GROUND VIBRATIONS IN OPENCAST MINE BLAST ON STRUCTURES VIS-À-VIS A LOCAL ENVIRONMENTAL EFFECT AND ITS MITIGATION THROUGH MINING TECHNOLOGY

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ABTRACT

This paper presents part of the work on ground vibrations induced by blasting, and to estimate safe maximum charge per delay to protect the nearby structures. Blasting near sensitive areas has always been a cause of concern and utmost care has to be taken to keep the charge per delay below the stipulated level A number of field visits were made to collect the geotechnical data, and monitoring ground vibrations induced by blasting. A number of blasts were monitored to study various blast parameters related to blasting Overburden and Coal benches and to understand the effect of blast on the surrounding structures, and rock mass conditions at the mine site. Drilling is accomplished by tire mounted drill machine capable of drilling large diameter holes of 159mm. The drilling pattern of the mine benches is based on the rock formation of the particular bench and varies with the variation in strata from 4 m to 6 m. Holes were charged with Bulk Emulsion Explosives in association with Booster(Cap sensitive). Nonel systems of initiation were used to reduce vibration. Accordingly, the safe charge per delay for the distance of 100 m, 200 m, 300 m, 400 m, and 500 m is 18.9 Kg, 75.9 Kg, 170.8 Kg, 303.7 Kg, and 474.5 Kg, respectively to keep the vibration level below 5 mm/sec for the above geomining conditions of Jindal Power Opencast Coal Mine- Tamnar.

The damage criteria was proposed by many organizations including USBM, DGMS, Indian Standards etc based on the Permissible PPV in mm/s and Frequency of the ground vibrations for various types of structures. The criteria based on the Permissible PPV in mm/s and Frequency of the ground vibrations for various types of structures was presented. In the present investigations safe charge per delay 3 was estimated through empirical model to limit the ground vibrations within safe limit of 5 mm/sec considering the structures as sensitive and not belonging to the owner. Hence, the mining technology in terms of blasting pattern and explosive charge was recommended for local environmental protection of the structures.

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1.0 GENERATION OF GROUND VIBRATIONS

When an explosive charge detonates, intense dynamic waves are set around the blast hole, due to sudden acceleration of the rock mass. Charging of blast holes in a typical quarry is shown in Fig 1.

The energy liberated by the explosive is transmitted to the rock mass as strain energy. The transmission of the energy takes place in the form of the waves. The energy carried by these waves crushes the rock, which is the immediate vicinity of the hole, to a fine powder.

Blast induced ground vibrations, which are propagated in rock, can be divided into three categories:

a. Compression waves

b. Shear waves and

c. Rayleigh waves.

The motion of the ground particle takes in three perpendicular directions viz. vertical, longitudinal and transverse directions.

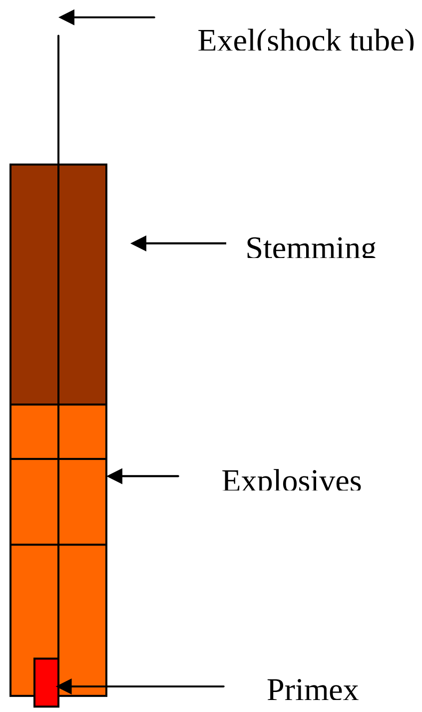

Fig 1: Charging of blast holes in a typical quarry

For the compression wave, the particle moves along the direction of propagation (longitudinal), while the shear wave moves across this direction (transverse). The Rayleigh waves have elliptical particle movements in the vertical plane (vertical). The particles rotate backward in this plane. Pictorial representation of the various zones and the phenomenon is shown in Fig 2.

