Ground Vibration — Unique Case Studies in Indian Coal Mines

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GROUND VIBRATION --- UNIQUE CASE STUDIES IN INDIAN COAL MINES

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ABSTRACT

In India, after nationalization of coal mines, the coal production has been enormously increased with the drastic increased in demand. Fulfilment of demand is met by opening up the highly mechanized surface mines. In the past, the Indian surface coal mines were, in general, using conventional drilling-blasting technique with conjugation of a number of combinations like shovel-dumper, dragline, FEL-dumper etc. In the overburden benches, large scale blasting generated ground vibrations leading to structural damage. In order to control this, reduction in maximum charge per delay has got the importance in the mind of the mining as well as geotechnical engineers. This reduction of charge per delay, have deployed either by using more number of delays in each hole or sometimes by using hole to hole delay. This concept was used and the study was conducted in the Indian surface coal mines and the detailed investigation was carried out and comparison on the ground vibration was made between hole to hole delay blasting and row blasting. The vibrations were carefully measured with the help of two Minimates plus Seismographs of Instantel Inc. Predictor equations have been established to arrive at the vibration levels considering both maximum charge per delay and total charge per delay. Calculation of scaled distance has got added place. From field investigations, it has been observed that the vibration level is lesser for the row to row blasting than the hole to hole blasting for a same scaled distance. The result shows the reverse trend of the earlier researchers dealing with blasting operations. To explain this typical result in proper justification a large number of case studies were conducted and the geological parameters are simulated with the scaled distance, maximum charge per delay and total charge blasted. Accordingly, a simulation package is developed which can help the practicing engineers dealing with this problems.

INTRODUCTION

The coal production in India has been steeply increased with the increased demand, especially after the nationalization of coal mines. This increase is mainly due to the high production rate of the opencast mines. All the opencast mines in India are using drilling & blasting with conjugation of a number of combinations of machinery, namely, shovel-dumper, dragline, FEL-dumper etc.

With the increase in the production, the availability of the seams in the sallower depth is becoming less. Mining of deeper seams are costly and to make it economically feasible, productivity has increased manifold. This requires large scale blasting, which disrupted the human habitation, if exists near to the blast face. The problem is mainly due to the blast vibrations which damaging the structures. So the new challenge in front of the surface mining is to get control over the blast vibration without compromising the productivity.

FACTORS AFFECTING GROUND VIBRATION

Langefors (1978) concluded that the structural damage due to ground vibration can be assessed by monitoring “Peak Particle Velocity (PPV)”. Further, it is a common belief that PPV lesser than 30mm/s is safer for brick & concrete structure and geologic structure considering long term effect. Pal (1999) considered a number of parameters, which directly or indirectly some affect the level of ground vibration and its attenuation during surface mine blasting and is given by :

i. Maximum charge/delay.
ii. Total charge blasted.
iii. Duration of the blast.
iv. Distance of the structure for the blast face.
v. Rock and rock mass properties.
vi. Blast pattern and initiation sequence.
vii. Drilling pattern and inclination of bore hole.
viii. Burden and spacing.
ix. Direction of the blast with respect to the structure.
x. Stiffness of the free face.
xi. Depth of the center of the charge from structure.
xii. Explosive properties.
xiii. Radius of the hole and radius of the charge.

PREDICTION FOR GROUND VIBRATION

A number of researcher time to time proposed a host of formula to predict the ground vibration of a blast. The major approaches and their formulae are discussed below-

Holmberg R. and Persson P.A. (1979) proposed a generalised equation for predicted peak predicted peak particle velocity as given by,

$$V = K \times D^{-B} \times Q^{A} \qquad \text{-------------} \quad (1)$$

Where,

V = peak particle velocity (mm/s).
D = distance of the measuring point (m).
Q = charge blasted per delay (kg).
K, A, B = empirical constants, based on the site condition.

Indian Standard Equation (1973): -

$$V = K \times \left(\frac{Q^{2/3}}{D}\right)^{B} \qquad \text{----------------} \quad (2)$$

Ghosh & Daemen Equation (1983): -

$$V = K \times \left(\frac{D}{Q^{1/2}}\right)^{-B} \qquad \text{-----------------} \quad (3)$$

Ambraseys & Hendron Equation (1968): -

$$V = K \times \left(\frac{D}{Q^{1/3}}\right)^{-B} \qquad \text{-----------------} \quad (4)$$

CASE STUDY

The trial blasts are conducted in a surface coal mine, situated in eastern India. The mine consists of three quarries named Quarry-A, Quarry-B & Quarry-E. The study has been mainly concentrated for the blasting of overburden and partings at Quarry-E. Few interesting blasting has also been observed at Quarry-A. Mishra and Pal (1995) conducted some extensive studies to optimize the ground vibration during blasting in the open cast mine and developed some models for prediction of vibration which are still in use.

