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Prediction of blast-induced ground vibration by ANN, USBM and CMRI formulae for safety of the structures near surface coal mines

Ground vibrations, air blasts, fly rocks, back breaks, noises are the ill effects of blasting which are unavoidable but certainly can be minimized up to permissible level to avoid damages to the surrounding environment, structures. Among all the ill effects, ground vibration is a major concern to the engineers, designers, and environmentalists. Various laws have been communicated by scientists and are being adopted to keep in check the ground vibration levels. This study is conducted to predict the blast induced ground vibration (peak particle velocity) using ANN, USBM and CMRI formulae for the safety of the structures existing near surface coal mines. The data obtained from the different mines are analyzed and the correlation for different models are established to see their predictability.

Keywords: Blasting; peak particle velocity; ANN; maximum charge per delay; surface mine

1.0 Introduction

Rock breakage using blasting technique is the most common method in mines, quarrying and civil engineering because it is cheaper and applicable in various geological conditions. The main problem of blasting is that explosive energy utilization has yet not improved due to which majority of the explosive energy is wasted in the form of ground vibration [1],[2]. Ground vibration leads to the crack in the nearby structures [3]. Peak particle velocity (PPV) is considered as the most important parameter in the evaluation of ground vibration [4]. It was first recommended by USBM [5] and Crandell [6], who used acceleration gravity index and energy ratio respectively as the basis for prediction of damages to surface structures [7],[8]. In 1971, USBM presented the general relationship for prediction of PPV. Many scientists worked to understand the behaviour of ground vibration on structures using different techniques as well as parameters[9],[10].

The damage that results from vibration will depend on the nature of the source, transmission characteristics of the intervening medium/strata, the inherent strength of the subject structure, height and rigidity of the structure and foundation design etc. [19]. Damage caused by ground vibration is dependent on the amplitude of the ground velocity and on the frequency of the ground motion. All the vibration standards till date are based on the resultant peak particle velocity of ground vibration because this is accepted as the best criterion for assessing levels of vibration damage. The recent trend is to refer to the frequency of the ground motion also. Low-frequency waves causes more damages to structures particularly in the case of multi-storied buildings. Different countries adopt different standards of safe limits of vibration in terms of peak particle velocity (PPV) for various types of structures [11]. A few standards widely accepted are given in Tables 1, 2 and 3 and the suggested formulae for prediction of PPV is given in Table 4.

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Table 1: USBM Standard for safe level of ground vibration [8]

Type of structure	Ground peak particle velocity (mm/sec)	
	High Frequency > 40 Hz	Low Frequency < 40 Hz
Modern homes (dry wall)	50.8	19.1
Older homes (plaster)	50.8	12.7

Table 2: German Standard Din 4150 of 1938 [12]

Type of structure	Peak Particle Velocity PPV (mm/sec)			
	At foundation level Frequency range (Hz)			At floor level of top most story (all frequencies)
	< 10	10-50	50-100	
(i) Building used as offices & industrial structures	20	20-40	40-50	40
(ii) Domestic houses & associated constructions, structures with plasters	5	5-15	15-20	15
Buildings which do not fall under (i) & (ii) and objects of historic interest or other sensitive structures	3	3-8	8-10	8

Table 3: Permissible peak particle velocity as per DGMS in India [13]

Type of structure	Dominant frequency, Hz		
	< 8 Hz	8 - 25 Hz	> 25 Hz
(A) Buildings/structures not belonging to the owner			
Domestic houses/structures (Kuchha brick and cement)	5	10	15
Industrial Buildings RCC and framed structures)	10	20	25
Objects of historical importance and sensitive structures	2	5	10
(B) Buildings belonging to owner with limited span of life			
Domestic houses/structures (Kuchha brick and cement)	10	15	25
Industrial buildings (RCC & framed structures)	15	25	50

Table 4: Different predictor equations [14], [15]

