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AStudy on Prediction of Blast Induced Ground Vibration by Different Approaches

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ABSTRACT

The main aim of this paper is prediction of blast induced ground vibrations (BIGV) by using both Empirical Equations and Artificial Neural Network (ANN). The ground vibrations are recorded and collected from a mine using a Minimate™device to evalute the most appropriate way to predict BIGV. A total of 26 blast data was collected from mine for prediction of Peak Particle Velocity (PPV). Out of 26 blast data 18 data samples were used for training, 4 data samples were used for validation and 4 data samples were used for testing. Also used for predictionof PPV by using different empirical equations. The performance of different empirical equations and ANN were observed based on Coefficient of Determination (R^2) and Root Mean Square Error (RMSE). At the end of this study, it was observed that the prediction by ANN gives more reliable and accurate results than empirical equation approach. High coefficient of determination value ($R^2 = 0.7897$) was observed by ANN technique. Also, the RMSE value obtained by ANN was very close to zero. It indicates that the Prediction of BIGV by ANN approach gives the more accuarate results than Empirical Equations.

KEYWORDS: Blasting, Ground Vibrations, Empirical Equations, ANN, Coefficient of determination.

1. INTRODUCTION

Mining is the activity of extracting the economic ore mineral from the earth. Mining industry is the backbone of economic growth of the country. In mining Drilling and Blasting are the main procedurespractised for the fragmentation of rock.These are the conventional methods used for breakage of rock mass and these methods have reasonable advantages in terms of technicalities, cost, efficiency and convenience, when compared to the cutting machines [1-3].

In blasting operation, explosives are used for effective breakage of rock mass. Whenan explosive charge explodes in the blast hole, itreleases a large volumeof hot gases in the form of high temperature and pressure.However only some part of this explosive energyi.e20% to 30% is utilized for the breakage of rock mass while remaining partis wasted and leads to some nettle problems like ground vibrations, air over pressure, noise, fly rock, backbreak & dust [4]. Among all the consequences of blasting, Ground Vibrations creates more nuisance like structural damage. To provide safety for the structures and personnel the blasting consequences should be within the allowable limit and safe thresholds [2]. There are several several factors which regulates the allowable limits of ground vibration, they are amount of explosive used, spacing, burden, no. of holes per blast, hole diameter, delay interval, etc. [4]. Ground Vibrations are measured in terms of PPV. Peak Particle Velocity is the ultimate velocity at which a particle moves in the ground relative to its inactive state, measured in mm/sec. PPV is measured in horizontal, vertical and transverse directions and the combined PPV of all directions is called as vector sum [5-6].

To minimize the effects caused by ground vibrations, the measurement and of ground vibrations are neededand also helps to fix the planfor blasting at safe conditions [7]. Severalinvestigatorsadvised various empirical predictoryequations and software approaches for the predictionofBIGV [5-6]. These prediction approaches enable engineers to maintain the PPV within the safety threshold.There are various empirical equations proposed by different researchers and geologists. Generally,these empirical equations assume that the intensity of ground motionmade by a blast differs with the amount of explosive used per delay and monitoring distance from the blast site. Based on these two parameters, several Scaled Distance Laws (SD) are framed by the researchers. SD laws which minimize the damage intensity of ground vibrations by predicting PPVs against SDs. The general relationship between PPV and SD can be written as

$$v = \alpha \times (SD)^{-\beta}$$

Where,v is the Peak Particle Velocity in mm/sec, SD is the Scaled Distance which is equal to $(D/\sqrt{W})$, α and $\beta$are the site constants [7].

Empirical approaches may vary due to large no. of influencing parametrs such as Hydrology, Geology, RQD, etc. and a complexity situation arises because of numerous inter-relationships among them. In such conditions empirical approaches may not be applicable for effective estimation of ground vibrations induced by the blasting. For effective prediction of ground vibration, various artificial intelligence algorithms are now being used in such complexity conditions. Since1980, the Artificial Neural Network (ANN) has risen in popularity as an area of artificial intelligence study and widely regarded as one of the most intelligent techniques for dealing difficult problems such as ground vibrations. ANN is gaining popularity among academic's planners, designers, and other as a helpful tool for completing their job because to its transdisciplinary nature[7-9].

