismic waves for investigating the effect of controllable and uncontrollable parameters on the PPV and frequency of waves due to blasts in mines and preventing the undesirable consequences of the vibrations intensity on the surrounding structures. Accordingly, one can cite the studies in which researchers, benefiting from smart instruments and considering the effect of different parameters related to the design of blasting pattern and the characteristics of rocks masses, have presented some models for predicting the PPV and frequency of seismic waves (Parida and Mishra, 2015; Verma and Singh, 2013; Alvarez-Vigil et al., 2012; Khandelwal, 2011; Khandelwal and Singh, 2006). In the results obtained from these studies, in addition to identification of the parameters influencing the velocity of seismic waves, it has been found that the models that have been developed via artificial intelligence exhibit a far better performance than models developed by multiple regression analysis (MRA) for predicting wave characteristics.

In some other studies performed in regard to vibrations resulting from mining blasts on the surrounding environment, using different instruments such as Voltra functions series, numerical methods and wave shape correspondence, the researchers have investigated the effects and consequences of blasting vibrations on rock structures and the existent facilities at surrounding regions of blasts. In the results obtained from these studies, first, some methods have been presented for predicting the vibrations inflicting the structure. Secondly, it was found that the vibrations resulting from blasts cannot incur damage to the structure surrounding the studied mines (Mohammadi Azizabadi et al., 2014; Liu et al., 2012).

The presence of discontinuities and fractures in the emission path of seismic waves causes wave refraction and reflection. The wave energy is attenuated and the intensity of vibrations is reduced at the site of structures as a result of the incidence of these phenomena. As some of the characteristics related to discontinuities have the greatest influence on mitigation of wave energy, different researchers have attempted to first identify the affecting characteristics of discontinuities on the waves velocity by conducting numerous experiments in laboratory or field and secondly by developing some models to determine the wave's refraction and reflection coefficients using analytical tools and methods (Yexue Li et al. 2011; Leucci and De Giorgi, 2006; Cai and Zhao, 2000).

Continuing the research on ground vibration caused by mining blasts, Ghasemi et al., in 2016 used the combination of artificial intelligence and evolutionary systems to present an optimal model. This model was able to predict the PPV in mine with a greater accuracy when compared with wave attenuation models presented by other researchers such as Nichollas or Langefors (Ghasemi et al., 2016).

The aim of this research was to develop a model for predicting the PPV caused by produced blasts in the Sarcheshmeh Copper Mine with a high accuracy based on some of the blast design parameters and the geo-mechanical properties of rock masses. Therefore, it was necessary; to identify the parameters that have the potential to develop such a model. For this purpose, the first 95 seismic maps were recorded in the mine. Then by using linear multiple regression analysis (LMRA), the process of performing regression was done. Accordingly, the effective parameters were specified as a linear relationship with the coefficient of determination of 0.53 for conducting the research.

As influence of the propagation medium properties on the intensity of emitted waves is complex, it was decided to employ a powerful predicting instrument such as the ANN and a model is developed for predicting the PPV based on the determined effective parameters. Therefore, the ANN was trained by 66 recorded seismic data series and a model was developed with a correlation coefficient of 0.854. In addition, it was decided that having known the existence of nonlinear relationships between the wave velocity and the influence parameters, the optimal model for more accurate prediction of the PPV which is also applicable easily at the site of the mine was created. For this purpose, first using MRA with the help of 66 seismic dataset, which had to be employed for training of the ANN, different nonlinear models are developed between the PPV and the four effective parameters. Next, using the PSO-GA combinational algorithm, the obtained coefficients for each of the parameters in the best nonlinear model, are optimized.

2. Geology of Sarcheshmeh Copper Mine

The porphyry deposit of Sarcheshmeh copper mine, with geographically location 55° 52′20″ E longitudes and 29° 56′40″ N latitudes, is situated about 160 Km southwest of Kerman city. This mine is an open pit mine and its geological structure is very complex. This complexity is due to the fact that there are several types of rock with different physical and mechanical properties, which during mineral creation with primary and secondary hydrothermal solutions are influenced by various alterations such as Propilitic, Biotite, Philic, and Potasic. These alterations occurred with different intensities in parts of the mine, which the rock masses such as Andesite, Granodiorit, Sarcheshmeh porphyry, Quartz eye, and Lite Fine porphyry are affected in the mine. Additionally, three types of dykes such as penetrated masses with various intensities of weathering, variable thicknesses, and with almost vertical slopes cut the rock masses. Finally, several faults trending north-south and east-southwest, along with a series of joint sets crush rock formations and dykes.

The whole of these cases cause the rock masses to weaken and therefore the values of mechanical properties relating to the rock formations are reduced in the mine. General information regarding the physical and mechanical properties of mine rocks is presented in Table 1 (Samareh et al., 2015).

3. Methodology

As earlier mentioned, the aim of this research was to develop an optimal nonlinear model, whereby the designer of blast at the site of mine is easily able to predict the PPV with the minimum information from the status of rock masses in the emission path of seismic waves, the properties of the consumed explosive and the blast design parameters. For this purpose, 11 parameters were considered in relation to the blasting patterns design, the consumed charge and the geo-mechanical properties of rock masses that these parameters were shown in Table 2. In this table, the values related to each of rock mass parameters were determined through the results of rock mechanic tests on 206 samples of drilling cores obtained from mine rocks, ROCLAB software or the surface or sub-surface surveys in the mine. In addition, number of 95 seismic mappings obtained from 20 blasts were recorded by seismic devices belonging to INSTANTEL, Canada across different extraction benches of the northern and northwestern part of the mine's extraction area. By reason, the registration location regarding the characteristics of vibration waves were positioned relatively far away from the blast epicenters and various rock masses with unique properties stood in the emission path of seismic waves. Therefore, the effectiveness of propagation medium