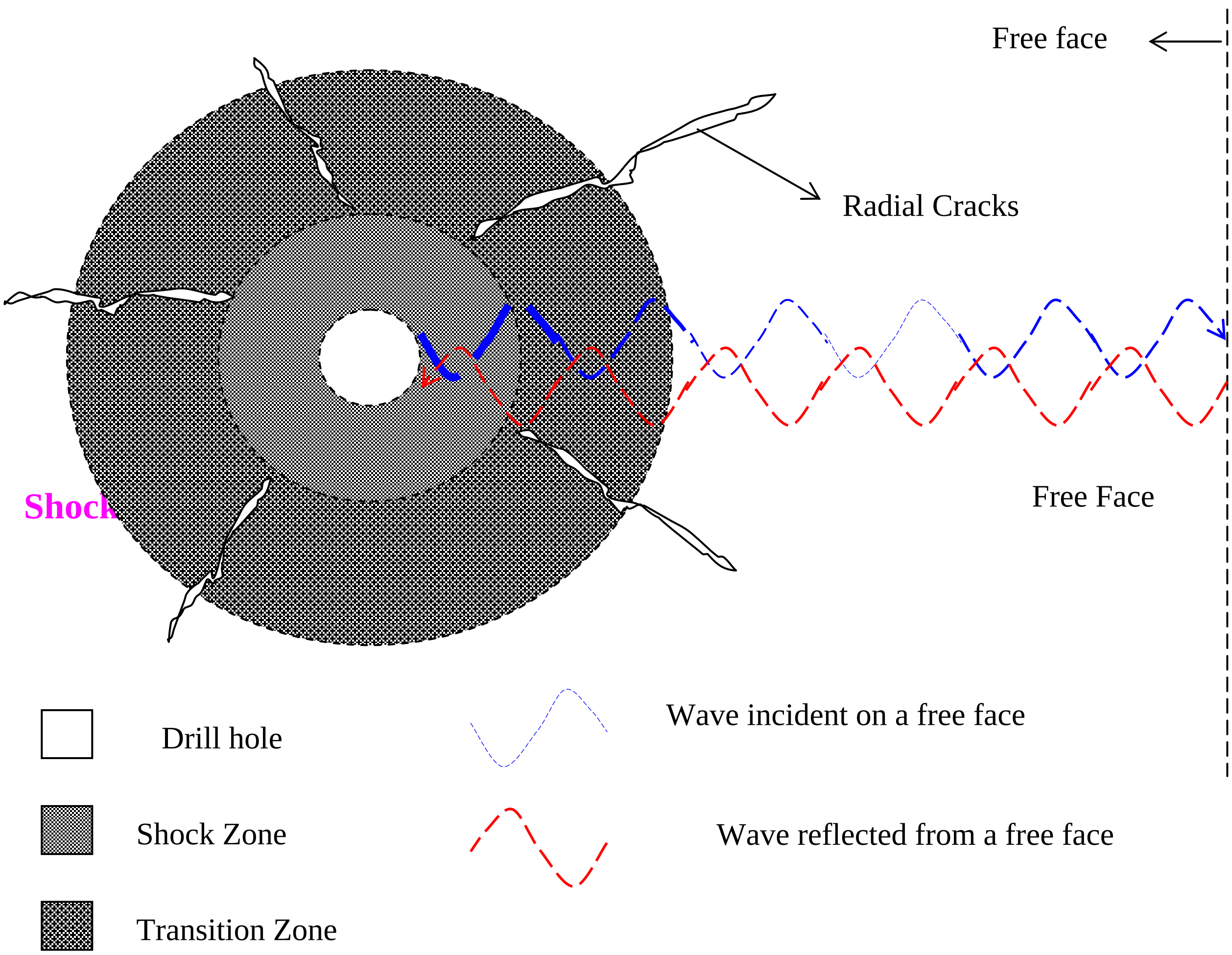

Fig 2: Pictorial representation of the various zones and the phenomenon of reflection of waves

The propagation velocity for the different wave types is dependent of the elasticity and density of the medium. Typical velocities for shear waves in rock vary from 2000-4000 m/s correspondingly for compression waves 3000-6000 m/s. For inhomogeneous and stratified rocks the propagation of wave energy is complicated.

During unfavorable conditions resonance and focusing effects may be created by the interference of incoming and reflecting waves. Under such conditions the vibrations may increase and not decrease when the distance from the blast source get larger.