1. USBM PREDICTOR	$V=K\left[\frac{R}{Q_{max}{}^{0.5}}\right]^{-B}$
2. Langefors and Kihlstrom predictor (1963)	$V=K\left[\left(\frac{Q_{max}}{R^{0.67}}\right)^{0.5}\right]^{B}$
3. Ambraseys-Hendron predictor (1968)	$V=K\left[\left(\frac{R}{Q_{max}{}^{0.33}}\right)\right]^{-B}$
4. Indian standard predictor (1973)	$V=K\left[\left(\frac{Q_{max}}{R^{0.67}}\right)\right]^{B}$
5. General predictor (1964)	$V= KR^{-B} (Q_{max})^{A}$

*Where, V is peak particle velocity; R is radial distance of monitoring station from blasting site; Q is maximum charge per delay and K and B, A are constants

2.0 Field details

A field study is conducted on sand stone overburden formation of a surface coal mine-A located in central part of the Jharia coalfield. The mine is being developed with benches of 6-9m height with drilling and blasting method of excavation. The bench consisted of fine-grained sandstone with the average compressive strength of 12.5-20 MPa and average tensile strength of 1.0 to 2.5 MPa which is determined in laboratory.

Fig.1: Rock samples for determining compressive and tensile strength of overburden rock

The samples of the rock collected from the working bench and core samples prepared for testing are as shown in Fig.1.

Explosive in the blasthole was site mixed emulsion (SME) (density 1 g/cc and V.O.D. 4200 to 4500 m/s shown in Fig.2 by deautriche plate and in hole VOD is determined by shotrak is shown in Fig.3) is initiated by the shock tube system in the blast-rounds. Sensitized emulsion is used as primer in the blast-rounds. All the blast rounds are drilled on rectangular drilling pattern. The delay sequencing of 17ms, 25ms and 42ms is used for surface delay and 250/275ms is used for in hole delay in the blast rounds Fig.4. Longitudinal section of a charged blasthole is illustrated in Fig.5. The seismographs used for monitoring ground vibration in the field is shown in Fig.6.