2. REALATED WORK

According to Manoj Khandelwal, et al. (2009), the ANN technique was the more economical to evaluate the Ground Vibration when compared with conventional vibration predictors based on coefficient of determination by using 22 blast data [1]. M.Monjezi, et al. (2012), evaluate and estimate the ground vibration at Shur River Dam in Iran by using various empirical equations and ANN based on the high conformity and it was observed that the ANN prediction is more accurate than empirical equation's prediction [4]. Abiodum Ismail Lawal and Musa Adebayo Idris, (2020), a mathematical model was developed based on ANN to predict the ground vibrations induced due toblasting by adopting feed forward back-propagation multi-layer perception from 14 datasets and compared with classical models, and finalized that ANN model approach gives best resultsin predictionof BIGV [10].Qiancheng Fang, et al. (2019), to predict ground vibrations, a new artificial intelligence technique was developed based on the M5Rules and ICA in open pit mines [14]. Reza Nateghi, (2012), ground vibrations wrerpredicted by using vibration monitors during 32 blasts at Gotvand dam and done the statistical evaluations on relationship between SD and PPV [15].

3. METHODOLOGY

3.1 EMPIRICAL EQUATIONS APPROACH FOR PREDICTION OF PPV

Various Empirical Equations proposed by different researchers, among them few equations are mostly used in mines to predict the ground vibrationsinduced by blasting. Those are proposed by USBM, Indian Standard, Ambrasey-Hendron and Langefors-Kihlstrom.

The equations used in this study are mentioned in Table1 [7-8].

Table1:Empirical Equations

S. No	*Researchers*	*Empirical formulas*
01	USBM	$v=\alpha\times[\frac{D}{\sqrt{W}}]^{-\beta}$
02	Indian Standard	$v=\alpha\times[\frac{W}{D^{2/3}}]^{\beta}$
03	Ambrasey-Hendron	$v=\alpha\times\left[\frac{D}{W^{0.33}}\right]^{-\beta}$

04	Langefors-Kihlstrom	$v = \alpha \times [\frac{W}{D^{2/3}}]^{\beta/2}$

Where v is the Peak Particle Velocity, D is the distance between blast site and the monitoring station in meters, W is the amount of explosive used per blast in kgs, α and β are the site constants.

The site constants are determined by plotting a graph between SD & PPV in a log-log plane. This is done individually for each equation because each equation has different scaled distance, these constants are shown in table 2 respectively [2]. The PPVs calculated by predictor equations were compared with the measured PPVs for determination of correlation coefficient. Coefficient of Determination (R^2) and Root Mean Square Error used to check the accuracy of allequations [7].

Table 2:Site Constants

S.No	*Empirical Formula*	*α*	*β*
01	USBM	3.6520	0.172
02	Indian Standard	1.4574	-0.515
03	Ambrasey-Hendron	4.4476	0.165
04	Langefors-Kihlstrom	0.8179	2.963

3.2 ARTIFICIAL NEURAL NETWORK APPROACH FOR PREDICTION OF PPV

The artificial neural network (ANN) contains three layers, they are hidden, input, output layers. The data of maximum charge per delay (MCPD) and measuring distance from blast site (D)are taken as the input data while measured PPV is taken as target (output layer) as shown in the Figure 1. The number of hidden layers is 10to obtain reliable output. Thesize of network inputs has a significant impact on a network's concert quality.

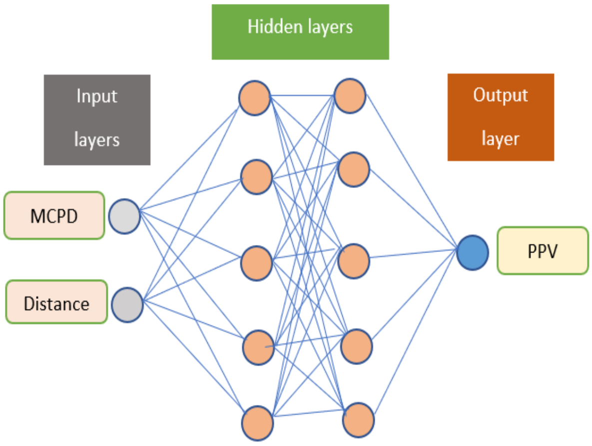

Figure 1: Structure of ANN

The neural network modelling process is done in three groups, they are testing, training and verification. As a result, three data groupings are used as training, verification and test data [5]. 70%, 15%, 15% of data is used for verification, testing and training respectively. The coefficient of determination (R^2) is used to check the accuracy of analysis.

By comparing the coefficient of determination (R^2) values obtained by both empirical and ANN technique, the best method was suggested to predict Blast Induced Ground Vibration i.e., ANN technique.

4. CASE STUDY & DATA COLLECTION

Data is collected from alimestone opencast mine in Andhra Pradesh. The mine has the production rate as 3.819 MT/A. The production is done in 2-shifts per day. For each shift one blasting operation has been carried out. The mine has top soil as overburden with height of 7m and limestone benches of height 9m each. There is only one OB bench and two limestone benches. In blasting operation, 150mm diameter holes are used and they are charged with 2m height of explosive charge. Ammonium Nitrate explosive is used for the blasting.

