ROCK BLASTING PRACTICES AND INDUCED GROUND VIBRATIONS IN OPENCAST MINES - CASE STUDIES

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ABSTRACT

This paper presents case studies on instrumentation with accelerometers, and scientific studies conducted on ground vibrations due to blasting with various types of explosive and accessories (Cartridge, Site Mixed Emulsions, electronic detonators etc) at Dunguri limestone mine, Jindal Power Opencast Coal Mine- Tamnar, and Baphlimali Bauxite Mines under M/S Utkal Alumina International Limited, Jayanthipuram Limestone Mine, The Ramco cements Ltd to design safe blasting practices to contain the ground vibration levels below the damage criteria to protect the structures surrounding the blasting site.. To minimize/eliminate the environmental impacts of rock blasting, utmost care has to be taken to keep the charge per delay below the stipulated level. Part of the scientific studies conducted on ground vibrations induced by blasting, and to estimate safe maximum charge per delay to protect the nearby structures are presented. A number of field visits were made to collect the geotechnical data, and monitoring ground vibrations induced by blasting for above excavations. A number of blasts were monitored to study various blast parameters related to blasting Overburden and pit benches and to understand the effect of blast on the surrounding structures, and rock mass conditions at the above four excavations. Further studies with application of trans-disciplinary research including Wireless Sensor Network (WSN) and Internet of Things (IoT) is also recommended for collection of more relevant data, analysis and communication of data for better implementation of the results at mine sites.

Keywords: Mining excavations, Environmental impacts of blasting, ground vibrations, PPV, frequency, opencast mines, Sensors, Limestone, Coal

INTRODUCTION

When an explosive charge detonates, intense dynamic waves are set around the blast hole, due to sudden acceleration of the rock mass. 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 (1). 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 Compression waves,, Shear waves and Rayleigh waves. The motion of the ground particle takes in three perpendicular directions viz. vertical, longitudinal and transverse directions. 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.

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. 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 along with corresponding frequency. Detailed scientific investigations on drilling and blasting including design of safe blasts vis-à-vis ground vibrations in various mines were conducted by the first author and details illustrated elsewhere [2-7].

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 (16-19). 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 are generally followed to estimate safe charge per delay to limit the ground vibrations within safe limit in Indian geomining conditions.

Table I: 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	5	10	15
b) Industrial Building	10	20	25
c) Sensitive Structure	2	5	10

Table 2: 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	10	15	25
b) Industrial Building	15	25	50

The parameters, which exhibit control on the amplitude, frequency and duration of the ground vibration, are divided in to Non-controllable Parameters , and 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 such as Charge Weight , Delay Interval, Type of Explosive, Direction of blast progression, Burden, spacing and specific charge, Coupling, Confinement, Spatial distribution of charges etc.

INSTRUMENTATION USED FOR THE STUDIES

Minimate Blaster is used for blast monitoring at various sites in and around the mine (Fig 1). Table 3 shows details of the instrument used for the study. The Minimate Blaster is a reliable blast monitoring in a simple and economical package with advantages such as Small, rugged package for portability and easy setup, Simple menu driven operation, Easy one button, download and reporting with concerned software, Continuous monitoring etc. Further studies with application of trans-disciplinary research including Wireless Sensor Network (WSN) and Internet of Things (IoT) is also being tried under the guidance of first author for collection of more relevant data, analysis and communication of data for better implementation of the results at mine sites. Following are some more advantages of the above instrumentation:

- Integral monitoring log records time and duration of monitoring jobs.
- Auto Record™ mode allows for continuous recording as long as activity cycles about the trigger level.
- Fully compliant with the International Society of Explosives Engineers (ISEE) - Performance Specifications for Blasting Seismographs -requirements with the ISEE Linear Microphone and an ISEE Geophone (2250Hz).
- Fully compliant to the DIN 456691 Standard with optional DIN Geophone (1315Hz).