Fig.2: Deautriche set up for determination of unconfined VOD

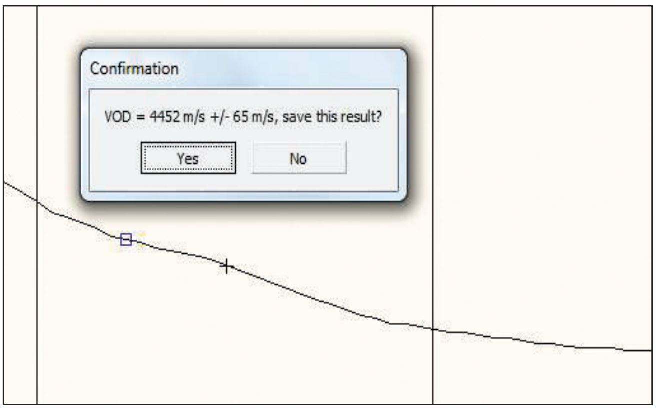

Fig.3: Analysis of in hole VOD

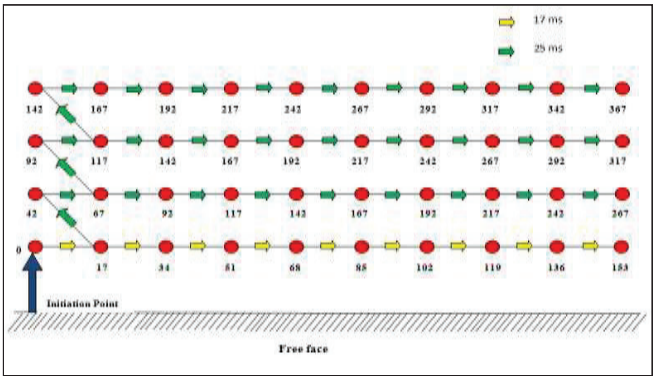

Fig.4: Drilling and firing pattern

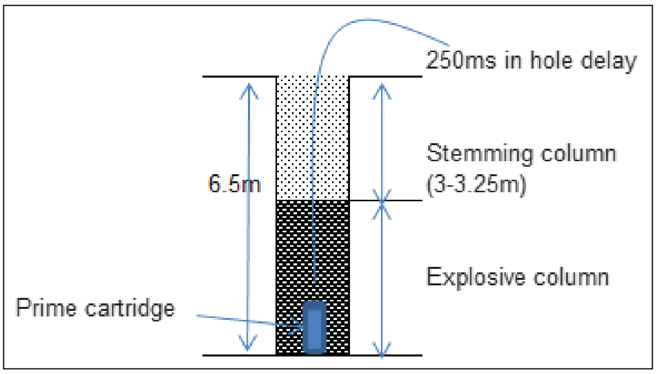

Fig.5: Blasthole section

Fig.6: Seismographs monitoring the PPV at mine

3.0 Result and discussions

In order to fulfil the research objective a total of 34 blasts are conducted in the mine and all blasts ground vibration are monitored using seismographs. The details of the blast parameters are given in Table 5.

TABLE 5: BLAST DESIGN PARAMETERS

	Burden, m	Spacing, m	Hole depth, m	MCPD, Kg	TCPD, Kg	Distance, m	PPV, mm/s
1	2.0	3.5	6	120	3500	151.65	4.99
2	2.0	3.5	6	120	3500	158.68	7.24
3	2.0	3.5	6	120	3500	140.17	7.57
4	3.0	3.5	6	120	3500	140.00	7.26
5	2.0	3.0	8	156	6800	119.79	7.32
6	2.0	3.5	8	156	6800	116.28	16.30
7	2.0	3.0	8	156	6800	206.95	4.79
8	2.0	3.0	8	156	6800	206.75	5.08
9	2.0	3.0	6	140	2500	135.73	6.59
10	3.0	3.0	6	140	2500	143.46	7.14
11	2.0	3.5	6	140	2500	143.26	7.54
12	2.0	3.5	6	135	6500	213.78	2.57
13	2.0	3.5	6	135	6500	234.22	3.21
14	2.0	3.5	6	135	6500	171.20	4.62
15	2.0	3.0	6	135	6500	171.00	5.06
16	2.0	3.5	4	120	4700	86.85	5.45
17	2.0	3.5	4	120	4700	82.71	5.98
18	2.0	3.5	4	120	4700	176.85	10.60
19	3.0	3.5	4	120	4700	176.50	9.83
20	2.0	3.0	10	210	11720	103.032	6.05
21	2.0	3.5	10	210	11720	146.86	5.32
22	2.0	3.0	10	210	11720	121.35	25.70
23	3.0	3.0	10	210	11720	12.00	25.21
24	2.0	3.0	8	225	8850	336.42	5.34
25	2.0	3.0	8	225	8850	281.49	4.58
26	2.0	3.5	8	225	8850	183.25	9.16
27	2.0	3.5	6	122	2900	143.64	2.99
28	2.0	3.5	6	122	2900	263.83	1.19
29	3.0	3.5	6	110	2050	157.40	10.60
30	2.0	3.0	6	110	2050	85.56	14.60
31	2.0	3.5	6	110	2050	316.77	1.25
32	2.0	3.0	6	151	3500	123.51	10.70
33	2.0	3.0	6	151	3500	250.41	1.73
34	2.0	3.0	6	151	3500	480.68	1.06

3.1 Data Analysis using Artificial Neural Networking

All recorded 34 sets of blast data are analyzed using MATLAB™ software. A feed forward back propagation is selected with 2 hidden layers and 1 output layer for the analysis of the data using ANN tool. The network is formed using 6 input parameters i.e. burden, spacing, hole depth, maximum charge per delay (MCPD), total charge per delay (TCPD), distance (R) and a single output that is (PPV) as shown in Fig.7. The method of back propagation is used to train an ANN. The method begins by computing the ANN output with the current weight values. At each criterion, the weights are updated in a way that the actual network output is closer and closer to the target. The activation function used is Z = LOGSIG (Z). The log sigmoid function is selected as it is partially differentiable [16].

