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Dependency of blast-induced ground vibration on the concentration and distribution of explosive charge in surface blasting

Highlights

- There is a noticeable impact of charge distribution and concentration on blast-induced ground vibration.
- An empirical equation for effective charge per delay computation has been developed.
- A new factor i.e. ratio of charge length and hole diameter has been introduced to determine the effective charge per delay.
- The new modified equation was found to be more precise with the RMSE values of ±2.42 mm/s and ±1.77 mm/s for Case-II and Case-III respectively.

Blast-induced ground vibration has always been a subject of concern for blasting engineers. Since many decades, a lot of research work has been carried out to identify the factors resulting in higher ground vibrations and are also optimized to reduce the ground vibration due to blasting. Explosives are charged in holes which are drilled in a particular pattern for distribution of energy of explosives and delays are provided between charged holes to utilize the explosive energy in efficient way and get the desired results. The effect of charge concentration and distribution on blast induced ground vibration still require verification with proper experimentations on field. This paper deals in understanding the influence of maximum instantaneous charge on blast-induced ground vibration in surface blasting while varying the charge concentration and distribution. With field experimentations and investigations, it has been found that the blast-induced ground vibration results at same scaled distance in terms of PPV values were different with different charge distribution. On the basis of obtained results, a new empirical relation has been developed based on charge distribution for computation of effective explosive weight per delay for multi hole simultaneous firing. The developed relation has also been validated in a different geological condition in a separate mine.

Keywords: Blast-induced ground vibration; charge concentration; charge distribution; explosives; peak particle velocity

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1.0 Introduction

The blast induced ground vibrations in terms of peak particle velocity (PPV) has become a crucial parameter in providing guiding principle for safe blasting to minimizing the damage to nearby property, sensitive and residential structures [1]. Also, PPV generation has now been used to investigate the explosives performance used in the mine blasts [2,3]. The characteristics of blasting induced ground vibrations depend critically on the amount of explosives detonated at any given time or maximum charge per delay, distance of the point of interest, the delay interval employed in the blast round and the prevailing local geology play important role in generation of vibration [4,5]. It is believed that optimum delay between the blastholes and rows of blastholes results into better fragmentation with lower level of vibration [6-10]. A proper combination of explosive weight and delay timing allows sufficient room for expansion of the rockmass (swelling) between rows in case of multi row blasts. Such restrictions in rockmass movement cause to increase particle velocity and decrease blasting efficiency [11-14]. The magnitude of blast vibration and its prediction depends largely on distance of blasting site and weight of explosives fired in a delay [15]. However, there are several unresolved issues in the precise prediction of vibration and they continue to be the subject matters of extensive research. Some of these unresolved issues in controlling the vibration amplitude are near-field versus far-field recording, distinction between short and long explosives column charge, determination of vibration limit for blast-induced damage and the use of 'seed waveform' [12, 16, 17]. Grant, Spathis and Blair, (1987) [18] suggested that it should be possible to alter the charge length in order to reduce the amplitude of blast vibration as measured on resonant structures such as residential buildings, bridges and (underground) mine installations. Equally important is the present indication that vibration amplitude does not necessarily increase with increased charge weight as is universally claimed. Although, if the charge weight per delay remain same but spatially distributed, the magnitude of ground vibration can be reduced. Some of the success of decking as a mechanism for reducing vibrations may be attributed to the change in spectral content and PPV reduction rather than the mere reduction in charge weight per delay [19, 20]. Whereas, in deriving predictive curves for controlling blasting vibrations, the concept of explosive weight per delay remains central [21]. For practical purposes explosives weight per delay is taken as the sum of explosives loaded in the blastholes and to be fired within 8 ms delay interval [22]. The usual firing time scattering characteristics of pyrotechnic detonators on one hand and precision of the electron detonator on the other make this assumption a highly subjective one [23-27]. Although, the commonly adopted rule of 8 ms has been demonstrated to be inadequate by several researchers in the past [28, 29]. This paper deals with the impact of concentrated and distributed charge on blast induced ground vibration and subsequently development of an empirical model for computation of effective explosive weight per delay for multi hole simultaneous firing. To translate and concretize this concept, trial blasts were conducted and blast induced ground vibration were monitored for tailor made as well as regular production blasts. It was also assumed that explosive parameters remained constant throughout the trial blasts as the same type of explosives and same batch of initiating systems and other accessories were used for experimentation.

