دانشگاه بین‌المللی امام خمینی
IMAM KHOMEINI INTERNATIONAL UNIVERSITY
Imam Khomeini International University
Vol. 4, No. 2, Summer 2019, pp. 10-15

Mineral Resources Engineering
نشریه مهندسی منابع معدنی
Journal of Mineral Resources Engineering (JMRE)

DOI: 10.30479/jmre.2019.9986.1220

Blasting Pattern Design For Decreasing The Ground Vibration Using Genetic Algorithm

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(Received: 21 Jan. 2019, Accepted: 06 Apr. 2019)

Abstract: Ground vibration is one of the most unfavorable consequences of the blasting operation in open pit mines, which assign about 40 percent of explosive energy. Ground vibration may cause some unsuitable effects such as destroying the surface structures, damaging the free face and generate back breaks, generating the over-size boulders and imposing additional costs to the mine because of the secondary blasting. Optimum blasting pattern design can help to reduce the above mentioned problems. Due to multiplicity of effective parameters and complexity of interactions among these parameters, empirical methods may not be fully appropriate for blasting pattern design. In this paper, using a combination of the Grey analysis and Genetic algorithm, addition to developing a new equation for estimating the ground vibration in Sarcheshmeh Copper Mine, blasting pattern is presented. The results show that with applying the proposed blasting pattern the average ground vibration will be decreased about 55 percent.

Keywords: Ground vibration, Grey analysis, Genetic algorithm, Blasting.

INTRODUCTION

Ground vibration is one of the unpleasant results of blasting in open-pit mines. According to the studies, 40% of the explosive energy is wasted as ground vibration rather than being used for useful processes such as rock fragmentation [1]. Ground vibration can not only impose serious damages to existing facilities in the mine, but may also impose irreparable damages to the residential areas close to the mine. This can also lead to large-scale rock fall in the surface mines. Also, ground vibration may have adverse effects on the stability of buildings, roads, dams and natural slopes. The blast-induced ground vibration can also affect the groundwater level and lead to the dried springs and, on a larger scale, to deforestation [2]. Accordingly, the ground vibration phenomenon may impose irreparable costs on mine and environmental projects. Therefore, it is very necessary to estimate and control this unpleasant phenomenon. In the present study, using a combination of grey analysis and genetic algorithm, in addition to presenting a mathematical relation for estimating the ground vibration in the Sarcheshmeh copper mine, the proposed blasting pattern is presented to reduce the vibration.

METHODS

1. GRET THEORY

Grey theory was first introduced by Deng in 1982 [3,4]. This theory is mainly focused on the study of the problems involved with incomplete information and small number of samples by searching for information from data in the systems that deal with the uncertainty. This analysis is a powerful tool for dealing with small and discrete samples based on the relationship between the desired target sequence and the sequence of effective relative factors [4].

2. DIMENTIONAL ANALYSIS

Dimensional analysis is an engineering method for deriving the equations that make it easy to analyze variable and complex systems. One of the best techniques for dimensional analysis is the Buckingham's π theory. According to this theory, having *n* variables, a relation in the form of the complete function $\varphi(\alpha,\beta,\gamma,...)=0$ can be constructed. To solve this relation, the corresponding function $f\ (\pi_1,\pi_2,\pi_3,...)=0$ should be defined. Finally, by solving this function, the interaction of each of the effective parameters on the external parameter can be determined.

3. GENETIC ALGORITHM

Genetic algorithm is a search-based technique for finding an approximate solution for the optimization and search problems. Genetic algorithm is a particular type of evolution algorithm that uses biology techniques such as inheritance and mutation. This algorithm was originally developed by John Holland in 1967. This method then extended with the efforts of Goldberg in 1989, and nowadays, it is well-positioned among other optimization methods due to its capabilities. The optimization steps in the genetic algorithm are as follows [5]:

1. Produce appropriate solutions in a random manner (chromosome) to solve the problem (production of primary population);
2. Evaluate the fitness function of each chromosome;
3. Each hypothesis is evaluated using the fitness function at each iteration. Then, some of the best hypotheses are selected using a probability function and the new population is formed. Some of these hypotheses are used in the same way, and the rest are used by genetic operators such as crossing and mutation to produce children.
4. Test the final conditions and choose the best solution;
5. Check the fitness and return to step 2.