Method of Mining

This mine was planned in consultation with BHPE Kenhill of Australia and the method adopted, is improved system of Haul Back mining in which the dumping of overburden is done at the same horizon. Overburden (top soil and stone above the first coal layer) and the inter burden (stone in between the seams) are removed by drilling and blasting. Heavy ANFO, and emulsion are used for blasting. The blasted materials are removed by the combination of hydraulic shovel and rear dumper. Coal is also blasted in the same manner but the loading is done by FEL onto the bottom discharge dumper. For the handling of larger size boulder produced from the blasting a Rock-breaker is also used.

The salient features of Quarry-E is given below —

Name of the mine: West Bokaro Quarry-E OCM
Year of opening: 1993
Life of mine: Three more years
Name of Mineral: Coal
Average Seam thickness: V seam → 2 m
VI seam →4m - 5 m
VII seam - 8 m
Strike length: 800 m
Location: South-West site of West Bokaro, Hazaribagh Dist., Bihar.
Area of the mine: 46 Acres
Reserves: 11 MT (as on 01-01-1998)
Depth of excavation: 95 m
Dip of the ore body: 1 in 12
Cut off grade: Grade 'F'
Grade of mineral: Combined grade-4
Overburden removal: 6.5 Mm^3 per year (target)
Coal production : 1.9 MT per year (target)
Explosive consumption: 3000 T per year

Machinery deployed:

The rock characteristics of the four blast faces are described in the Table-1.

Table 1: - Rock Characteristics of Quarry -- E

Name	Capacity	No.
Hydraulic excavator	6 m^3	05
Rear dumper	50 ton	22
Drill master	150 mm (dia)	07
Bull dozer	410 HP/320 HP	07
Bottom Dumper	60 ton	07
Front-end-loader	8 m^3	03
Motor grader	180 HP	02
Rock Breaker	N.A	01
Water tanker	28 KL	02

Field trials were basically concentrated at four overburden benches of Quarry 'E'. These are named as –

i) 7 O/B, Old Overman Shed.

ii) 7 O/B-1, X Seam Area
iii) 7 O/B, X Seam Area (Top Bench).
6 O/B, Sarna Area.

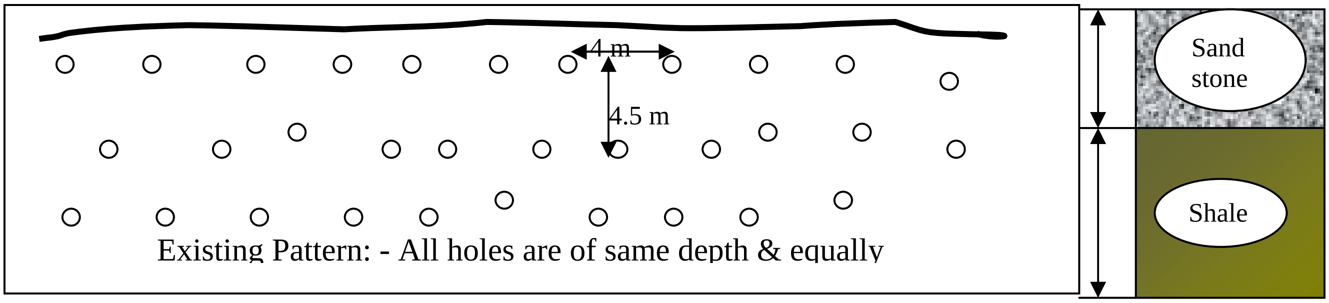

Fig. 1: Typical blast pattern and the litho logy of the overburden bench

The present recommended blast design of the mine is as follows—

1. Dia. of the drill: - 150 mm.
2. Drill pattern: - Staggered.
3. Burden: - 4m.
4. Spacing: - 4.5m.
5. Deck charging: - Seldom practiced.
6. Explosive used: -
   - Base charge → ICI made Primex 100gm/250gm.
   - Column charge→ ICI made Powergel – Emulsion Bulk loading.
   - IBP made Indogel → Emulsion Bulk loading
   - In hole initiation → Excel 200ms/ Detonating Fuse
   - Inter hole initiation → Excel NTD 17ms & 42ms / Detonating Fuse/ Relay 25ms.

