PUNIT PAURUSH
PIYUSH RAI
and
SURESH KUMAR SHARMA

Influence of blast size on the relation between ground peak particle velocity and scaled distance in open pit limestone mines – a case study

The present study was carried out in a limestone mines of Chhattisgarh, India to examine the effect of the number of holes detonated in a blast round on ground vibrations induced by blasting operations at different locations ranging from 100m to 370m in the mine. In this study, the trial blasts were categorized into 4 major groups depending on the number of holes fired in the blast rounds. First group consisted of up to 25 blast holes, second group of 26-50 blast holes, third group of 51-75 blast holes and fourth group consisted of 76-100 no. of blast holes. Ground vibrations in terms of peak particle velocity (PPV in mm/s) were recorded using standard seismographs in the field. Multi-variate linear regression (MLR) was carried out to determine the effect of number of holes on the PPV. Further, peak particle velocity (PPV) vs. scaled distance (SD) relationship were plotted and a comparison of the coefficient of determination (R^2) was made for the data set associated with all the grouped holes and combined data set. The results of the study showed that the number of holes do not have any significant impact on the relationship obtained between ground vibration (PPV) vs SD with increasing number of holes by blasting operations in limestone mines.

Keywords: *Ground vibration, peak particle velocity, scaled distance, MLR*

1. Introduction

Blasting is one of the economical methods used for numerous activities such as fragmenting rock mass in mining tunnelling, civil construction, and other miscellaneous engineering works. However, apart from rock breaking, blasting calls for attending a number of nuisances, such as air overpressure, fly rock, ground vibration, dust hazard, etc. Here, it may be consequent to state that only 20-30% of the energy is utilized in fragmenting and displacement of the rock mass, while the rest is dissipated in the form of ground vibration, air blast, noise and fly-rocks etc. [1]. Ground vibrations are of major concern as they result in the deterioration of existing surface structures and create nuisances to the residents in the vicinity of mines. In the recent years, environmental issues caused by blasting operations have become one of the most serious concern [2-7]. Therefore, the improvement of existing blasting practices paves a way ahead for safety and productivity. The amount of explosive blasted is the major source of seismic wave generation in any blast [8]. However, many researchers have stated that the total amount of explosive does not affect the blast-induced ground vibrations. Whereas, some studies believe that the total amount of explosives blasted in a blast round has a significant effect on the generation of blast induced ground vibrations, and the intensity of the vibration often intensifies with increased explosive quantity [9-11].

During blasting a blast round, the number of holes and the total amount of explosives can be altered by the operators. PPV and scaled distance are two important parameters to assess the ground vibration due to blasting. The number of holes and also, length to width ratio of the blast round affects the ground vibration.

It is also recommended by DGMS that the size of the blast should be restricted to less number of holes at a time to avoid a higher level of ground vibrations [12]. In light of forgoing discussions in the present paper, an attempt has been made to assess the impact of the number of blast holes and the total amount of explosive blasted in a blast round, on the relationship between ground vibrations (PPV) and scaled distance (SD). The research was carried out in the open pit mines of limestone in Chhattisgarh, India.

2. Objective of the study

The present study aims to investigate the effect of the total number of holes and thereby the quantity of charge on ground vibration due to blasting. Statistical analysis was carried out with the following objectives.

1. To categorise the blasting dataset in groups on the basis of number of holes blasted in the blast rounds for assessment of ground vibration in nearby locations.
2. To assess the impact of the number of holes and thereby the size of blast round on the relationship between

Messrs. Punit Paurush, Piyush Rai and Suresh Kumar Sharma, Department of Mining Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi, U.P., India. Email: punitp.rs.min15@itbhu.ac.in / prai.min@itbhu.ac.in / sureshsharma.min@itbhu.ac.in

ground vibrations (PPV) induced by real time blasting operation in the limestone mines and scaled distance (SD). This was carried out by following analysis:

(a) To develop the relationship between PPV and SD with the help of MLR (multi-variate linear regression) technique for the identified groups of trial blast and also for the combined blasting data formed by merging all the groups irrespective of a number of blast holes.

(b) To evaluate and compare the coefficient of determination (R^2) between all the data categorized as per hole grouping and also for the combined set of data.