The three important wave characteristics, which are significant for blast damage, are amplitude, frequency and duration. The amplitude, which is given as acceleration, particle velocity or displacement, depends on detonating charge, length of the charge, confinement, damping conditions in the ground, the building response and the distance between the object and blasting. Concerning ground conditions and building response nothing can be done.

The frequency of vibration wave is strongly dependent of distance. Generally, the frequency of blast induced ground vibration varies from 10-100 Hz. For short distance of 1-3 m, frequencies of 60-100 Hz are the norm, but values up to 400 Hz also exist. At distances more than 100 m the frequency will normally be found in the area of 15-30 Hz. Vibrations below 25 Hz can excite high levels of mid wall motions (typically 4 times) and generate most of the secondary noise, rattling and other annoyances. Frequencies below 10 Hz are most serious for potential damage from structure racking. They produce large ground displacements and high level of strain.

Earlier peak particle velocity was the sole criterion for the ground vibration standards. However, after the role of frequency in the damage to the structures became known, it is now common to prescribe maximum permissible peak particle velocity alongwith corresponding frequency.

2.0 DAMAGE CRITERIA:

The damage criteria was proposed by many organizations including USBM, DGMS, Indian Standards etc based on the Permissible PPV in mm/s and Frequency of the ground vibrations for various types of structures. The criteria based on the Permissible PPV in mm/s and Frequency of the ground vibrations for various types of structures as per DGMS (1997) as presented below in Table 1 and 2 is followed for the present investigations to estimate safe charge per delay to limit the ground vibrations within safe limit of 2 mm/sec considering the structures as sensitive and not belonging to the owner.

Table 1: Damage criteria vis-à-vis Buildings / Structures belonging to the owner

Type of Structure	Dominant Excitation Frequency

	<8 Hz	**8 to 25 Hz**	**> 25 Hz**
a) Domestic Houses	5	10	15
b) Industrial Building	10	20	25
c) Sensitive Structure	2	5	10

Table 2: Damage criteria vis-à-vis Buildings / Structures NOT belonging to the owner

Type of Structure	**Dominant Excitation Frequency**		
	<8 Hz	**8 to 25 Hz**	**> 25 Hz**
a) Domestic Houses	10	15	25
b) Industrial Building	15	25	50

When an explosive charge is detonated in a blast hole, the rock immediately surrounding the charge is fractured, split apart and is displaced. At a certain distance from the blast hole, the explosive energy decreases to a level, which causes no further shattering or displacement and continues to travel through the rock as an elastic ground vibration? The ground motion is literally a wave motion spreading outwards from the blast, much as the ripples spread outwards from the impact of a stone dropped into pool of water.

The earth, or rock, through which this wave travels, is considered to be an elastic medium, composed of individual particles. As a disturbance occurs, each of these particles is set into a oscillatory motion about their positions, a wave is then generated as each particle transmits energy successively to the next. Energy losses occur with each successive transmission, so that as the vibration wave spreads outward, it diminishes the intensity, and the particles gradually return to their rest/mean positions.

The damage criteria was proposed by many organizations including USBM, DGMS, Indian Standards etc based on the Permissible PPV in mm/s and frequency of the ground vibrations for various types of structures. The criteria based on the Permissible PPV in mm/s and frequency of the ground vibrations for various types of structures as per DGMS (1997) is presented in Table 1 and 2. Accordingly, the same is followed in the present investigations to estimate safe charge per delay to limit the ground vibrations within safe limit of 5 mm/sec as the frequency was within the limits of 8 to 25 Hz for the present observations (considering the structures as sensitive and not belonging to the owner.

3.0 PARAMETERS INFLUENCING PROPAGATION AND INTENSITY OF GROUND VIBRATIONS:

The parameters, which exhibit control on the amplitude, frequency and duration of the ground vibration, are divided in two groups as follows:

a. Non-controllable Parameters

b. Controllable Parameters

The non-controllable parameters are those, over which the Blasting Engineer does not have any control. The local geology, rock characteristics and distances of the structures from blast site are non-controllable parameters. However, the control on the ground vibrations can be established with the help of controllable parameters. The same have been reproduced below:

1. Charge Weight	5. Burden, spacing and specific charge
2. Delay Interval	6. Coupling
3. Type of Explosive	7. Confinement
4. Direction of blast progression	8. Spatial distribution of charges