Table 3: Specifications Of The Instrument Used For The Study

Key Features	Easy to use Auto Record record stop mode Built for blasters
Channels	Microphone and Triaxial Geophone
Available Memory	30 events
Record mode	Manual and Continuous
Available sample rate	1024 to 4096 S/s per channel
Unit Dimensions	81 X 91 X160 mm
Unit weight	1.4 kg
User Interface	8 domed tactile keys
Product rank	Low cost

GEOMINING DETAILS

Scientific study was conducted on ground vibrations due to blasting at Dunguri limestone mine, Jayanthipuram Limestone Mine, The Ramco cements Ltd , ACC ltd, JPL –Tamnar Coal Mine, and UAIL Bauxite mine for estimation of explosive charge per delay for keeping the ground vibrations within the safe limits of Peak particle velocity and frequency. Details of the studies were presented in various reports of concerned mines (2-8)

Fig 1: Instrumentation for monitoring of ground vibrations due to blasting

ANALYSIS OF OBSERVATIONS

Case Study-1

The vibro-graph was installed at a predetermined distance in the range of 150 to 750 m from blast site to the monitoring station to monitor the ground vibrations generated from blast at Dunguri Lime stone mine (Fig 2). The Fly rock, fragmentation and muck pile tightness was assessed qualitatively using visual inspection. The Peak particle velocity (PPV) was measured for experimental blasts with respect to the distance from the blast site to the monitoring station with varying Charge per delay for various experimental blasts. Dominant Frequency , and Sound Pressure levels (SPL) were in the range of 2-34.3 Hz, and 100-140+, respectively (Table 4).

Table 4: Details Of Monitoring Distance, Ppv, And Frequency Of Ground Vibrations In Dunguri Mine, Acc

Distance (m)	No of holes	PPV (mm/s)	Frequency (Hz)	SPL (dBL)
500	64	L-1.33, T-0.953, V-1.59, PPV-1.62	21.5	114
150	67	L-1.65,T-2.98,V-3.24, PPV-4.16	19.8	125
300	99	L-2.54,T-2.22,V-1.91, PPV-3.52	2	100
200	15	L-2.29,T-1.14,V-1.59, PPV-2.52	2.25	100
400	80	L-1.27,T-1.46,V-1.71, PPV-2.05	11.3	134
500	40	L-0.69,T-1.33,V-0.06, PPV-1.33	24	126
600	96	L-0.76,T-0.69,V-0.63, PPV-0.873	25.3	116
750	55	L-0.127,T-.127,V-0.063,PPV-0.191	18.3	110
150	130	L-4.95,T-6.60,V-8.13, PPV-8.60	2.25	140+
500	58	L-0.572,T-2.98,V-1.08,PPV-3.10	34.3	130
150	63	L-4.45,T-5.46,V-0.953,PPV-6.10	17.8	140+

Ground vibration monitoring stations with various experimental blasts in the above mine were located during the investigations at a distance of 150 to 750 m from the blast site. Experimental blasts were conducted with explosive charge per delay in the range of 30 to 55 kg, and total number of holes per blast was in the range of 15 to 130. At 750 m distance from the blast site, maximum PPV observed was about 0.191 mm/s, while maximum PPV recorded for a distance of 150 m was 8.6 mm/sec. Maximum PPV observed at a distance of 200 m to 500 m was within the range of 2.52 to 1.33 mm/sec. Observations shows that explosive charge of 50 kg per delay would induce PPV less than 5 mm/sec beyond 200 m distance from the blast site with the present blasting practice in the mine.To predict the safe charge per delay for reducing the damage potential for various distances from the blast site, regression analysis was done. Fig 3 shows the event report of typical balst and result of regression analysis for estimation of safe charge per delay to contain the ground vibrations within safe limits. In majority of the observations, the maximum air over pressure recorded was within 140 dBA, which is within the safe limits. The dominant frequency of ground vibration in the range of 2 to 34.3 Hz for distances from 150 m to 750 m in the experimental trials. Since the structures with normal civil construction may have a natural frequency of about 20 Hz, it is suggested to meticulously design the blasts with explosive charges considering both PPV and frequency content.