By performing the above steps, the genetic algorithm will be able to achieve the optimal solution in various problems [5].

CASE STUDY

Sarcheshmeh copper mine is one of the largest reserves of porphyry copper located 160 km southwest of Kerman. From the geological point of view, Sarcheshmeh copper deposits belong to the Tertiary era and have many complications. The exploitation of the mine is done using the open-pit mining. The final slope of the mine is 32-34° and the bench slope is 62.5°. The width and height of the benches are 8.75 and 12.5 m, respectively. The diameter of the blast holes is 9 in and the depth of the holes is about 15 m. The ANFO is often used as the main explosive. Data on ground vibration in 150 explosive blocks was collected. Other information on the explosion pattern is provided in Table 1.

NUMERICAL ANALYSIS

1. GREY ANALYSIS

In order to investigate the effects of blasting pattern parameters on the ground vibration, these parameters were used as grey analysis inputs. Fig. 1 shows the numerical value obtained from the grey analysis to achieve the correlation between the ground vibration caused by the explosion and other effective parameters. In order to determine the importance of the parameters affecting the ground vibration according to the experts, the 80% correlation is determined for the separation of the parameters. This means that the

Table 1. Input and output parameters used for modeling

	Parameter	Range	Unit	Symbol
Input	Burden	2-7.5	m	B
	Spacing	2-11	m	S
	Delay between rows	15-70	ms	D_e
	Specific charge	0.1-0.24	Kg/m^3	q
	Number of rows in each blasting	2-7	-	n
	Distance to monitoring point	600-2845.05	m	μ
	Maximum hole in dealy	6-32	-	θ
	Charge per dealy	1332-10985	Kg	ch
	Point load index	6.51-8.9	MPa	σ
Output	Peak particle velocity	0.49-77.3	mm/s	ppv

factors with the correlation above 80% are classified as effective factors and the factors with the correlation lower than 80% are classified as secondary factors with lower importance.

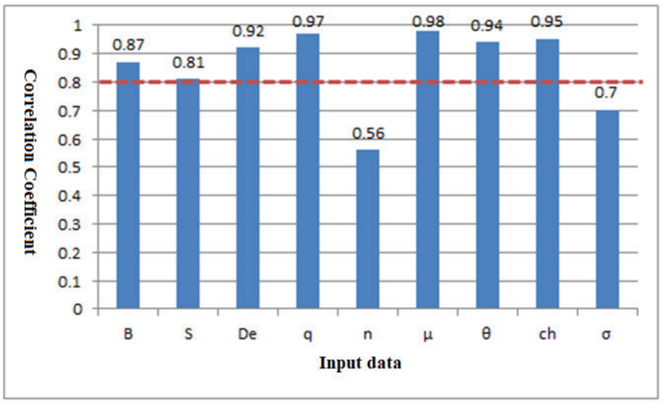

Figure 1. Result of gray analysis on Sarcheshmeh copper mine data

From the analysis of the data on the Sarcheshmeh copper mine, it can be seen that the distance of the monitoring point from the blasting, total charge, spacing, burden, delay between the rows, specific charge and maximum number of holes in each delay are the most important factors affecting the ground vibration. The results of grey analysis are considered as inputs of dimensional analysis.

2. Dimensional analysis

In the next step, all dimensioned parameters should be converted to the reference parameters including length (L), mass (m), and time (T). Since the parameter of the maximum number of holes in each delay is unit less, it is referred to as the dimensionless parameter and is assigned the unity value in the calculation process. Therefore, the dimensions of the input and output variables are defined as [B] = L, [S] = L, [q] = $FL^{-4}T^2$, [ch] = $FL^{-1}T^2$, [μ] = L, [De] = T, and [PPV] = LT^{-1}. Table 2 shows the dimensional matrix of input and output parameters.