2.0 Methodology

In this investigation, experimentation was designed in such a way to vary the concentration and distribution of explosive charge. Keeping the same explosive charge per delay with different concentration and distributed differently is used for blasting. An opencast coal mine was selected for conducting experimental blasts on field. Experimental blasts were conducted in three different cases i.e. single hole charge with explosive "Q" and charge length "L", two holes simultaneous (without any delay) blast with charge length of "L/2" and charge with "Q/2" explosive each and three holes simultaneous blast with charge length of "L/3" and charge with "Q/3" explosive each was conducted on field. In Case-2 and Case-3 the spacing between the hole is kept 3.5 meters and burden i.e. distance between hole and free face in all three case were kept 3 meters. The diameter of hole remains same in all the three cases, type of explosive used is site mixed bulk emulsion and is of same manufacturer. The holes were detonated using cast boosters and detonating fuse were used as there was no delay detonators required and all the holes were detonated simultaneously in each case separately. Holes were drilled in same bench at same mines to keep the geological condition same while experimentation.

Three experimental cases designed are:

Case-1: In this case, blast was conducted with single hole charged with "Q" kg explosive concentrated in "L" meter charge length with "d" holes diameter and vibration is recorded at distance "D" meter.

Case-2: In this case, blast was conducted with two holes detonating simultaneously charged with "Q" kg of explosive distributed equally in two holes (i.e. Q/2 kg explosive in each hole) concentrated in "L/2" meter charge length keeping the diameter of hole same as "d". Vibrations were recorded at distance "D".

Case-3: In this case, blast was conducted with three holes detonating simultaneously charged with "Q" kg of explosive distributed equally in three holes (i.e. Q/3 kg explosive in each hole) concentrated in "L/3" meter charge length keeping the diameter of hole same as "d". Vibrations were recorded at distance "D".

The cases are shown in Fig.1.

The PPV values of each blasts i.e. single hole, two holes and three holes blast were recorded using seismograph. The data collected was analysed to obtain and develop an

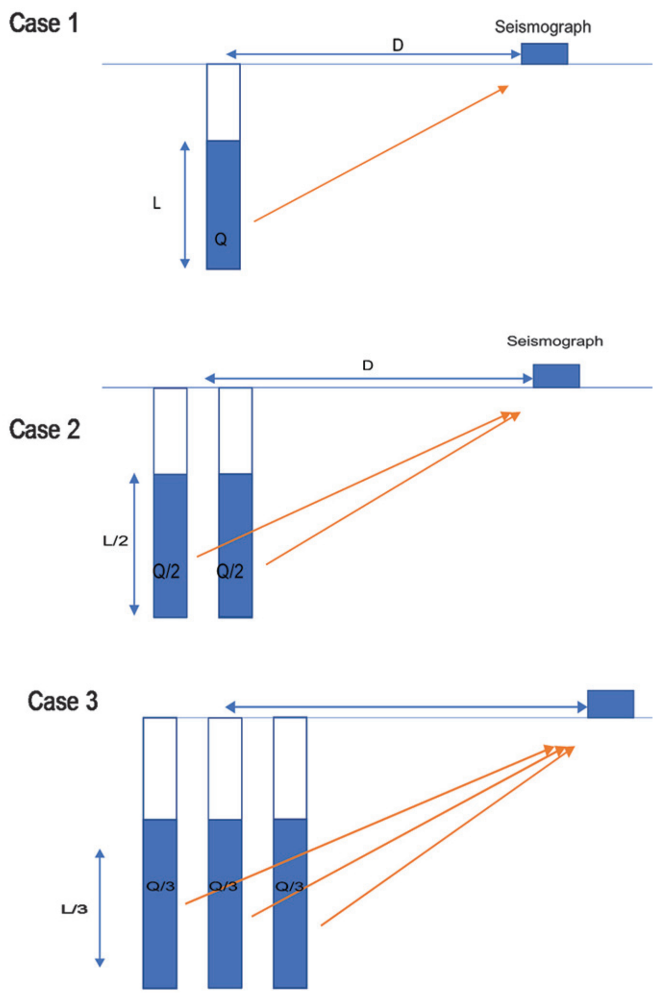

Fig.1: Experimental case for blasting same charge with different concentration and distribution.