Fig 2: A view of blasting in trial blast at Dunguri mine, ACC (Case study-1)

Predictor equation in terms of the scaled distance (x) and PPV (Peak particle velocity) developed to represent the data for utilization in estimation of safe explosive charge per delay to keep the vibration level within the safe limits is as in Eq.1.

$$PPV = 489.21(\text{Scaled distance})^{-1.4} \quad (\text{Eq.1})$$

Since the PPV levels were within safe limits of damage level criteria (< 5 mm/sec) for any type of structures other than sensitive structures, the blasting pattern may be followed with the respective explosive charge per delay as shown in Table 5 for containing the PPV of ground vibration within damage limit for various distances from the blast site.

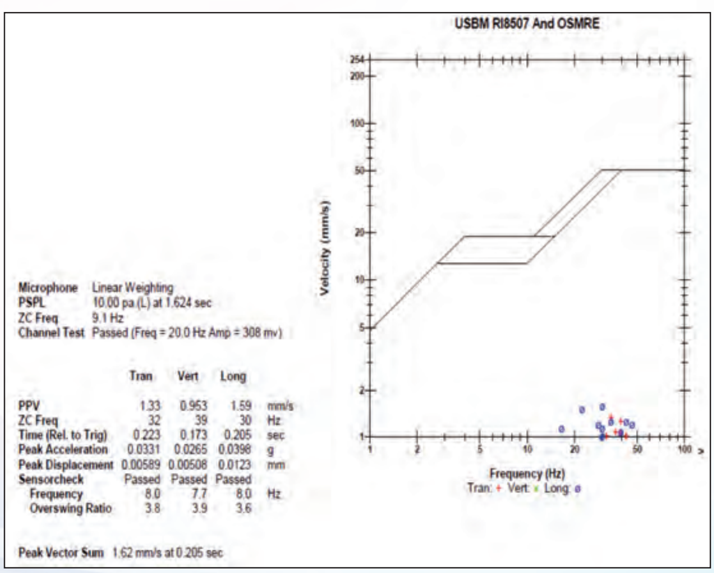


Fig 3: Event Report of a typical Blast at Dunguri mine, ACC

Table 5: Estimation Of Charge Per Delay (Kg) For Containing Ppv Within 5mm/Sec

Distance	Charge per delay (Kg) for containing PPV within 5mm/sec
100	14
150	32
200	57
250	90
300	129
350	176
400	229
450	290
500	358

Case Study-2

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. 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 4 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 Table-6. 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 (Eq.2) 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.

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 -6: Blast Vibration study report –Case study-2

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

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

Case Study-3

Details of monitoring distance, PPV, and frequency of ground vibrations etc for a typical experimental blast are shown in Table 8. Emulsion matrix is observed to be a non explosive material having density of 1.40 g/cm3. NONEL system was used for initiation with accessories TWINDET-17/125 ms, TLD – 25 ms etc. Maximum charge/delay was in the range of 35 – 50 kg in the trial blasts. EMULBOOST manufactured by M/s IDL of 125 g cartridge weight was used as booster charge. The density of SME emulsion matrix is reduced by chemical gassing and below 1.30 g/cm3 detonation was observed. The density change on rate of gassing of matrix was also measured in the field conditions. Detailed measurement of density of the emulsion mixture supplied by M/s Keltech Energies Ltd at the study site without gassing was 1.4 g/cc which are found to be non-explosive. The density was 1.3 g/cc with gassing reduced to a minimum of 1.04 g/cc even after 4 hours of gassing.