Table 2. Dimensional matrix

	PPV	B	S	ɵ	μ	D_e	Q	ch
F	0	0	0	0	0	0	1	1
L	1	1	1	0	1	0	4	-1
T	-1	0	0	0	0	1	2	2

By analyzing the multivariate regression from the study databases and comparing the correlation coefficient obtained in SPSS software for the linear and nonlinear relationships, it was found that the nonlinear equation is more suitable due to the higher correlation coefficient. The relationship between the input parameters and the ground vibration using dimensional analysis is presented in equation (1).

$$PPV = \frac{168.85}{De}(q/ch)^{-1.48} B^{-5.64} S^{3.43} \mu^{-1.22} \theta^{-1.18} \quad (1)$$

Root mean square error (RMSE) of the mathematical relation presented for the estimation of ground vibration was calculated to be 3.49. The correlation coefficient obtained for this equation is 78%. Figure 2 shows the comparison between the actual and predicted ground vibration training data. Figure 3 also shows the difference between the actual and predicted ground vibration data using the relation presented in the test data.

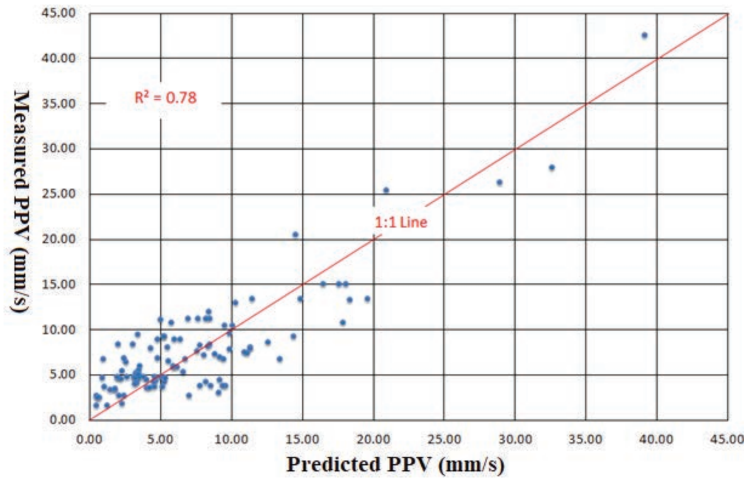

Figure 2. Correlation coefficient of proposed relation

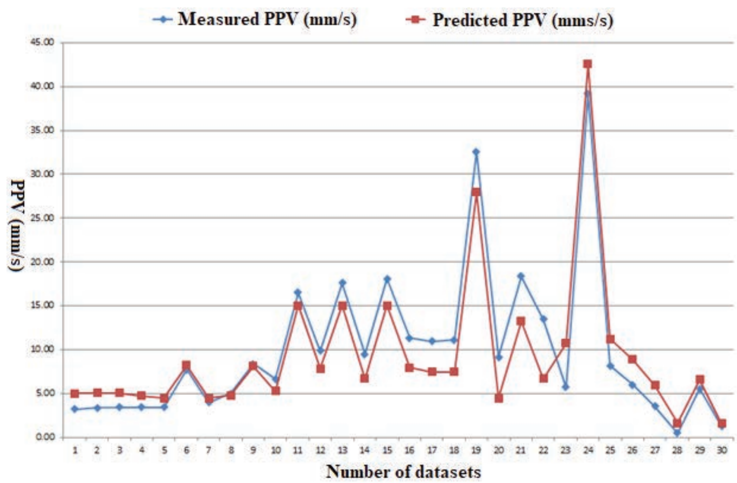

Figure 3. Comparison of predicted and actual ground vibration

3. Genetic algorithm

MATLAB software was used to improve the explosion pattern by genetic algorithm (GA). The process is started by recalling the objective function, and then, the input parameters with the related lower and upper bounds are given to the algorithm. In order to access the best results by genetic algorithm, it is necessary to accurately determine the options related to the algorithm including the population size, selection functions, reproduction, and determination of the maximum number of generations. To select the best options in a particular problem, the trial-and-error method is the best solution [5].