Figure 2: Measuring of PPV by Minimate™

The data of 26 blasting operations was collected from the mine. The data including maximum charge per delay, measuring distance and PPV of each blasting operation. The Peak Particle Velocity is measured by using Minimate™ device which is an advanced monitoring technology with unequaled versatility and flexibility. It consists of a ISEE Geophone and ISEE Linear Microphone to measure Peak Particle Velocity in mm/sec and Air Over Pressure in dB respectively. The equipment used at site is shown in the Figure 3.

5. RESULTS& DISCUSSIONS

As discussed above, the peak particle velocities of 26 blast data are predicted by using empirical equations and ANN as shown in the table 3. A multi regression analysis done between predicted PPV's and measured PPV's individually for each empirical equation and ANN. The following equation is used for calculation of RMSE value for each approach.

$$RMSE = \sqrt{\frac{1}{M}\sum_{i=1}^{n}(x - x')^2}$$

Where, M is the no. of data sets, x is the measured ppv value, x' is the obtainedppv value.

Table 3: Prediction of PPV

S.NO	MEASURED PPV (mm/s)	PPV OBTAINED BY USBM	PPV OBTAINED BY INDIAN STANDARD	PPV OBTAINED BY AMBRASEYS-HEDRON	PPV OBTAINED BY LANGIFORS-KHILSTROM	PPV OBTAINED BY ANN
1	1.02	1.97	1.15	2.18	0.98	1.22
2	2.06	1.93	1.30	2.15	2.00	2.16
3	1.91	1.84	1.73	2.09	0.48	2.04
4	3.08	1.93	1.30	2.15	3.00	2.18
5	1.63	1.74	2.39	2.02	0.18	1.53
6	1.69	1.72	2.62	2.00	0.14	1.51
7	2.00	1.93	1.44	2.16	1.80	1.99
8	1.53	1.71	2.66	2.00	0.13	1.51
9	2.90	1.87	1.58	2.11	0.63	2.87
10	1.68	1.76	2.22	2.04	0.23	1.56
11	2.87	1.86	1.62	2.10	0.59	2.68
12	1.28	1.71	2.66	2.00	0.13	1.51
13	1.09	1.76	2.27	2.03	0.21	1.55
14	3.83	2.03	1.28	2.27	3.8	3.71
15	1.03	1.75	2.36	2.02	0.19	1.54
16	1.53	1.70	2.80	1.90	0.11	1.50
17	1.05	1.75	2.30	2.03	0.21	1.54
18	1.65	1.70	2.80	1.99	0.11	1.50
19	1.96	1.76	2.27	2.03	0.11	1.55
20	2.07	1.81	1.89	2.07	0.37	1.72
21	2.23	1.73	2.50	2.01	0.17	1.52
22	3.32	1.88	2.00	2.17	0.32	3.25
23	1.18	1.75	2.30	2.03	0.21	1.54
24	2.62	1.88	2.27	2.14	0.21	3.14
25	1.70	1.70	2.80	1.90	0.11	1.50
26	1.49	1.68	2.97	1.90	0.11	1.49
Coefficient of determination (R^2)		0.396	0.250	0.394	0.356	0.789
RMSE		0.69	1.13	0.69	1.51	0.34

The coefficient of determination of each equation are shown in figures.