empirical model for computation of effective explosive weight per delay for multi hole simultaneous firing. The trialblasts were conducted at Giddi-C opencast coal mine, Argada Area, Central Coalfields Limited (CCL), a subsidiary of Coal India Limited. Further, the equation/relation developed has been validated in Quarry AB, West Bokaro, India a captive coal mine of Tata Steel Limited.

3.0 Giddi-C opencast coal mine, Argada area, CCL

Giddi-C is an opencast coal mine of Central Coalfield Limited, a subsidiary of Coal India Limited.

3.1 Location of site

Giddi-C is a part of South Karnapura coalfields situated in Ramgarh district (Jharkhand) and lies between latitude 23°24' 21"N and 23°43' 00"N and longitude 85°20' 25"E and 85°25' 00"E and at an altitude of 378m above mean sea level. The project is under the administrative control of CCL' Argada area. Giddi-C is connected with Ramgarh by motorable roads both via Sirka and Gidi-A collieries. It is situated at a distance of 25 km from Ramgarh via Sirka colliery. The Patratu Saunda branch line of eastern railway extends to the middle of the property. Average thickness of seam is ranged from 15.0-21.0 m with an inclination of 1 in 2.86. A satellite view of mine is shown in Fig.2.

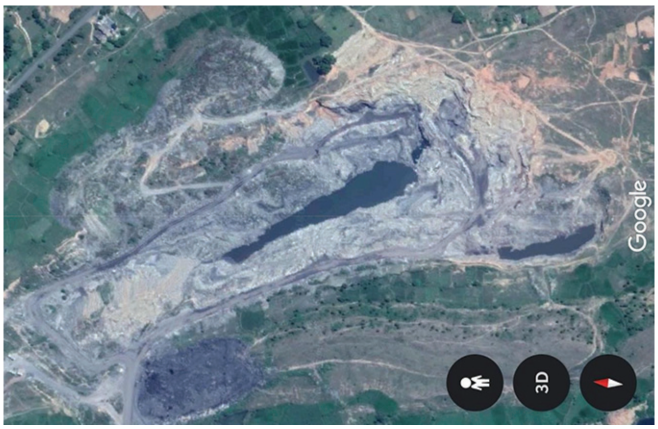

Fig.2: A satellite view of Giddi-C opencast coal mine, CCL. (Source: Google Earth)

4.0 Data collection

As explained in above section, experimental blasts with three different cases were conducted at Giddi-C coal mine (Fig.1). Total 12 blasts and 24 blast vibration events (2 events each blasts) were recorded with Case-1, Case-2 and Case-3. The vibrations were recorded using two seismographs minimate^{TM} (Instantel Inc., Canada). The vibrations were recorded at varied distances from the blast site. The details of blasts conducted along with vibration reading are shown in Table 1.

The PPV values recorded were plotted against its scaled distance (SD) as per square root scaled distance approach in Fig.3.