The blast result was also 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 110 to 175 m from blast site to the monitoring station to monitor the ground vibrations generated from blast. The Fly rock, fragmentation and muck pile tightness was assessed qualitatively using visual inspection. The Peak particle velocity (PPV) was measured for experimental blasts with respect to the distance from the blast site to the monitoring station with varying Charge per delay for various experimental blasts. The maximum air over pressure recorded was within 80 dB (L), which is within the safe limits. The blasting operation produced PPV less than 15 mm/sec, which is within safe limit for the industrial structures belonging to the owner in the frequency range of <8 Hz and 8-25 Hz for distances up to 110 m to 175 m.

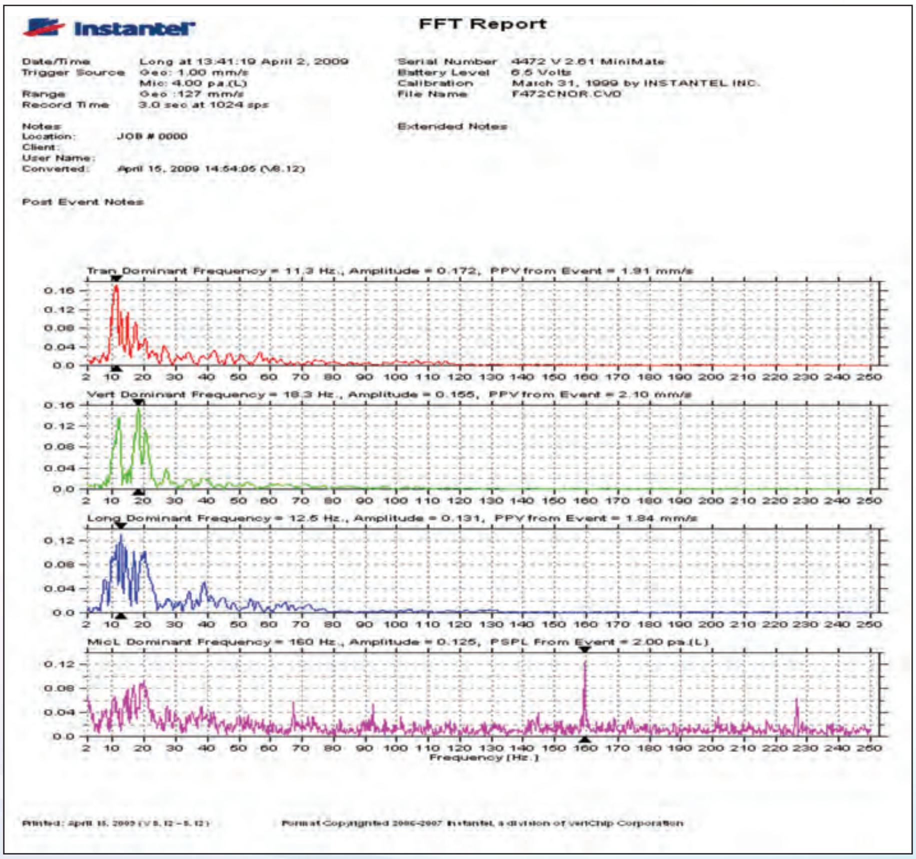


Fig 4: Wave pattern in a typical blast vibration data-Case study-2

Table 8: Details Of Trial Blasts – Case Study-3

Sl no	Particulars	FACE 1	FACE 2
1	Location of Blast	2nd Bench/RL 1025	1st Bench/RL 1030
2	Type of Strata	HARD	HARD
3	ORE/OB	BAUXITE	OVER BURDEN
4	Hole Dia in mm	160	160
5	Drill hole Pattern	STAGGERED	STAGGERED
6	Depth of the hole in m	8	6
a	Burden in m	4	3.5
b	Spacing in m	5	4.5
c	Total no of holes blasted	57	152
7	No of rows	4	4
8	Max Charge per hole in Kg	80	55
9	Max Charge per Delay in Kg	80	110
10	Fly Rock distance in m	15	16
11	Misfire if any	NO	NO
12	smoke if any	NO	NO
13	PPV mm/sec	5.55	12.5
14	Frequency in Hz	6.1	13.5
15	Distance from Observation Station to Blasting site in m	150	125
16	Total quantity of SME used in Kg	4500	7810
17	Total quantity of Emul Boost used in kg	14.250	35.750
18	Total quantity of Explosive used in kg	4514.250	7845.750
19	Percentage of Booster used	0.4	0.4
20	Type of detonators used	Nonel Initiation	
21	Stemming Material used	DRILL CUT	DRILL CUT
22	Fragmentation	Good	Good
23	Throw	As desired	As desired