3. Salient details of the study

A total of 113 trial blasts were conducted, and ground vibration levels were recorded using seismograph in surface limestone mines, Chhattisgarh, India (Fig.1). The blasts were carried out in limestone formation with minor intercalations of shale and clay bands without any significant geological anomaly. Fig.2 gives an overview of the study mine. The limestone formation in the mines was mainly the sedimentary carbonate rocks, which were usually skeletal fragments of marine organisms.

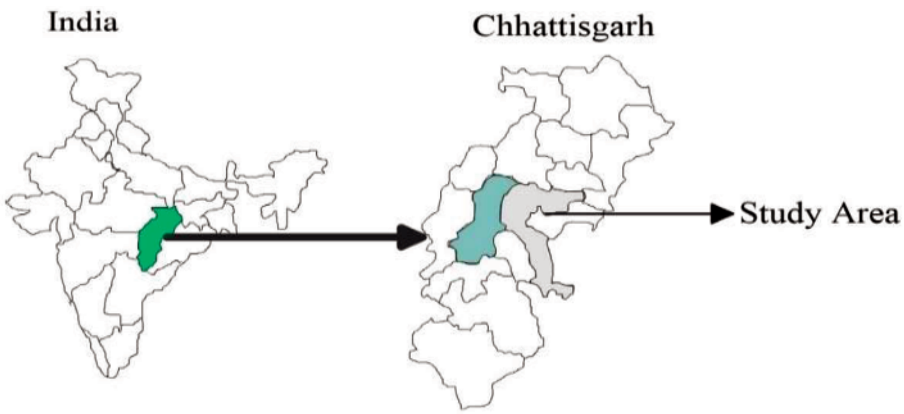

Fig.1 The study area (location of limestone mines)

Fig.2 Overview of study mine

In the conducted trial blasts, the average burden was 2.5 m, the average height of the bench varied from 7-8m, and the average depth of blast holes was kept 10m. Non-electric delay detonators were used for blast initiation. The delay periods of 42 and 65 ms were used between the holes and between the rows, respectively. The trial blasting data and results associated with the identified groups (Tables 1, 2, 3 and 4) were critically evaluated to determine the effect of the number of holes on ground vibration.

4. Methodology

The methodology involved the conduct of trial blasting in the field scale for collection of data in terms of the measurement of PPV, evaluation of scaled distance and statistical analysis of the obtained data. In the present fieldwork, the number of blast holes in various study blast rounds were different. Furthermore, the number of rows also varied from 2-3 rows in different blast rounds, minimum rows being two and maximum being three rows. Accordingly, as per the number of holes blasted in various trial blasting rounds, the blasting dataset was categorized into 4 major groups, as tabulated in Tables 1-4. Further, it is worth mentioning here that because of changes in the number of holes and number of rows, the size of the blast rounds in terms of their length/width (L/W) ratio also changes. The range of L/W ratio for different blasting rounds vis-a-vis change in number of holes and number of rows is given in Table 5.

A representative blast round layout with 34 blast holes, fired in 3 rows is illustrated in Fig.3. L/W ratio for this blast round is 4.8. Now, assuming these 34 holes to be blasted in two rows (as illustrated in Fig.4), the L/W ratio would be higher (20.4). Therefore, it is quite obvious that with the change in the number of holes and the number of rows, the blast size also changes. In the given study, the number of holes was grouped as up to 25, 26-50, 51-75, and 76-100 for evaluating the impact of number of holes and the overall amount of explosive on ground vibrations.

The values of scaled distances and PPV have also been revealed in Tables 1, 2, 3 and 4 respectively for four trial blasting data sets, classified as per the number of holes fired.

Subsequently, the statistical analysis was performed in the 4 groups of trial blasting data set

Table 1 Trial blasting data set for upto 25 number of holes. (41 blasts in total)