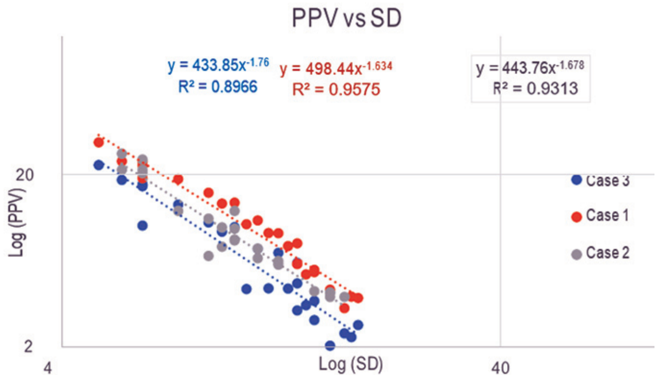

Fig.3: Plot PPV vs SD with different experimental cases at Giddi-C mine

It can be observed from Fig.3 that the PPV values for the blasts conducted with same maximum charge per delay, PPV values at same scaled distance were lowest in experiments with Case-3 and highest during experiments with Case-1. Also, it can be seen that the site constant values for two-hole (Case-2) and three holes (Case-3) blast were different from the single hole (Case-1) blasts. As per the prevailing concept of square root scaled distance by United State Bureau of Mines (USBM), it is believed that in same geological conditions for same scaled distance the values of PPV must remain same. In the above cases, at same geology and same scaled distances, by varying the concentration and distribution of charge a significant change in PPV has been found. This implicates that the concentration and distribution of charge does affect the maximum charge per delay and the effective charge per delay during Case-2 and Case-3 was not the same as that of designed maximum charge per delay. Therefore, it is tried to calculate the effective charge per delay during different distribution and concentration of charge.

5.0 Effective charge per delay

The scaled distance predictor equation obtained from Case-1 i.e. from single hole blast is believed to be the most reliable equation as the maximum charge per delay was exactly known in this case. The scale distance predictor equation obtained from Case-1 blasts is (Fig.3):

$$PPV = 498.44 \times (SD)^{-1.634}$$

$$SD = D/(\sqrt{Q}) \quad \text{... (1)}$$

It implies site constant value $k = 498.44$, $n = -1.634$.

Where,

SD is scaled distance (m/kg$^{0.5}$); D is distance of vibration measurement site from blast site (m); Q is effective charge per delay (explosive charged in hole in Case-1) (kg)

In case of Case-2 and Case-3, it is obvious that the effective charge per delay will be more than the charge in a single hole and will be less than the total explosive charged in total number of holes. Keeping the note on the variation in charge distribution and concentration, the PPV values and

TABLE 1: DETAILS OF BLASTS CONDUCTED ALONG WITH VIBRATION READING

	Case-1 (hole diameter d=160mm)				Case-2 (hole diameter d=160mm)				Case-3 (hole diameter d=160mm)			
	Charge in a hole(Q)	Distance (m)	Charge length(L) in m	PPV (mm/s)	Charge in a hole(Q)	Distance (m)	Charge length(L) in m	PPV (mm/s)	Charge in a hole(Q)	Distance (m)	Charge length (L) in m	PPV (mm/s)
1	60	45	2.4	24	30	120	1.2	4.2	20	45	0.8	18.69
2	60	50	2.4	23.82	30	140	1.2	3.9	20	50	0.8	17.66
3	60	80	2.4	13.8	30	130	1.2	4.12	20	80	0.8	9.914
4	60	90	2.4	10.87	30	45	1.2	26.57	20	90	0.8	7.435
5	60	70	2.4	15.731	30	50	1.2	24.56	20	70	0.8	10.563
6	60	75	2.4	13.63	30	80	1.2	12.34	20	75	0.8	9.346
7	60	50	2.4	22.78	30	90	1.2	7.45	20	50	0.8	17.16
8	60	60	2.4	18.93	30	70	1.2	6.75	20	60	0.8	13.41
9	60	100	2.4	9.154	30	75	1.2	7.64	20	100	0.8	7.029
10	60	110	2.4	7.976	30	50	1.2	21.34	20	110	0.8	6.149
11	60	85	2.4	10.32	30	60	1.2	12.34	20	85	0.8	4.329
12	60	95	2.4	9.18	30	100	1.2	6.12	20	95	0.8	4.37
13	60	105	2.4	7.712	30	80	1.2	8.4	20	105	0.8	4.357
14	60	115	2.4	5.26	30	100	1.2	6.3	20	115	0.8	3.487
15	60	120	2.4	5.432	30	130	1.2	4.1	20	120	0.8	3.687
16	60	110	2.4	6.073	30	45	1.2	21.4	20	110	0.8	4.673
17	60	150	2.4	3.842	30	50	1.2	20.5	20	150	0.8	2.671
18	60	145	2.4	3.904	30	80	1.2	9.7	20	145	0.8	2.272
19	60	50	2.4	19.15	30	90	1.2	6.54	20	50	0.8	10.14
20	60	40	2.4	30.93	30	70	1.2	11.13	20	40	0.8	22.78
21	60	110	2.4	6.056	30	75	1.2	9.9	20	110	0.8	3.254
22	60	120	2.4	5.588	30	80	1.2	8.3	20	120	0.8	2.855
23	60	140	2.4	3.35	30	100	1.2	6	20	140	0.8	2.389
24	60	130	2.4	4.292	30	130	1.2	3.9	20	130	0.8	2.024