The ground vibration data including Peak particle velocity (PPV), the distance from the blast site to the monitoring station; the explosive Charge per delay for various blasts was analyzed for understanding the effect of ground vibrations induced by blasting at Baphlimali Open Cast bauxite Mine. The following predictor equation (Eq.3) 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

$$\textbf{PPV} = 19.681\ (\text{Scaled distance})^{-0.427}\ \textbf{(Eq.3)}$$

Case Study-4

Nineteen Trial blasts were conducted during August to December 2019 at Jayanthipuram Mines of The Ramco cements Ltd (8). Salient observations of monitoring of ground vibrations during recent experimental blasts in December 2019 are shown in Table 9. Fig 5, and 6 shows monitoring of blasting operations with Minimate instrument, and the status of structures surrounding the Jayanthipuram village near Jayanthipuram mine site, respectively. Fig 7 represents a typical report related to ground vibrations generated by experimental Blasts at the mine site. The blast result was also assessed in terms of ground vibrations, its frequency, air over Pressure produced and Fly rock. The vibro-graph was installed at a predetermined distance in the range of 100 to 350 m from blast site to the monitoring station to monitor the ground vibrations generated from blast. The Fly rock, fragmentation and muck pile tightness was assessed qualitatively using visual inspection. The Peak particle velocity (PPV) was measured for experimental blasts with respect to the distance from the blast site to the monitoring station with varying Charge per delay for various experimental blasts. Air Overpressures measured in the above trial blasts was in the range of 114 to 131 dB, which is within the damage limits of any structures. Fly rock observed was in the range of about 7 to 9 m and in almost all blasts it was within 50 m from the blast site, without causing any concern for the safety of the structures. Powder factor obtained for various experimental blasts with above parameters was in the range of 5.4 to 6. 8 tons per kg of explosive. Total explosive charge during the above experimental blasts was in the range of 1300 to 2800 kg. Table 8 shows Details of monitoring distance, PPV, and frequency of ground vibrations in Jayanthipuram Limestone Mine, The Ramco cements Ltd considered for analysis.

Fig 5: Monitoring of blasting operations with Minimate instrument at Jayanthipuram mine

Table 7: Ground vibration parameters related to experimental blasting at Jayanthipuram Limestone Mine during December 2019

Sl No	Date	PPV(mm/sec)	Instrument Distance	Maximum Charge/Delay(Kgs)
15	3/12/2019	2.19	250	120
16	5/12/2019	1.33	320	150
17	20/12/2019	4.87	320	236
18	21/12/2019	3.89	310	175
19	24/12/2019	2.64	320	87.50