The initial value of the genes is determined randomly based on the interval presented in Table 1. The chromosomes are examined based on the options and the fitness function presented in equation 1. The convergence of the model is shown in Figure 4. After running the program, the chromosome with the least error as the final solution was selected as the proposed explosion pattern. The results of optimizing the genetic algorithm are shown in Figure 5. Table 3 was prepared in order to determine the effect of each input parameter on the amount of the explosion-induced ground vibration and to select the optimal explosion pattern. Considering the effective role of the "distance from the explosion" parameter, three explosion patterns were proposed to minimize the ground vibration proportional to different distances.

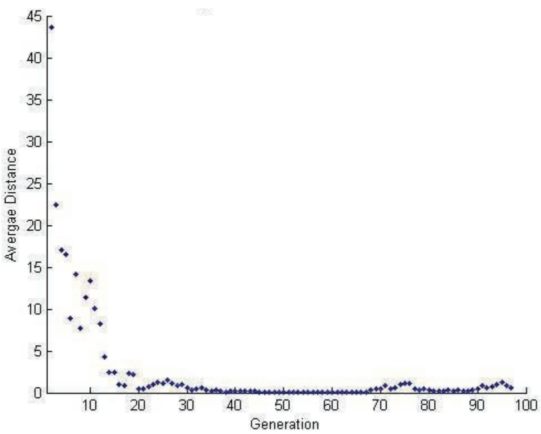

Figure 4. Model convergence or average speed of chromosomes

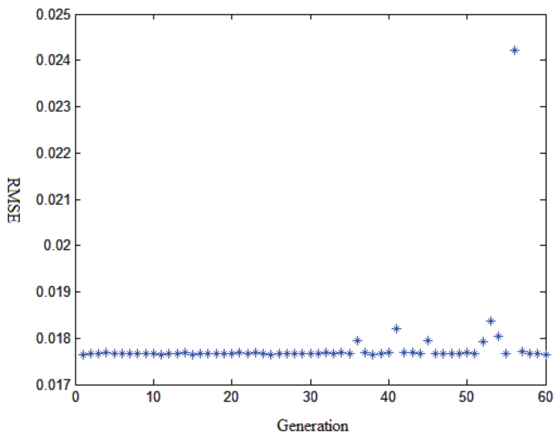

Figure 5. Improvement of objective function in genetic algorithm

By applying the parameters obtained by the genetic algorithm in the fitness function (equation 1), the PPV values are calculated.

Table 3. Results of proposed explosion pattern using genetic algorithm

Blasting pattern number	Distance to monitoring point (m)	Burden (m)	Spacing (m)	Dealy between rows (ms)	Charge per dealy (Kg)	Specific charge (Kg/m^3)	PPV (mm/s)
1	608	7.5	10	15	4522	0.132	5.52
2	1045	7.5	10	50	6067	0.179	3.56
3	1330	7.5	10	70	7246	0.181	2.89

CONCLUSIONS

In this paper, the data on ground vibration in Sarcheshmeh copper mine were evaluated and analyzed. In order to estimate the ground vibration and improve the blasting pattern in this mine, the combined grey analysis and genetic algorithm methods were used for the first time and the following results were obtained:

- A mathematical relation was proposed using dimensional analysis method to calculate the Peak particle velocity (PPV) based on the blasting parameters. This relation can estimate the PPV with the correlation coefficient of 0.78 and the RMSE of 3.49.
- The presented combined method is a powerful tool for optimizing the blasting pattern.
- In order to minimize the PPV, three blasting patterns were presented proportional to different

measurement distances to the face.

- Based on the results of grey analysis, the distance from the face and the specific charge are the most important parameters affecting the PPV.
- The results obtained from the genetic algorithm showed that the change in input parameters could reduce the average ground vibration to 55% of the current value.
- Although the methodology introduced here can be extended to other mines, the mathematical relation is merely developed for the study mine.

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