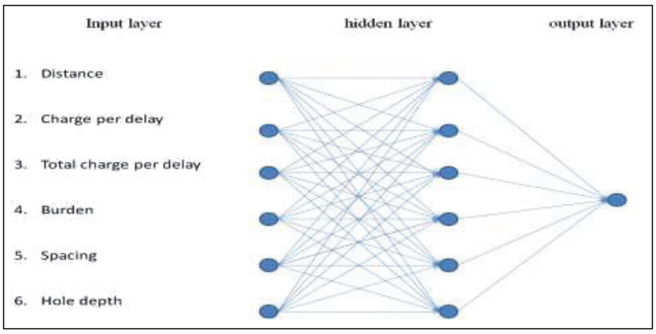

Fig.7: Showing the general layout of artificial neural network

The obtained output is compared to the actual output and difference between is also calculated, and this difference is multiplied by the weights in the input layer. The bigger the weight is, the stronger will be the connection between them.

TRAINLM is often the fastest back propagation algorithm in the toolbox and is highly recommended as a first-choice supervised algorithm, although it does not require memory than another algorithm. The training occurs according to TRAINLM training parameters, shown with their default values in Fig.8.

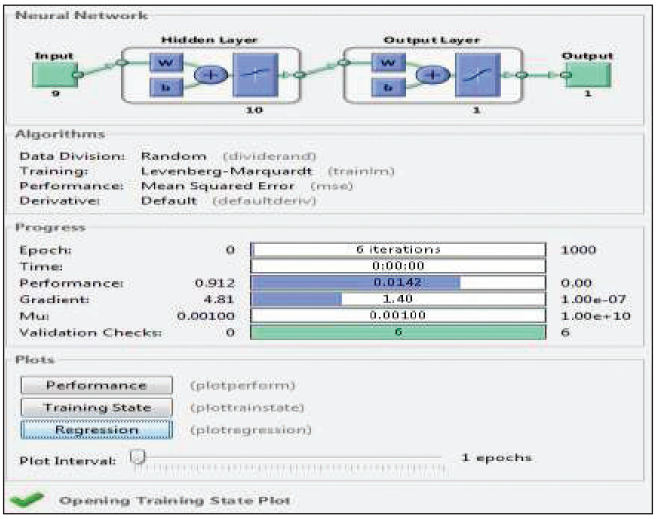

Fig.8: An illustration of the training network in MATLAB

The limitation of this function is that it uses Jacobian for calculations, which assumes that performance is a mean or sum of squared errors. Therefore, networks trained with this function must use either the MSE or SSE performance function [24]. Before an ANN can be used for any practical purpose an ANN must be trained. The training is a process during which the weights are adjusted to reach some desired goal. ANN's learning process is performed using a dataset. The training set has two parts input and target. The training set input contains the set of input that must be applied to the network. The training set target includes the set of desired values at the output of the ANN when each of the input set specified in the training set input is applied.

After the ANN training has been completed, the network performance has to be validated. The validation set is used after the neural network has been trained to assess its performance. The validation set is similar to the training set but not equal. To monitor the process, the output of ANN can be compared to the desired output. The purpose of this two sets is to assess how well the neural network will behave with other dataset and applications. The training set must include all the possible training cases which will guarantee that neural network will similar as that of the training and validation set.

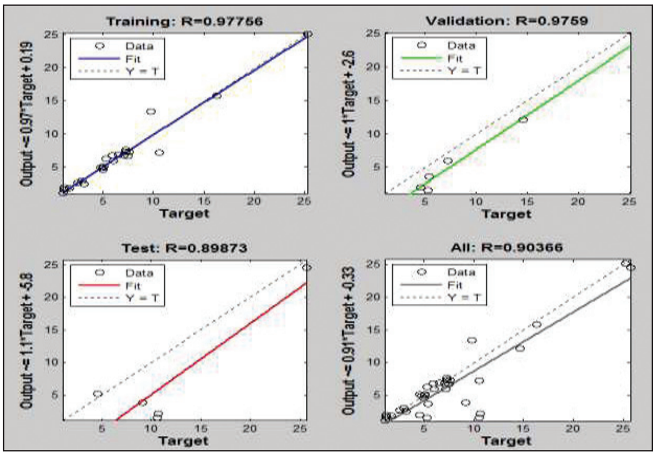

Fig.9: Results of the regression analysis carried out on the training, validation sets