Row to row connection → Relay 25ms

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Study of Ground Vibrations

The details of the trial blasts are given in Table-2 and the details of the blast hole statistics and their analysis are shown in Table-3. Two Minimate Plus seismograph of Instantel Inc. Canada were used for monitoring ground vibration at different distances opposite to the blast direction. Square root scaling has been used for developing predictor equations, separately for row to row delay blasting and hole to hole delay blasting. It has been tried to set a correlation in between PPV and Scaled Distance (using maximum charge/ delay and total charge) for both the cases. The plotted graphs are given in Fig. 2 and Fig. 3.

Table 2: - Blast Details of Samples Rocks Tested

Rock Properties	7 O/B, Old Overman Shed	7 O/B-1, X-seam Area	7 O/B, X seam Area Top bench	6 O/B, Sarna Area
No of Blast Studied	4	4	3	4
Bench Height (m)	6.5 m & 13 m	6 - 6.5	12.5 - 13	12 - 12.5
No of Rock layers	3	2	2	2
Top Layer				
Rock type	Coarse Grained Sandstone	Coarse Gr. Sandstone	Coarse Grained Sandstone	Shale
Thickness (m)	1.5 – 2.5	1.5 – 2.3	0.5 – 0.7	4.5
Joint Set Details	No Joint Set	No Joint Set	No Joint Set	Jointed
J_1 set (dip/direction)				
J_2 set (dip/direction)				
Layer Thickness (cm)				5 - 30
Joint Plane Spacing (cm)				100 - 150
Point Load Index (MPa)	0.8	2.0	2.7	2.28
Compressive Strength (MPa)	20	48	68	53
Middle Layer				
Rock type	Shale			
Thickness	3.5			
Joint Set Details	Highly Jointed			
J_1 dip/direction	85^0/N260^0			
J_2 dip/direction	Not Visible			
Layer Thickness (cm)	1 - 45			

Joint Plane Spacing (cm)	5 - 50			
Point Load Index (MPa)	1.27			
Compressive Strength (MPa)	30.5			
Bottom Layer				
Rock type	Coarse Grained Sandstone	Shale	Shale	Coarse Gr. Sandstone
Thickness	4.2 – 5.5	3.5	12 - 12.5	8.0
Joint Set Details	No Joint Set	Jointed	Jointed	No Joint Set
J_1 dip/direction		85^0/N5^0		
J_2 dip/direction		80^0/N280^0		
Layer Thickness (cm)		5 - 30		
Joint Plane Spacing (cm)		10 - 15		
Point Load Index (MPa)	2.175	1.27	3.5	1.2
Compressive Strength (MPa)	52	30.5	84	28.43
Remarks	High speed photograph shows stemming ejection and spalling starts at softer middle layer	Problematic strata prone to boulder generation and fly rock.	Relatively homogeneousness of the bench rocks easier the blast design.	Blast design is easy with soft-top & hard bottom. Possibilities of cast blasting due to nearness of Dump.

Table 3: Blast Hole Statistics and its Detailed Analysis

Blast ID	Maximum Charge / Delay (kg) [Q_d]	Total Charge (kg) [Q_t]	Distance (m) [D]	Peak Particle Velocity (mm/s) [PPV]	$D/Q_d^{0.5}$	$D/Q_t^{0.5}$	Peak Particle Velocity (mm/s) [PPV]
For hole to hole delay blasting							
1	380	9880	190	16.00	9.75	1.91	16.00
2	275	11500	150	19.56	9.05	1.40	19.56
3	225	6000	70	49.78	4.67	0.90	49.78
4	95	1590	70	31.62	7.18	1.76	31.62
5	225	8300	350	9.40	23.33	3.84	9.40
6	190	1800	90	18.03	6.53	2.12	18.03
7	260	3360	210	13.72	13.02	3.62	13.72
8	450	5000	200	11.43	9.43	2.83	11.43
9	190	1140	80	21.59	5.80	2.37	21.59
10	240	2160	126	23.37	8.13	2.71	23.37
11	400	5670	170	11.94	8.50	2.26	11.94
For row to row delay blasting							
12	1150	14500	250	14.99	7.37	2.08	14.99
13	1363	11880	120	34.59	3.25	1.10	34.59
14	500	2500	125	19.30	5.59	2.50	19.30
15	240	2240	195	1.00	12.59	4.12	1.00
16	1200	8000	120	30.48	3.46	1.34	30.48
17	400	6000	150	7.62	7.50	1.94	7.62
18	760	4000	150	17.78	5.44	2.37	17.78
19	285	1525	70	12.19	4.15	1.79	12.19