site equation values were empirically analyzed. After conducting mathematical evaluations and using hit and trial approach, it has been empirically found that the effective charge per delay during blasting with distributed charged i.e. during Case-2 and Case-3 blasts can be computed as:

$$Q_{effective} = N^{\frac{L}{Md}} \times Q$$

Here, M is a constant factor which is defined as:

$$M = \begin{cases} 10 \text{ if } \quad 1 < L/d < 10 \\ 100 \text{ if } 10 < \quad L/d < 100 \\ 1000 \text{ if } 100 < \ L/d < 1000 \end{cases} \quad \text{... (2)}$$

After the value of effective charge per delay is obtained using equation 2, it can be used in scaled distance equation (equation 1) obtained from the Case-1 (single hole blast) blasts to predict the precise PPV values as:

$$SD_{effective} = \frac{D}{\sqrt{Q_{effective}}} \quad \text{... (3)}$$

$$PPV = kSD_{eff}{}^{n} \quad \text{... (4)}$$

L = Charge length (m)

d = Diameter of hole (m)

Qefffective = Effective charge per delay (kg)

N = Number of holes blasted simultaneously (two in Case-2 and Three in Case-3)

Q = Charge per hole (kg)

SDeff = Effective scaled distance ($mkg^{-0.5}$)

In equation 2, the concentration of explosive has been quantified with the help of ratio of charge length (L) to diameter (d) of hole and the distribution of charge has been quantified with the help of number of holes (N).

6.0 Analysis

The effective charge per delay was computed using equation 2, and the PPV values were predicted for Case-2 and Case-3 blasts. The predicted and actual PPV values for Case-2 and Case-3 blasts are shown in Table 2.

The actual PPV and PPV when calculated using effective charge per delay concept were compared for Case-2 and Case-3 in Figs.4 and 5 respectively. It has been found that the root mean square error (RMSE) values for Case-2 and Case-3 were ±1.92 mm/s and ±1.77 mm/s respectively.

The lower values of RMSE prove the precision in prediction of PPV using the developed effective charge per delay concept.

Table 2: The predicted and actual PPV values for case-2 and case-3 blasts

Case-2		Case-3	
Actual PPV	Predicted PPV using effective Q	Actual PPV	Predicted PPV using effective Q
4.20	4.91	18.69	17.95
3.90	3.82	17.66	15.11
4.12	4.31	9.91	7.01
26.57	24.41	7.44	5.78
24.56	20.55	10.56	8.72
12.34	9.53	9.35	7.79
7.45	7.86	17.16	15.11
6.75	11.86	13.41	11.22
7.64	10.59	7.03	4.87
21.34	20.55	6.15	4.17
12.34	15.25	4.33	6.35
6.12	6.62	4.37	5.29
8.4	9.53	4.36	4.50
6.3	6.62	3.49	3.88
4.1	4.31	3.69	3.61
21.4	24.41	4.67	4.17
20.5	20.55	2.67	2.51
9.7	9.53	2.27	2.65
6.54	7.86	10.14	15.11
11.13	11.86	22.78	21.76
9.9	10.59	3.25	4.17
8.3	9.53	2.86	3.61
6	6.62	2.39	2.81
3.9	4.31	2.02	3.17

7.0 Validation of concept

The equation 2, developed using the collected data has been validated at Quarry AB, West Bokaro which is a captive coal mine of Tata Steel Limited.