4.0 REDUCTION OF GROUND VIBRATIONS:

To protect a structure, it is necessary to minimize the ground vibrations from the blast. The acceptable techniques for reduction and control of vibrations are:

a. Reduce the charge per delay: This is the most important measure for the purpose. Charge per delay can be controlled by:

   i. Reducing the hole depth.

   ii. Using small diameter holes

   iii. Delayed initiation of deck charges in the blast holes

   iv. Using more numbers of delay detonators series

   v. Using sequential blasting machine

b. Reduce explosive confinement by:

   i. Reducing excessive burden and spacing

   ii. Removing buffers in front of the holes

   iii. Reducing stemming but not to the degree of increasing air-blast and fly rock

iv. Reducing sub-grade drilling

v. Allowing at least one free face

vi. Using decoupled charges

vii. Drilling holes parallel to the bench face

viii. Accuracy in drilling

c. Limit the explosive confinement to bedrock if the overburden can be excavated by other means.

d. Square patterns produce more vibrations

e. Limit frequency of blasting

f. Time the blasts with high ambient noise levels

g. Use controlled blasting techniques

h. Use a low VOD and low density explosive

5.0 AIR-OVERPRESSURE:

Pressure waves emanated in the atmosphere by the detonating charge is called air-overpressure/noise. The intensity of noise depends upon the quantity of the charge and its confinement. . The frequency of the pressure waves in the range of to 20 Hz. To 20 kHz are in the audible range.
The air overpressure is calculated in dB (A) or Pa.
The dB (A) is calculated by the following formula

$$dB = 20\log\left(P / P_o \right)$$

Where P is measured pressure and P_o is the reference pressure of 0.00002 Pa.
A low level of air-over pressure plays an important role in causing distress because of rattling windows. At present we don't have any standards regarding levels of air-over pressure. However, type of the damage that occurs by air-overpressure (as established by different researchers) is reproduced in Table 3.

The principle sources of air-over pressure are:

a. Detonation of unconfined charges.

b. Too short stemming or improper stemming material

c. Venting of high velocity gases through poorly designed blasts.

The techniques to control air-over pressure are:

a. Use of NONEL in place of D-cord in the blasts near the residential area.

b. Reduction in the size of the blast.

c. Avoiding top initiation.

d. Avoiding excessive delays between the rows.

e. Avoiding blasting in early morning, late afternoon and evening when temperature inversions are likely to occur.

f. Avoiding blasting when the wind is blowing towards residential area as the sound waves travel in the direction of the wind.

Table 3: Type of Damage Due to Air Over pressure

Structural Damage	Value in dB-L
Plaster Cracks	180
Loose Windows sash rattles	176
Failure of Badly Installed Window Panes	140-145
Failure of Correctly Installed Window Panes	Over 168
All Window Panes Fail	176

6.0 GEOMINING DETAILS

Jindal Power Open Cast Coal Mine is captive mine of Jindal’s 1000 MW (4 x 250 MW) thermal power plant. The block is located between Longitudes - 83°29'40" to 83°32'32" (E) and Latitude - 22°09'15" to 22°05'44" (N) falling in the topo sheet no. 64 N/12 (Survey of India). A view of Jindal Opencast mine, Tamnar, JPL and condition of the workings during October’09 at Jindal Opencast mine, Tamnar, JPL are shown in Fig 3 and 4 , respectively.

In general area of the coal block - Jindal Power Open Cast Coal Mine is almost flat with small undulations from surface the litho logical section comprises about 3-4mtr unconsolidated loose soil/alluvium. Below the top soil there is weathered shale/sandstone up to 6–8mtrs depth. The weathered shale/sand stone are competitively loose in nature and can be excavated without blasting. Below weathered mental (which varies from 3 – 10 mtr), the rock is hard, compact and massive in nature it can be excavated only after blasting. Thus the average depth of the excavation of these excavations, which can be removed, is about 6 m.

In the sub-block IV/2 & IV/3 only lower groups of Gondwana seams have been deposited. Strata are gently dipping by 2 to 5 southwesterly. The general strike of the seams in NW-SE, which is almost uniform throughout the block. Two normal faults of small magnitude have been deciphered based on the level difference of the floor of the seams, though the presence of some minor faults of less than 5 m throw cannot be overruled.