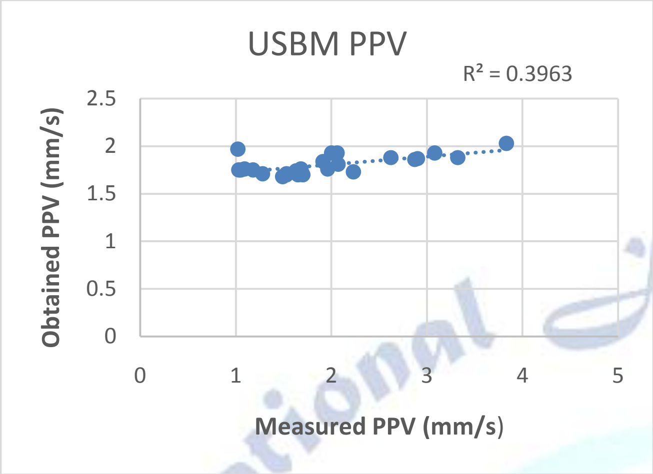

Figure 3: USBM vs Measured PPV

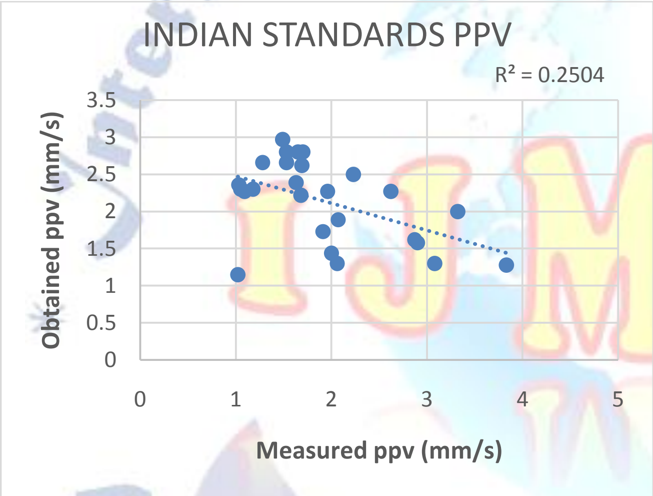

Figure 4: Indian Standards vs Measured PPV

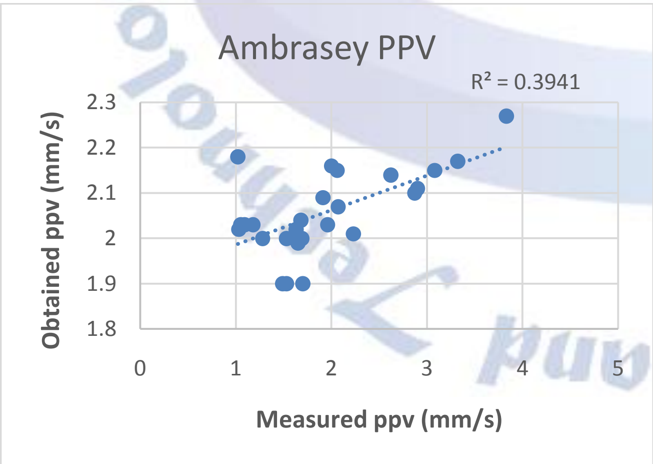

Figure 5: Ambraseys vs Measured PPV

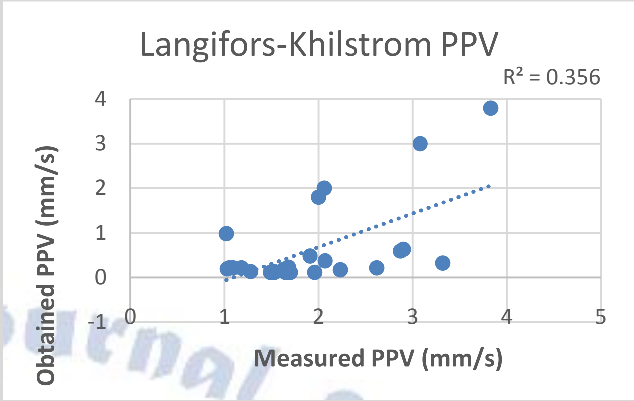

Figure 6: Longifors-Khilstrom vs Measured PPV

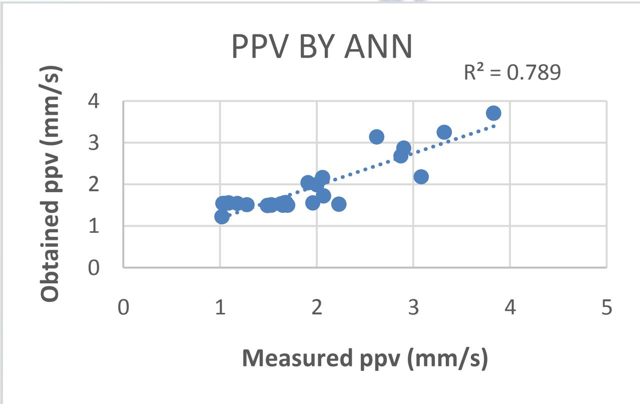

Figure 7: ANN vs Measured PPV

All R^2 and RMSE values of each predictor were calculated and observed that R^2 value of ANN is more than empirical equations

6. CONCLUSION

In this study, a total of 26 blast data sets were collected from an opencast limestone mine, in India. The dataincludes maximum charge per delay (MCPD), distance from monitoring station to the blast site (D) and peak particle velocity (PPV). A comparative study was conducted and evaluated an appropriate way to predict the ground vibrations by using empirical equations and ANN based on coefficient of determination and root mean square error.The R^2 value obtained by USBM, Indian Standard, Ambreseys, Longifors-Khilstrom and ANN are 0.3963, 0.2504, 0.3941, 0.3562, and 0.7897 respectively. It is observed that the ANN approach gives more accurate results to predictPPV than Empirical equations as high R^2 value (0.7897). It is also found that root mean square error obtained by ANN is very close to zero, it indicates that ANN is the best method to predict ground vibrations. Finally, this study suggest that ANN technique should employ in mine to evaluate the allowable limits of ground vibrationsto reduce the effects of ground vibrations.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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