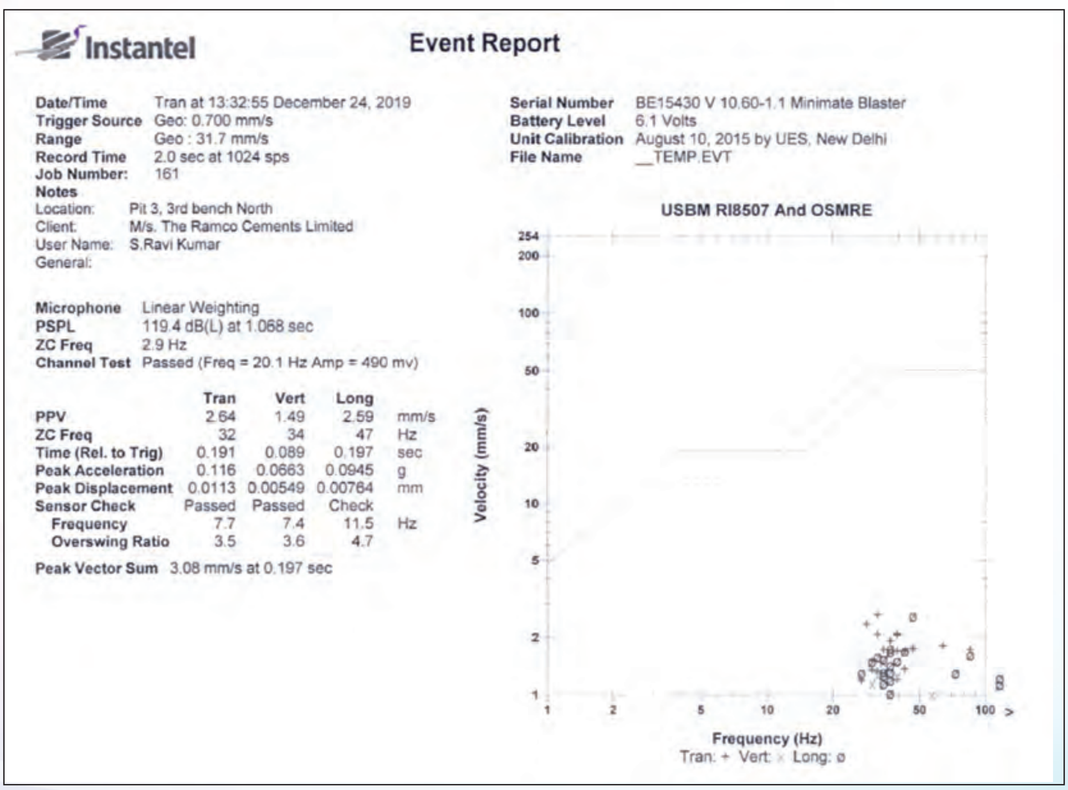
In majority of the observations, the maximum air over pressure recorded was about 131 dBA, which is within the safe limits. The dominant frequency of ground vibration in the range of 7.9 to 37 Hz for distances from 100 m to 300 m in the experimental trials. Since the structures with normal civil construction may have a natural frequency of about 20 Hz, it is suggested to meticulously design the blasts with explosive charges considering both PPV and frequency content.

Predictor equation in terms of the scaled distance (x) and PPV (Peak particle velocity) developed to represent the data for utilization in estimation of safe explosive charge per delay to keep the vibration level within the safe limits for Jayanthipuram Mines of Ramco Cement Ltd is as in Eq.4.

$$\textbf{PPV} = 368.1\ (\textbf{Scaled distance})^{-1.51} \quad (\textbf{Eq.4})$$

In majority of the blasts, the dominant frequency is above 8 Hz, and hence Damage criteria vis-à-vis Buildings / Structures not belonging to the owner was considered for design of safe blast in the above geomining condition to contain the vibration levels within PPV of 10 mm/secs. Fig 11 shows Typical Structures at the Jayanthipuram village located at about 200 to 600 m from Jayanthipuram Lime mine. Since the PPV levels were within safe limits of damage level criteria (< 10 mm/sec) for any type of structures other than sensitive structures, the blasting pattern may be followed with the respective explosive charge per delay as shown in Table 9 for containing the PPV of ground vibration within damage limit for various distances from the blast site.