Blast no.	No. of holes	Total amount of explosive (kg)	Chargeper delay(kg)	Distance (m)	Scaled distance(m)	Peak particle velocity (mm/s)
1	11	506	46	300	44.23	1.25
2	12	432	36	250	41.67	2.15
3	22	968	44	280	42.21	1.75
4	15	360	24	230	46.94	3.25
5	17	680	40	300	47.43	1.98
6	18	324	18	120	28.28	5.45
7	20	640	32	200	35.35	6.45
8	9	171	19	250	57.35	1.25
9	24	1080	45	150	22.36	7.25
10	13	585	45	300	44.72	2.15
11	16	720	45	300	44.72	2.48
12	21	840	40	300	47.43	1.55
13	17	765	45	320	47.70	2.15
14	14	308	22	300	63.96	1.45
15	22	1012	46	370	54.55	1.25
16	25	1125	45	150	22.36	5.15
17	16	736	46	180	26.53	5.85
18	17	765	45	200	29.81	5.25
19	14	263.9	18.85	130	29.94	6.15
20	17	765	45	200	29.81	3.5
21	23	1035	45	120	17.88	9.15
22	21	401.52	19.12	150	34.30	7.25
23	21	339.36	16.16	200	49.75	3.25
24	18	756	42	250	38.57	1.65
25	25	1125	45	250	37.26	2.45
26	18	328.5	18.25	100	23.40	10.25
27	12	504	42	150	23.14	5.55
28	18	1845	45	200	29.81	5.12
29	16	704	44	200	30.15	4.85
30	20	880	44	115	17.33	8.15
31	24	1080	45	150	22.36	11
32	20	840	42	170	26.23	6.34
33	17	765	45	200	29.81	4.25
34	25	478.75	19.15	180	41.13	5.15
35	21	945	45	150	22.36	8.25
36	16	672	42	220	33.94	4.25
37	24	1080	45	260	38.75	5.15
38	20	840	42	200	30.86	6.25
39	16	704	44	200	30.15	3.85
40	24	1056	44	200	30.15	4.25
41	25	1050	42	140	21.60	9.85

individually to evaluate the impact of blast sizes (number of holes) and total quantity of explosive fired on the ground vibrations due to blasting. Furthermore, the relationship between PPV and scaled distance was developed for 4 individual groups of trial blasts and also for entire 113 trial blasting data set by merging all the four groups.

A representative longitudinal section of the charged blast hole is illustrated in Fig.5. In this charged blast hole section, the average length of the blast hole is 10 m. The amount of explosive is filled up to the height of 6.5-7 m, and the length of stemming is approximately 3-3.5 m.

Ground vibrations have been characterized by measurement of Peak Particle Velocity (PPV). The PPV depends mainly on the maximum charge, the distance between

Table 2 Trial blasting data set for 26-50 number of holes. (31 blasts in total)

Blast no.	No. of holes	Total amount of explosive (kg)	Chargeper delay(kg)	Distance (m)	Scaled distance(m)	Peak particle velocity (mm/s)
1	38	1064	28	300	56.69	1.45
2	27	1269	47	300	43.75	1.49
3	33	726	22	250	53.30	1.52
4	36	1008	28	230	43.46	3.42
5	30	1320	44	200	30.15	4.85
6	29	1305	45	150	22.36	7.85
7	42	1764	42	300	46.29	2.75
8	46	2070	45	250	37.26	6.15
9	50	2250	45	300	44.72	4.15
10	33	1485	45	400	59.62	2
11	49	440	44	300	45.22	0.66
12	33	726	22	300	63.96	0.44
13	29	1305	45	250	37.26	2.25
14	30	540	18	300	70.71	1.72
15	41	1845	45	115	17.14	11.15
16	29	1218	42	200	30.86	4.25
17	40	880	22	120	25.58	7.45
18	30	1260	42	150	23.14	5.15
19	35	1435	41	110	17.17	10.85
20	46	2070	45	250	37.26	1.2
21	21	339.36	16.16	200	49.75	1.55
22	33	1386	42	150	23.14	5.15
23	27	1188	44	300	45.22	1.25
24	30	1260	42	200	30.86	5.25
25	30	1350	45	150	22.36	5.15
26	30	1350	45	100	14.90	9.25
27	31	1364	44	250	37.68	4.95
29	30	1350	45	150	22.36	7.95
30	37	1628	44	150	22.61	7.25
31	39	1755	45	135	20.12	4.85

the blast and the measuring point, and the peculiarities of the medium [13]. The peak particle velocity (PPV) and scaled distance (SD) were analysed carefully. The scaled distance has been computed by standard equation (Eq. 1) that requires the distance between the blast and the measuring points and the maximum charge per delay.