The Mand Raigarh basin is a part of IB River - Mand - Korba master basin lying within the Mahanadi graben. Sub block IV/2 & IV/3 of Gare-Pelma area is structurally undisturbed except one small fault (throw 0-15 m) trending NE-SW with westerly throws. The strike of the bed is NW-SE in general with dip varies from 2° to 6° southwesterly. The strata shows rolling dip.

Fig 3: A view of Jindal Opencast mine, Tamnar, JPL

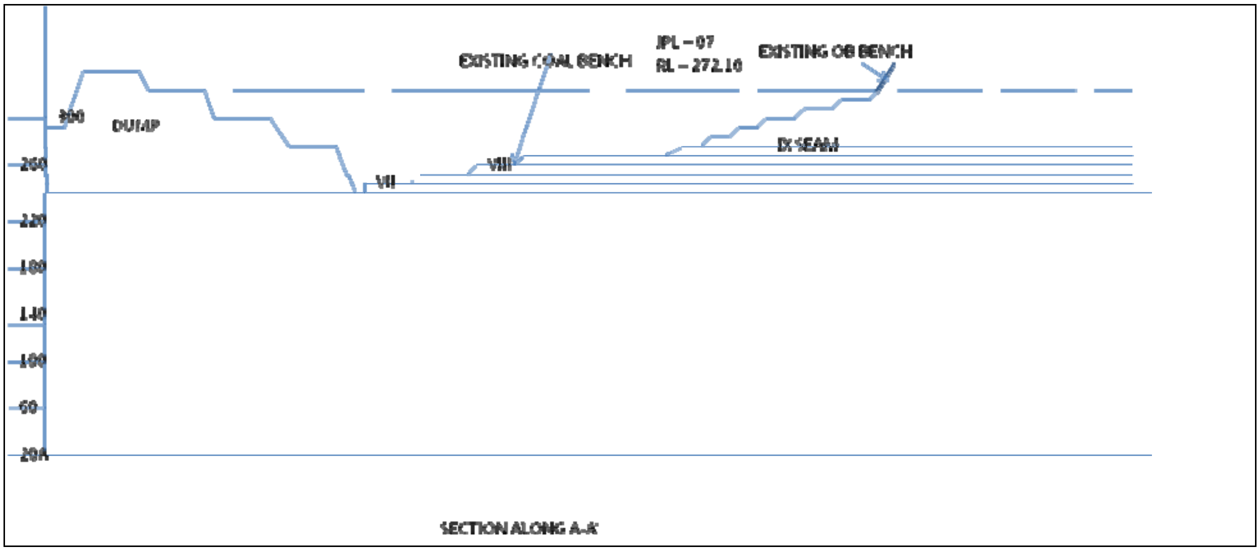

Fig 4: condition of the workings during October'09 at Jindal Opencast mine, Tamnar, JPL

6.1 BLASTING PRACTICES AT THE MINE

Open pit mining at Jindal Power Open Cast Coal Mine is being carried out with shovel dumper combinations for both overburden excavation and Coal production with the following drilling and blasting procedures.

6.1.1 Drilling

Drilling is accomplished by tyre mounted drill machine capable of drilling large diameter holes of 159 mm. The drilling pattern (Table 6) of the mine benches is based on the rock formation of the particular bench and varies with the variation in strata.

Table 6: Drilling pattern at Jindal Power Open Cast Coal Mine

Strata	2-3 m		3.5-5 m		6 m	
	Spacing	Burden	Spacing	Burden	Spacing	Burden
Shale	4	3.5	5	4	5-6	4.5-5
Hard Sand stone	3.5	3	4.5	3.5	5	4

Banded sand stone	4	3.5	5	4	6	5
Coal	5	4	6	4	7	5

The general trend is to keep the spacing between the drill holes in the range of 5 to 6 m and the burden in between 3.5 m to 4.5 m. The depth of the hole varies in the range of 2.0 m to 6.5 m. Drilling is carried out in staggered fashion.

6.1.2 Blasting

Holes were charged with Bulk Emulsion Explosives in association with Booster (Cap sensitive). The charging pattern of the hole and Exel Initiation systems is shown in Figure 1 and 5 , respectively.. For Sensitive areas -Nonel systems of initiation are used to reduce vibration and Noise. For Non Sensitive areas and for Coal Benches - Detonating Fuse with Surface Delay/relay are utilised.