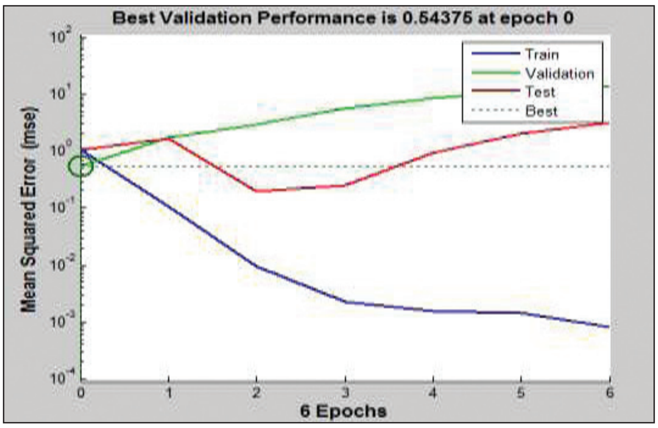

Fig.10: Mean square error (MSE) versus the network epochs

The graphs seen in Fig.9 are the stages of neural network training. The data which is input into the network is divided into three parts, 70% of the data is used for training the network and 15% is used for validating the model formed after training and 15% is used for testing the model.

To assess the quality and behaviour of an artificial neural network the mean squared error (Fig.10) is typically used for comparison purposes. It is computed between the actual network output and the target. The number of hidden neurons can be increased to reduce the mean square error.

An epoch is a measure of the number of times all of the training vectors are used once to update the weights. For batch training, all the training samples pass through the learning algorithm simultaneously in one epoch before weights are updated.

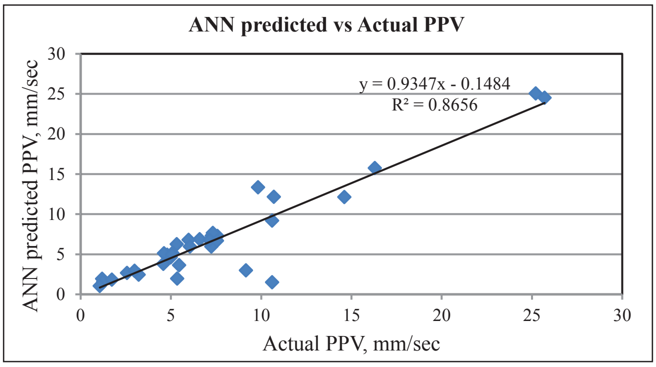

Fig.11: Relationship between actual PPV and ANN predicted PPV

A graph of the actual PPV vs ANN predicted PPV is plotted in the Fig.11.There is a negligible difference between the actual and the predicted PPV but in few cases the difference between the predicted and the actual value is considerable. The difference may be due to improper positioning of the instruments or human error.

3.2 Data Analysis using USBM and CMRI formulae

All 34 blasts data given in Table 5 are used for predicting the PPV values using USBM and CMRI formulae. A comprehensive regression analysis is done for getting the coefficients of USBM equation and CMRI equation.

After obtaining those coefficient value and actual field monitored data Table 6 is derived for a comparative study to identify the accuracy of predictors. The graphs of the actual PPV vs USBM predicted PPV and actual PPV vs CMRI predicted PPV is plotted in Figs.12 and 13 respectively.