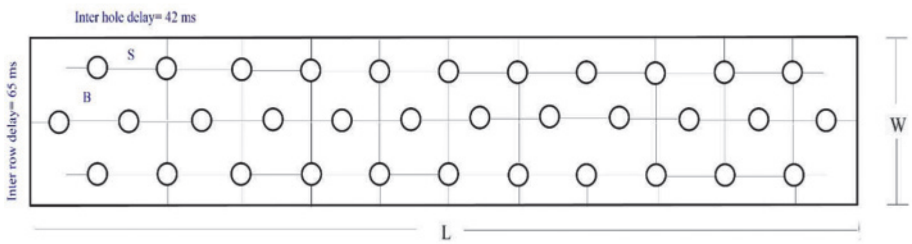

Fig.3 The layout of blast round with three rows

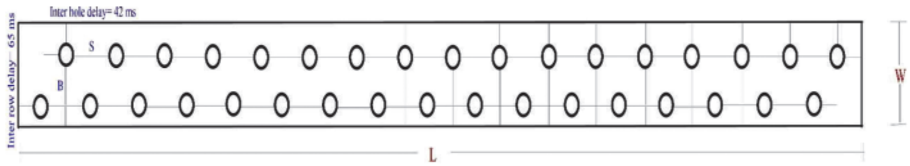

Fig.4 The layout of blast round with two rows

$$SD = \frac{R}{W^{0.5}} \quad \text{... (1)}$$

Where SD is scaled distance, R is the distance between blast and measuring point (m), and W is the maximum charge per delay (kg).

PPV is related to scaled distance by the given Eq.2 established by USBM, which is the most often used formula for PPV estimation [14].

$$PPV = k \times (SD)^{-\beta} \quad \text{... (2)}$$

Where, PPV is peak particle velocity (mm/s), SD is scaled distance, k and β are the site constants.

Table 3: Trial blasting data set for 51-75 number of holes. (25 blasts in total)

Blast no.	No. of holes	Total amount of explosive (kg)	Chargeper delay(kg)	Distance (m)	Scaled distance(m)	Peak particle velocity (mm/s)
1	53	2385	45	290	43.23	4.25
2	52	2288	44	300	45.22	3.95
3	55	2475	45	270	40.24	4.3
4	51	1224	24	250	51.03	3.2
5	62	2728	44	150	22.61	6.75
6	61	2745	45	150	22.36	6.95
7	74	3330	45	170	25.34	6.25
8	58	2610	45	200	29.81	5.25
9	75	3300	44	180	27.13	5.85
10	72	3168	44	200	30.15	2.4
11	58	2610	45	220	32.79	2.12
12	54	2430	45	200	29.81	3.12
13	59	2655	45	150	22.36	6.25
14	71	3195	45	200	29.81	7.24
15	74	3256	44	100	15.07	11.25
16	64	2880	45	200	29.81	6.24
17	66	2772	42	300	46.29	2.12
18	55	2420	44	250	37.68	3.1
19	62	2790	45	350	52.17	1.45
20	70	3080	44	200	30.15	5.15
21	69	3105	45	200	29.81	4.25
22	75	3375	45	100	14.90	8.25
23	74	3256	44	150	22.61	6.25
24	55	2310	42	300	46.29	2.85
25	68	3060	45	100	14.90	11.25

Table 4: Trial blasting data set for 76-100 number of holes. (16 blasts in total)

Blast no.	No. of holes	Total amount of explosive (kg)	Chargeper delay(kg)	Distance (m)	Scaled distance(m)	Peak particle velocity (mm/s)
1	78	3276	42	300	46.29	3.15
2	88	3960	45	200	29.81	5.85
3	91	3822	42	250	38.57	4.85
4	89	4005	45	200	29.81	5.45
5	95	4275	45	330	49.19	4.35
6	93	4092	44	180	27.13	8.25
7	79	3555	45	150	22.36	7.95
8	100	4500	45	200	29.81	7.15
9	98	4312	44	280	42.21	4.98
10	87	3915	45	250	37.26	5.24
11	77	3388	44	200	30.15	8.45
12	81	3645	45	370	55.15	2.55
13	89	3916	44	150	22.61	5.25
14	96	4320	45	200	29.81	7.85
15	99	4455	45	350	52.17	1.25

Table 5: Range of L/W ratio with the increasing number of holes

No. of holes	L/W ratio (Range)	No. of rows
Upto 25	5.5-7.8	2
26-50	8-15.63.6-6.4	23
51-75	15-216.8-10	23
76-100	22.8-27	2
	10-13.2	3

The methodology, as described above, is clearly explained in Fig.6.