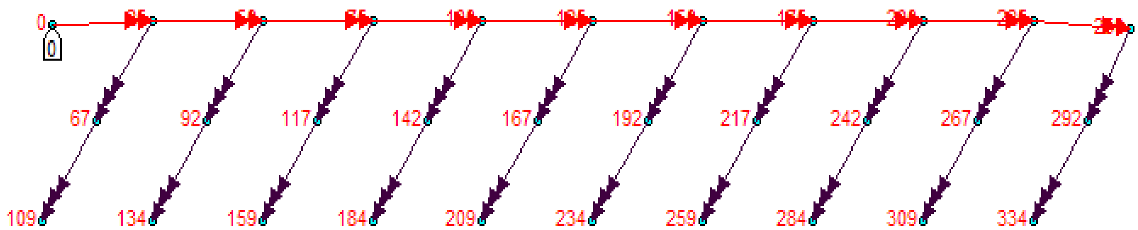

Fig 5: Initiation with Non Electric Detonators

7.0 OBSERVATIONS AND ANALYSIS OF THE GROUND VIBRATION DATA

Many blasts were monitored for estimation of suitable charge per delay for keeping the ground vibrations within the safe limits of Peak particle velocity and frequency. Blasts were monitored by the team of Blasting Experts and assisted by Blasting In charge of Jindal Power Open cast Coal Mine along with the present investigators. Damage criteria vis-à-vis Buildings / Structures NOT belonging to the owner, and Damage criteria vis-à-vis Buildings / Structures belonging to the owner are followed as per the guidelines presented in Table 1 and 2, respectively.

The blast result was assessed in terms of ground vibrations, its frequency, air over Pressure produced and Fly rock. The vibrograph was installed at a predetermined distances in the range of 100 to 350 m from blast site to the monitoring station to monitor the ground vibrations generated from blast. The Flyrock, fragmentation and muckpile tightness was assessed qualitatively using visual inspection. The Peak particle velocity (PPV) was measured for various blasts with respect to the distance from the blast site to the monitoring station including the Charge per delay for various blasts.

Details of observations including the wave pattern in a typical blast is presented in Figure 6 with the damage criteria of OSMRE/USBM indicating that the ground vibrations vis-à-vis frequency content of vibration is within the safe limit for the structures corresponding to the distance of about 150 m from the blast site. Blast Vibration study report of Jindal Power Open cast Coal Mines for a typical blast is presented in APPENDIX-A.

The ground vibration data for various blasts including Peak particle velocity (PPV), the distance from the blast site to the monitoring station; the Charge per delay for various blasts was analyzed for understanding the effect of ground vibrations induced by blasting at Jindal Power Open Cast Coal Mine. The following predictor equation in terms of the scaled distance (x) and PPV (Peak Particle Velocity) is found to represent the data, and proposed for utilization in estimation of safe explosive charge per delay to keep the vibration level within the safe limits.

$$\mathbf{PPV = 290.12\ (Scaled\ distance)^{-1.296}} \qquad \text{-----(1)}$$

Accordingly, the safe charge per delay recommended to keep the vibration level below 5 mm /sec is presented in Table 7 for the above geomining conditions of Jindal Power Opencast Coal Mine- Tamnar.

Table 7: The safe charge per delay to keep the vibration level below 5 mm/sec at various distances from the blast site

Distance of blast site from the Kosumpali village (m)	Safe Charge/Delay (kg)
100	18.9
200	75.9
300	170.8
400	303.7
500	474.5

CONCLUSIONS

Analysis of the Blast vibration data from various blasts indicated the following predictor equation-1 in terms of the scaled distance (x) and PPV (Peak Particle Velocity). Accordingly, the safe charge per delay recommended to keep the vibration level below 5 mm /sec for the above geomining conditions of Jindal Power Opencast Coal Mine- Tamnar was estimated. The safe charge/delay for a distant of 300m, 400m and 500m between the blast site and the Kosumpali Village is 170.8 kg, 303.7 kg and 474.5 kg respectively.