7.1 Quarry AB, West Bokaro, Tata Steel Limited

The location and geological details of the mine site are as follows:

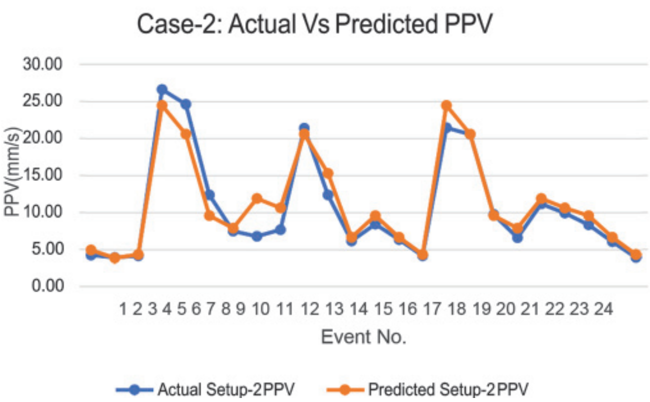

Fig.4: Plot showing actual vs predicted PPV for case-2 with RMSE ±1.92 mm/s.

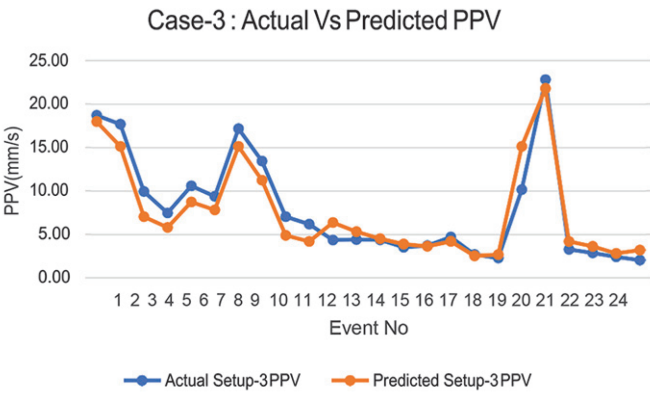

Fig.5: Plot showing actual vs predicted PPV for case-3 with RMSE ±1.77 mm/s.

Quarry AB is a coal mine in West Bokaro coalfield. West Bokaro coalfield is one of the important coalfields of Damodar valley coalfield and geographically located in the state of Jharkhand. West Bokaro coalfield extends over an area of 180 sq.km long and 12 km in width and is located between latitudes 23p 44’00" and 23p 50’30" and longitudes 85p 24’00" and 85p 42’00" (Fig.6).

Fig.6: A satellite view of quarry AB opencast coal mine, Tata Steel Limited. (Source: Google Earth)

The quarry AB is a broad half basin, with its closure on the west. The other half of the basin is represented by East Bokaro Coalfield. The Pre-Cambrian Gondwana boundary in the north is marked by an east-west trending set faults. The southern boundary of the basin is generally normal. The regional strike of the Gondwana sediments is more or less east-west, but varies from ENE-WSW to NW-SE at places may be due to faults and unevenness of the basement. The Barakar strata show evidences of rolling in the eastern part of Ghato property and in the adjacent Kedla area. In Ghato area, a synclinal structure is formed in a narrow trough formed by two sub parallel north-south trending faults, the Banji fault in the west and the Kedla fault in the ease and is truncated in the south by the Dhuni fault and in the north by Chutuanala faults with southerly and northerly throw respectively.

Table 3

Particulars	Case-1	Case-2	Case-3
No of blasts	7	7	7
Total blasts events recorded	14	14	14
Depth of hole (m)	6.0	4.0	3.0
Charge length	2.1	1.05	0.7
Spacing (m)	-	3.5	3.5
Burden (m)	3.0	3.0	3.0
Diameter of holes (mm)	160	160	160
Type of explosive	Site mixed Emulsion	Site mixed Emulsion	Site mixed Emulsion

7.2 Data collection and validation

The trial blasts were conducted in all the three cases set up as shown in Fig.1. The details of blasts conducted has been summarized in Table 3.

The regression performed with the single hole blasts i.e. Case-1 is used to find out the scaled distance equation and site constants.