5. Result and discussion

In this study, with the help of statistical analysis, the effect of the total number of holes on ground vibration induced due to the blasting operations has been investigated on different blast sizes (depending on the number of holes and number of rows contained in the blasts). During this investigation, the blast rounds have been categorized into four groups, as already described in Tables 1, 2, 3 and 4. Accordingly, the following four groups were identified (i) Up to 25 (ii) 26-50 (iii) 51-75 and (iv) 76-100 number of holes and, for these groups, 41, 31, 25 and 15 vibration measurement data were recorded respectively. The L/W ratios for the identified groups has been revealed in Table 5. It is clear that with increase in number of holes, keeping the same number of rows, the L/W ratio increases which, in turn implies increase in blast size and firing of blast rounds with increased quantity of explosive.

The data obtained from the trial blasts in respect of PPV and scaled distance were statistically evaluated by the MLR technique to determine the coefficient of determination. The peak particle velocity (PPV) vs. scaled distance (SD) graphs were plotted for the data, and the correlation coefficients were determined. Data associated with each identified group of blast were analysed separately. Also, the statistical analysis was performed on combined data set by merging the trial

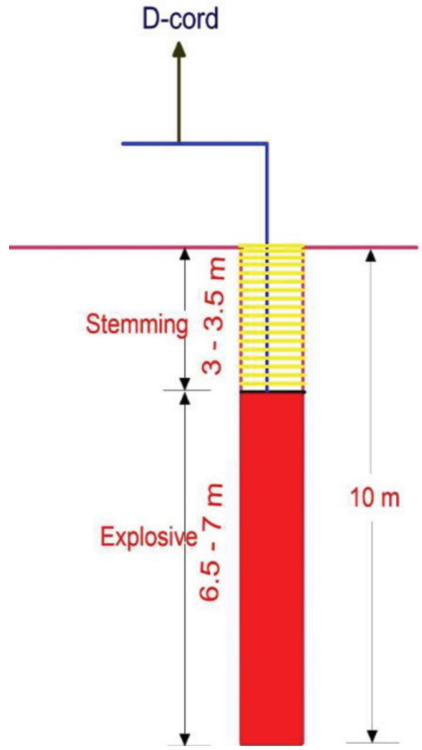

Fig.5 Representative charged blast hole section (not to scale)