Table 6: Actual and predicted PPV values (mm/sec)

USBM predicted PPV values (mm/sec)	CMRI predicted PPV values (mm/sec)	ANN predicted PPV values (mm/sec)	Actual PPV values (mm/sec)
5.89	3.47	4.61	4.99
6.33	3.12	5.96	7.24
5.59	4.14	7.28	7.57
5.36	4.15	7.32	7.256
9.54	7.35	7.66	7.32
9.95	7.77	15.76	16.30
4.4	2.19	4.93	4.79
4.41	2.19	5.14	5.08
7.41	5.21	6.88	6.59
6.85	4.65	6.77	7.14
6.86	4.66	6.69	7.547
3.79	1.58	2.66	2.57
3.33	1.11	2.46	3.21
5.2	2.99	5.12	4.62
5.21	3.00	4.97	5.06
12.49	10.32	3.64	5.45
13.38	11.21	6.79	5.98
4.57	2.35	1.51	10.60
4.58	2.37	13.36	9.83
14.57	12.40	5.95	6.05
8.829	6.64	6.25	5.32
11.56	9.38	24.53	25.7
21	9.43	25.07	25.21
4.45	0.64	1.98	5.34
4.1	1.47	3.80	4.58
7.77	4.58	2.99	9.16
4.32	4.00	2.94	2.99
1.5	0.40	1.94	1.19
8.06	2.85	9.20	10.60
14	9.82	12.14	14.60
2.1	-0.35	1.60	1.25
9.93	6.74	12.16	10.70
2.6	1.06	1.82	1.73
1.5	-0.94	1.06	1.06

From Table 6 it is seen that there is variation between

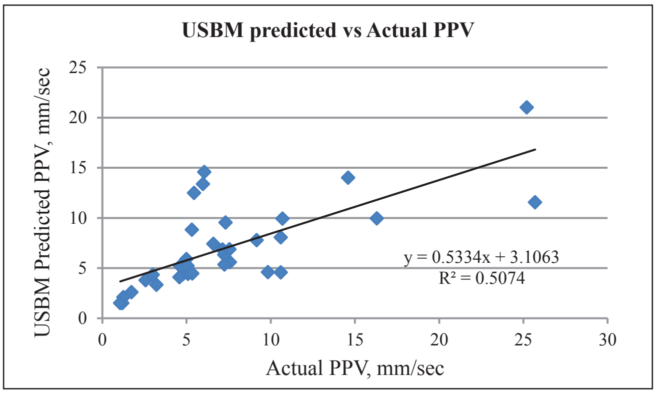

Fig.12: Relationship between actual PPV and USBM predicted PPV

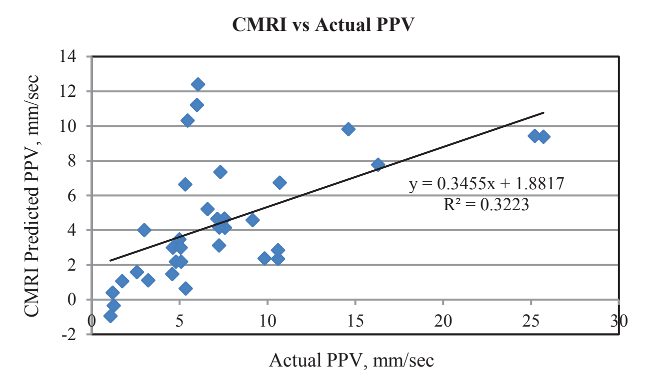

Fig.13: Relationship between actual PPV and CMRI predicted PPV

the actual values and the predicted values. The variation between the USBM predicted value and the actual value is significantly large in some cases while the variation between the CMRI predicted and the actual value is significantly large in most of the cases. The variation between the ANN predicted and the actual value is almost similar. So it can be said that ANN is the best predictor compared to the other two predictors for prediction of PPV values for the safety of the mines and surrounding structures.

4.0 Conclusions

From the above study, it was observed that ground vibration is a destructive output result due to rock blasting. Therefore, it should be carefully handled before implementation of designed blast round. There are various techniques to predict the ground vibration but from this study, it is found that ANN technique can predict near to the actual ground vibration. The percentage of error obtained from ANN estimation is 4.86% which is lower when compared to the empirical relationship given by USBM or CMRI. This will help the blast designers to design the design parameters more cautiously considering the site conditions and structures.

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