The site constant values and scaled distance equation of the site were obtained and presented as equation 5 below.

$$PPV = 57.90\ (SD)^{-0.887} \quad \dots (5)$$

The values of Case-2 and Case-3 were predicted using the developed approach i.e. equation 2 of this paper. The results of predicted versus actual values for Case-2 and Case-3 are plotted in Figs.8 and 9 respectively. The RMSE values obtained in Case-2 and Case-3 prediction were ±1.07mm/s and ±1.03 mm/s respectively.

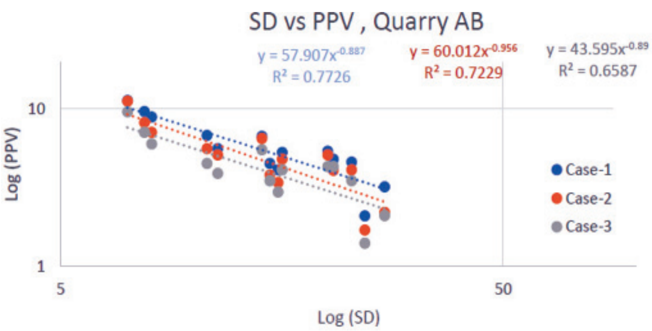

Fig.7: Plot b etween PPV and SD in all three cases at Quarry AB, Tata Steel Limited.

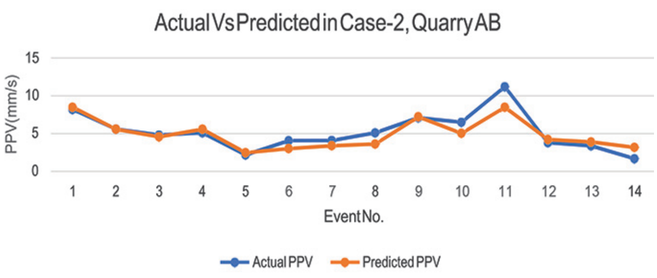

Fig.8: Plot showing actual vs predicted PPV for case-2 with RMSE ±1.07 mm/s at quarry

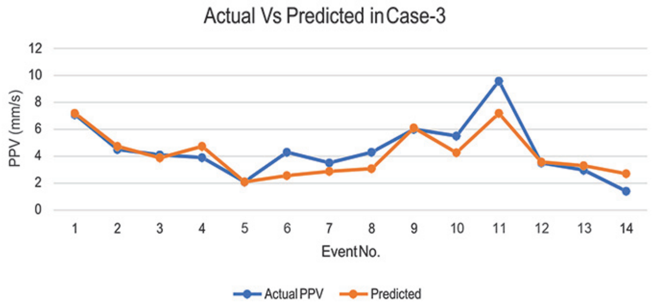

Fig.9: Plot showing actual vs predicted PPV for Case-3 with RMSE ±1.03 mm/s at quarry

The small RMSE values show the effectiveness of the developed empirical relation. The equation has been validated in a completely separate geological condition and found to be very effective and useful.

8.0 Conclusions

The experimental blasts were conducted at an opencast coal mine. Three sets of trial blasts each with different concentration and distribution of explosives were conducted to investigate its influence on blast-induced ground vibration. The PPV values recorded in the three sets of blasts were plotted against its scaled distance and is presented in Fig.3. It has been found that the PPV values were highest when the explosive charge was concentrated in a single hole (Case-1), while, the PPV values were recorded to be the lowest when the same maximum instantaneous charge was distributed in three holes. The observed variation of PPV at the same site (geological condition) and scaled distance indicates that there is a noticeable impact of charge distribution and concentration on blast-induced ground vibration. Therefore, to predict the precise values of PPV using ground vibration predictor equation, a factor containing the effect of charge concentration and distribution is required to be incorporated in it. To incorporate the same, an empirical equation for effective charge per delay computation has been developed where a new factor i.e. ratio of charge length and hole diameter has been introduced to determine the effective charge per delay. The new modified equation has been validated with the recorded PPV values and the prediction of PPV were found to be more precise with the RMSE values of ±1.92 mm/s and ±1.77 mm/s for Case-2 and Case-3 respectively. Therefore, the concept of effective charge per delay with modified predictor equation can be used for all such cases where charge distribution varies while the maximum charge per delay remains same in similar geological condition.

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