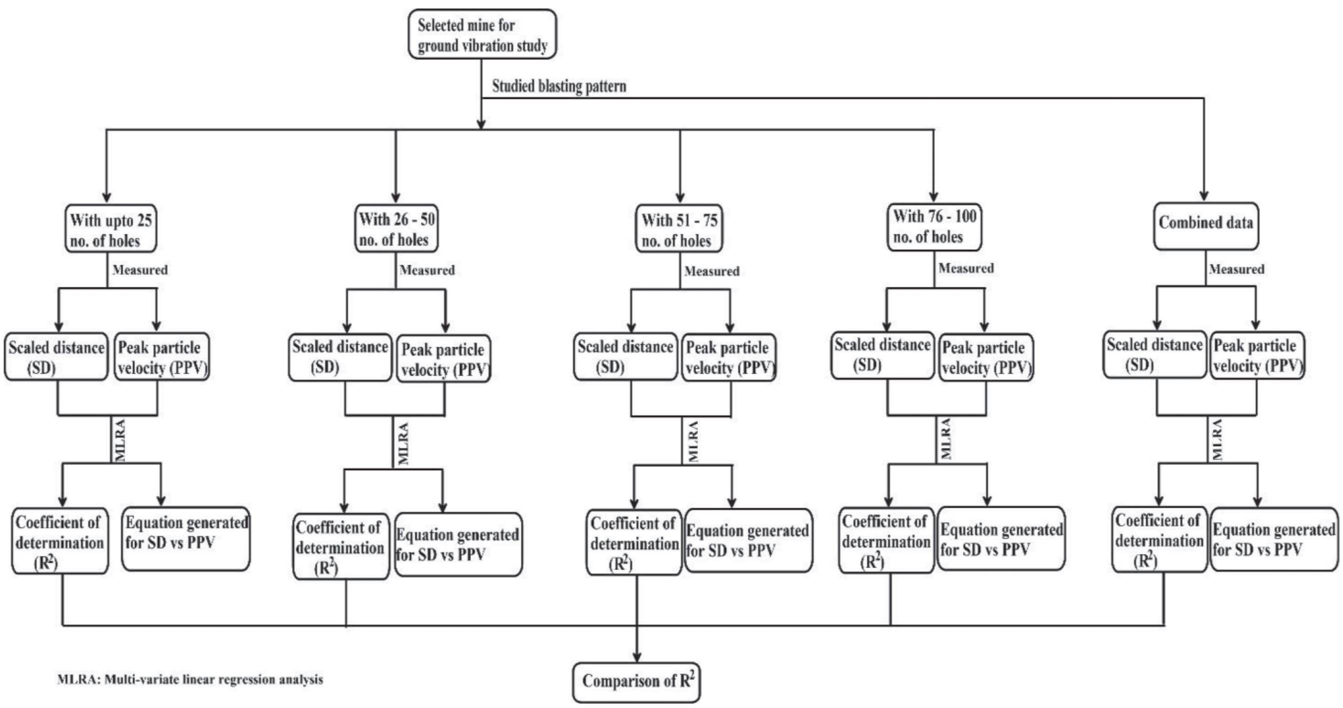

Fig.6 Illustration of research design

blasts of different group in a single and separate group.

With the help of the MLR technique, the graphs for the data sets between peak particle velocity (PPV) and scaled distance (SD) were plotted for the 4 identified groups as illustrated in Figs.7, 8, 9 and 10.

The developed statistical equations, along with regression coefficients between the PPV and scaled distance for the identified 4 groups and for combined data set as explained above, are given in Eqs. 3, 4, 5, 6 and 7, respectively.

The coefficient of determination (R^2) calculated by statistical analysis for the identified groups was found to be 0.67, 0.67, 0.66, and 0.69. The coefficient of correlation calculated for the overall data (all groups combined) was found to be 0.66.

From the developed equations, it may be observed that for all grouped holes data and combined data, the values of regression coefficients were nearly identical. The developed equations with the value of the coefficient of determination (R^2) are given in Eqs.3-7.

Trial blasts with upto 25 holes

$$PPV = 448.4 \times (SD)^{-1.658} \quad (R^2 = 0.67) \quad ... (3)$$

Trial blasts with 26-50 holes

$$PPV = 445.8 \times (SD)^{-1.622} \quad (R^2 = 0.67) \quad ... (4)$$

Trial blasts with 51-75 holes

$$PPV = 463.2 \times (SD)^{-1.669} \quad (R^2 = 0.66) \quad ... (5)$$

Trial blasts with 76-100 holes

$$PPV = 665.5 \times (SD)^{-1.48} \quad (R^2 = 0.69) \quad ... (6)$$

For entire data (113 blasts)

$$PPV = 760.9 \times (SD)^{-1.502} \quad (R^2 = 0.66) \quad ... (7)$$

The comparison was made for the PPV-SD relationships obtained from the grouped hole data together with the total data (Fig.11). The results reveal close coefficients of determination, suggesting the lack of a significant difference between separate analysis and collective data analysis. The corresponding lines point out that the number of holes in open pit mines and therefore, the total amount of explosive do not affect the ground vibrations induced by blasting, in the present case.