Fig 6: Typical Structures at the Jayanthipuram village located near Jayanthipuram Limestone mine-Ramco cements Ltd



Instantel

Event Report

Date/Time Tran at 13:32:55 December 24, 2019
Trigger Source Geo: 0.700 mm/s
Range Geo : 31.7 mm/s
Record Time 2.0 sec at 1024 sps
Job Number: 161
Notes
Location: Pit 3, 3rd bench North
Client: M/s. The Ramco Cements Limited
User Name: S.Ravi Kumar
General:

Serial Number BE15430 V 10.60-1.1 Minimate Blaster
Battery Level 6.1 Volts
Unit Calibration August 10, 2015 by UES, New Delhi
File Name __TEMP.EVT

Microphone Linear Weighting
PSPL 119.4 dB(L) at 1.068 sec
ZC Freq 2.9 Hz
Channel Test Passed (Freq = 20.1 Hz Amp = 490 mv)

	Tran	Vert	Long	
PPV	2.64	1.49	2.59	mm/s
ZC Freq	32	34	47	Hz
Time (Rel. to Trig)	0.191	0.089	0.197	sec
Peak Acceleration	0.116	0.0663	0.0945	g
Peak Displacement	0.0113	0.00549	0.00764	mm
Sensor Check	Passed	Passed	Check	
Frequency	7.7	7.4	11.5	Hz
Overswing Ratio	3.5	3.6	4.7	

Peak Vector Sum 3.08 mm/s at 0.197 sec

Fig 7 : Event Report of Blast on 24.12.19 at Jayanthipuram Limestone Mines

CONCLUSIONS

On the basis of the scientific experimental study conducted with various instrumentation for understanding of behaviour of ground vibrations induced by blasting with various types of explosive and accessories (Cartridge, Site Mixed Emulsions, electronic detonators etc) of benches in four mines, following are the conclusions and recommendations for protection of surface structures and safe design of blasting in respective opencast mines:

1. In Dunguri open cast limestone mine, ACC, it is recommended to use less than 358 kg as explosive charge per delay to contain the ground vibration level below 5 mm/sec beyond the distance of 500 m. Blasting operation with blasting parameters; 4.0 – 5.0 m spacing, and 2.5 – 3.5 m burden for bench heights of 10 m was observed to be safe with Aquadyne explosive of 50 kg of charge per delay beyond 200 m distance from the blast site. The dominant frequency of ground vibration in the range of 2 to 34.3 Hz for distances from 150 m to 750 m in the experimental trials.

2. 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 was recommended to keep the vibration level below 5 mm/sec for the above geomining conditions of Jindal Power Opencast Coal Mine-Tamnar.

3. At UAIL Mines, blasting operation with bench heights of 5.5 – 8.0 m was observed to be safe and productive with powder factor of 2.41 to 4.22 ton/kg of explosive with 520 kg of SME charge per delay, and 80 kg of SME charge per hole with 3.5- 4.5 m spacing, and 2.5 – 3.5 m burden. Emulsion matrix is a non explosive material having density of 1.40 g/cm3. The density of emulsion matrix is reduced by chemical gassing and for density below 1.30 g/cm3 detonation was observed. The density was 1.3 g/cc with gassing, and reduced to a minimum of 1.04 g/cc even after 4 hours of gassing. Ground vibration levels and air overpressures were within the safe limits for a distance beyond 110 m from the blast site with good fragmentation, muck profile, and acceptable fly rock.

4. During studies from August to December, 2019 for blasting of benches in Jayanthipuram Limestone Mine, The Ramco cements Ltd , Blasting operation with blasting parameters; 4.0 – 5.0 m spacing, and 3.0 – 3.5 m burden for bench heights of 9 m was observed to be safe with ANFO explosive of about 9.3 to 236 kg of charge per delay beyond 100 m distance from the blast site. The dominant frequency of ground vibration in the range of 7.9 to 37 Hz for distances from 100 m to 350 m in the experimental trials. Air overpressures were observed to be within damage limits for the above blasting practices.

On the whole, it is recommended to use respective explosive charge per delay to contain the vibration levels as per the damage criteria for various distances from the blast site in the above four mines. To improve the economics of blasting operations, air deck blasting may be followed with detailed studies on costs of drilling, explosives, blasting, mucking, transportation, crushing etc. for the opencast mine. Further studies with application of trans-disciplinary research including Wireless Sensor Network (WSN) and Internet of Things (IoT) is also recommended for collection of more relevant data, analysis and communication of data for better implementation of the results at mine sites.

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