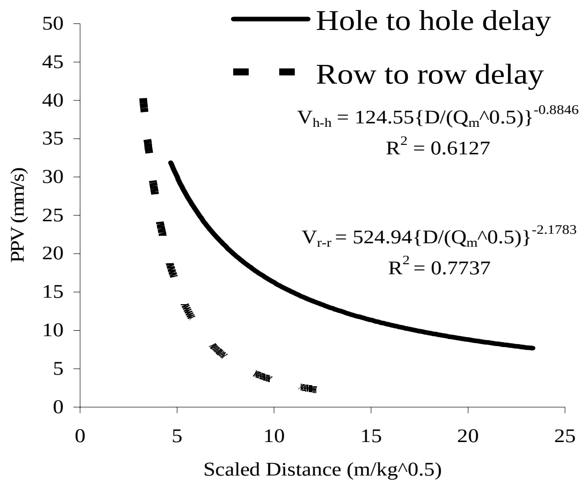

Fig. 2: Vibration predictor using maximum charge per delay

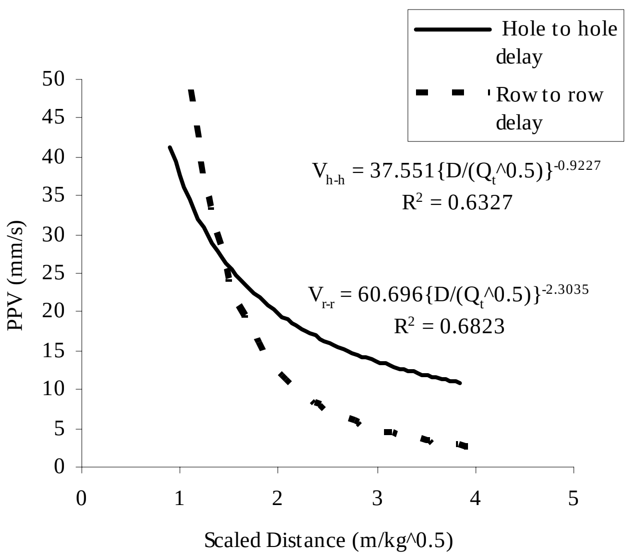

Fig. 3: Vibration predictor using total charge

The vibration predictor established considering maximum charge delay for both row to row delay and hole to hole delay are given by,

$$V_{r-r} = 525 \times \left(\frac{D}{Q_m^{1/2}} \right)^{-2.17} \qquad \text{---------------} \quad (5)$$

$$V_{h-h} = 125 \times \left(\frac{D}{Q_m^{1/2}} \right)^{-0.88} \qquad \text{---------------} \quad (6)$$

where,

V_{h-h} = peak particle velocity for hole to hole delay blasting (mm/s),

V_{r-r} = peak particle velocity for row to row delay blasting (mm/s),

D = distance of the measuring point from the blast hole (m),

Q_m = maximum charge blasted in one delay (kg).

From the Fig. 2, it can be seen that the row to row delay generates lesser ground vibration than hole to hole delay. This seems that incorporating more number of delays to reduce maximum charge per delay concept is not useful to control ground vibration.

The concept of total charge blasted has been used to establish vibration predictor again for both the cases (hole to hole and row to row) and the predictors are given by,

$$V_{h-h} = 38 \times \left(\frac{D}{Q_t^{1/2}} \right)^{-0.92} \qquad \text{----------------} \quad (7)$$

$$V_{r-r} = 61 \times \left(\frac{D}{Q_t^{1/2}} \right)^{-2..30} \qquad \text{----------------} \quad (8)$$

where,

V_{h-h} = peak particle velocity for hole to hole delay blasting (mm/s),

V_{r-r} = peak particle velocity for row to row delay blasting (mm/s),

D = distance of the measuring point from the blast hole (m),

Q_t = total charge blasted (kg).

From Fig. 3 it is also clear that row to row blasting produces lesser ground vibration. This seems that the initiation direction has an significant effect on the level of ground vibration produced by a blast round.

CONCLUSION

From the above investigation, it is observed that the vibration is lesser for the row to row blasting rather than the hole to hole blasting for a same scaled distance. The result is same for both the cases of maxm. charge/delay and total charge blasted. These results are just reverse from the common idea of the blast personals that the use of more delays to reduce charge/delay would generate lesser ground vibration. Blast initiation direction may have significant effect on ground vibration, may be in terms of resistance to breakage, and needs further investigations.

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