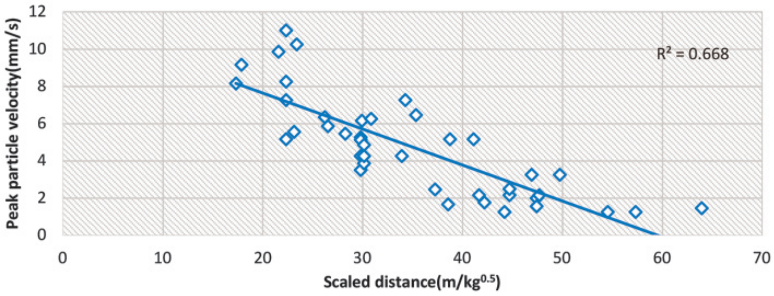

Fig.7 PPV vs SD graph for upto 25 number of holes

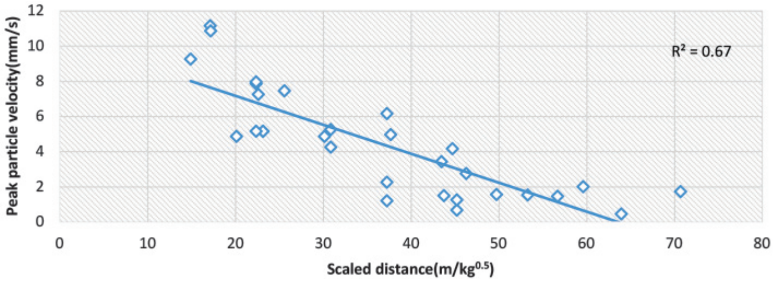

Fig.8 PPV vs SD graph for 26-50 number of holes

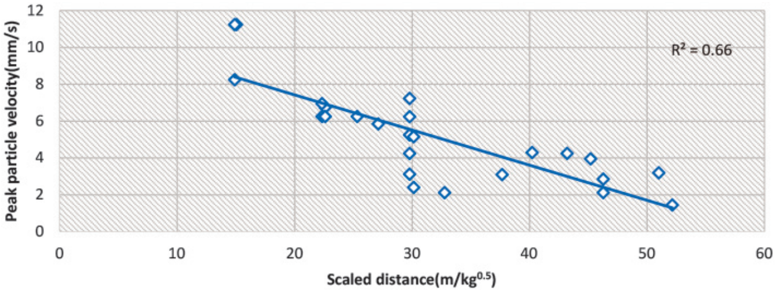

Fig.9 PPV vs SD graph for 51-75 number of holes

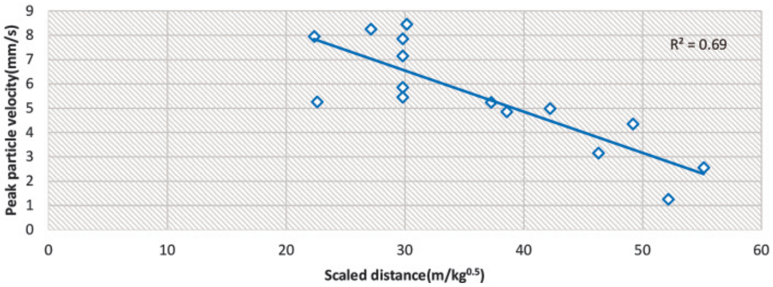

Fig.10 PPV vs SD graph for 76-100 number of holes

Therefore, it may be clearly interpreted that the number of holes, number of rows, and quantity of explosives do not have any significant effect on the relationship between PPV and SD. The four categories of the blast with an increasing number of holes have provided an informative result to this effect. This can be attributed to effective utilization of inter hole and inter row delay combinations. Hence, larger blast rounds with increasing number of holes can be carried out without increasing the level of ground vibrations in relation with scaled distance in field scale blasting provided proper delay combinations are used. The results of four grouped blasting dataset and combined group dataset derived almost similar coefficient of determination (R^2). Negligible difference between separate analysis and collective analysis of the data indicates efficacy of blast designs. It may be further inferred that if the blasts are properly designed, the number of holes, number of rows, size of blast rounds and quantity of explosive fired in the blast round shall not increase the coefficient of determination values of all the grouped hole and combined data set.

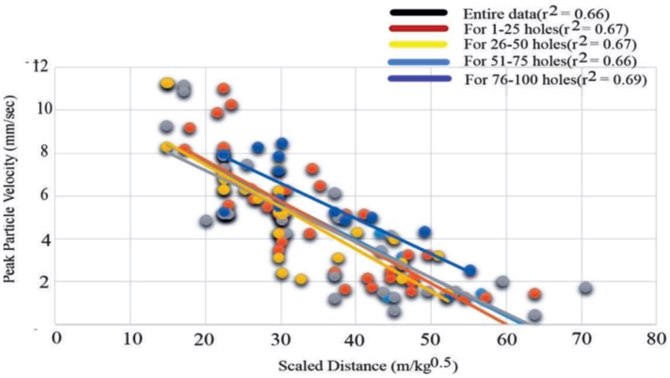

Fig.11 PPV-SD graph for comparison of data sets of grouped holes and entire data

6. Conclusions

Following are the important conclusions that may be drawn from the present research work:

1. By changing the number of holes and number of rows fired in the blast round the blast size (L/W ratio) and also, explosive quantity fired in the blast rounds gets changed drastically.
2. The almost identical R^2 value for different blast round sizes reveals that there is no significant impact of the number of blast holes, number of blast rows, L/W ratio and explosive quantity fired in a blast round, on the relationship obtained for blast induced ground vibration (PPV) vs SD.
3. The graphical trends for individually grouped data and combined data are almost identical, which corroborates the foregoing conclusion.
4. From the above two conclusions, it may be safely concluded that in the study limestone mines the blasts were designed with proper inter-row and inter hole delays due to which the blast energy was properly coordinated, and even with the increase in explosive quantities, the variation of PPV with SD remained almost identical.
5. By increasing the number of holes, the PPV vs SD relation are almost similar, which inferred that when we take different scaled distance the value of PPV remains almost similar in all the cases with increasing number of holes.

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References

1. Uysal O, Erarslan K, Cebi MA, Akcakoca H. (2008): Effect of barrier holes on blast induced vibration. *International Journal of Rock Mechanics and Mining Sciences*, Jul, 1;45(5):712-9.
2. Ozdemir K, Kahriman A, Tuncer G, Akgundogdu A, Elver E, Ucan ON. (2004): Fragmentation assessment using a new image processing technique based on adaptive neuro fuzzy inherence systems. in proceedings of the annual conference on explosives and blasting technique, (Vol. 2, pp. 181-188). ISEE. 1999
3. Felice JJ. (1993): Applications of modelling to reduce vibration and airblast levels. In International symposium on rock fragmentation by blasting (pp.145-151).
4. Tuncer G, Kahriman A, Ozdemir K, Guven S, Ferhatoglu A, Gezbul T. (2003): The damage risk evaluation of ground vibration induced by blasting in Naipli Quarry. In third international conference: modern management of mine producing, geology and environmental protection, SGEM-2003, Varna, Bulgaria, Jun (pp. 9-13).
5. Erarslan K, Uysal Ö, Arpaz E, Cebi MA. (2008): Barrier holes and trench application to reduce blast induced vibration in Seyitomer coal mine. *Environmental Geology*; 54(6):1325-31.
6. Uysal O, Cavus M. (2013): Effect of a pre-split plane on the frequencies of blast induced ground vibrations. *Acta Montanistica Slovaca*;18(2):101-9.
7. Görgülü K, Arpaz E, Uysal Ö, Durutürk YS, Yüksek AG, Koçaslan A, Dilmaç MK. (2015): Investigation of the effects of blasting design parameters and rock properties on blast- induced ground vibrations. *Arabian Journal of Geosciences*. Jun 1; 8(6):4269-78.
8. Yuvka S, Beyhan S, Uysal O. The effect of the number of holes on blast-induced ground vibrations. *Environmental Earth Sciences*. 2017; 76(17):621.
9. Singh PK, Roy MP, Sawmliana C, Singh RB, Singh DP. (2000): Damages to underground openings due to surface blasting. In1st world conference on explosive and blasting technique. Munich (pp.79-88).
10. Roy MP, Singh PK, Singh VK, Senapati G, Mishra AK, Jawed M. (2012): Concept of effective explosive weight per delay for prediction of vibration in open-pit blasting. Rock Fragmentation by Blasting: Fragblast; 10:457-63.
11. Singh PK, Roy MP. (2008): Damage to surface structures due to underground coal mine blasting: apprehension or real cause? *Environmental geology*. Jan 1;53(6):1201-11.
12. Dhariwal PC. (2012): A specialised blasting technique to maintain better safety and productivity in limestone mines of JK Cement Works. In Rock Fragmentation by Blasting: The 10th International Symposium on Rock Fragmentation by Blasting, (Fragblast 10) 2013 (pp. 817-821). Taylor & Francis Books Ltd.
13. Abdel-Rasoul EI. Measurement and analysis of the effect of ground vibrations induced by blasting at the limestone quarries of the Egyptian cement company.
14. Armaghani DJ, Momeni E, Abad SV, Khandelwal M. (2015): Feasibility of ANFIS model for prediction of ground vibrations resulting from quarry blasting. *Environmental earth sciences*; 74(4):2845-60.