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Notes
Location: JOB # 0000
Client:
User Name:
Converted: April 15, 2009 14:54:05 (V8.12)

Extended Notes

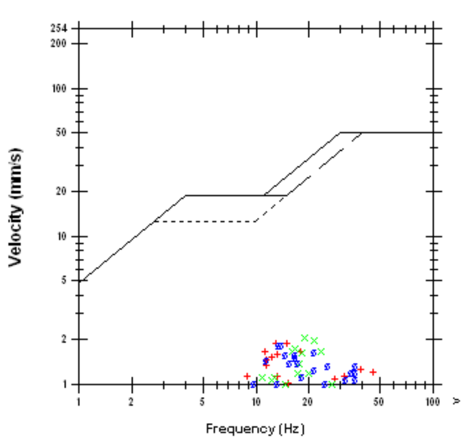
Post Event Notes

Microphone Linear Weighting
PSPL 2.00 pa.(L) at 0.191 sec
ZC Freq N/A
Channel Test Check (Freq = 0.0 Hz Amp = 36 mv)

	Tran	Vert	Long	
PPV	1.91	2.10	1.84	mm/s
PPV (Ponderated)	1.87	2.10	1.91	mm/s
PPV	56.6	57.4	56.3	dB
ZC Freq	15	19	13	Hz
Time (Rel. to Trig)	0.565	0.437	0.229	sec
Peak Acceleration	0.0464	0.0331	0.0398	g
Peak Displacement	0.0220	0.0166	0.0220	mm
Sensorcheck	Passed	Passed	Passed	
Frequency	8.0	8.0	7.8	Hz
Overswing Ratio	3.5	3.4	3.5	

Peak Vector Sum 2.54 mm/s at 0.567 sec

N/A: Not Applicable



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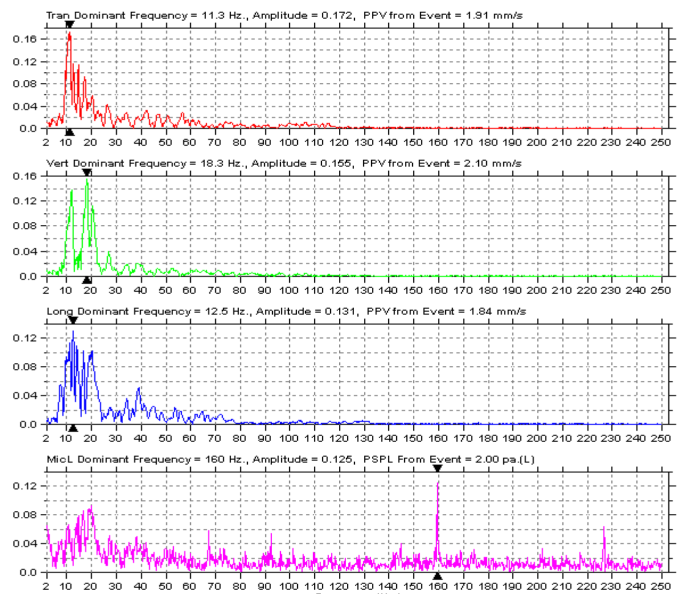

Fig 6: A typical blast vibration data

APPENDIX- 1

Blast Vibration study report

1	Date of Blast	**07/07/08**
2	Location	VIII Seam OB
3	Strata	Medium hard Sand Stone
4	No of Holes	47
5	Depth of Holes (Mtr)	4.5 to 6.0
6	Burden x Spacing (Mtr)	4.0 x 6.0
7	Diameter of Holes (Mtr)	159 mm
	Explosives Used	
8	Powergel B- 1 (SME) in Kgs	1500
9	Primex (100gm pellets) in Kgs	4.70
10	Total Explosives in Kgs	1504.70
11	**Accessories Used**	Exel (250/25MS, 42MS,65MS)
12		Electric Detonator
13	Maximum charge/ Delay (Kgs)	70
14	Volume Blasted (Cu. Mtr)	6158.0
15	Powder Factor (Cu.Mtr/Kgs)	4.10
	Post Blast Observations	
16	Blast fragmentation	Good
17	Fly Rocks	Within 20Mtr.
18	Throw	Normal
19	Muck File	Good

Distance (Mtr.)	**200**	**300**
PPV (mm/Sec)	3.75	2.35
Frequency (Hz)	23	18
Noise dB(L)	-	114