Strategic planning to reduce ground vibration, air overpressure and flyrock in a mine at a sensitive area

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Strategic planning and execution at the Benti–Bagda Limestone Mine of M/s Jharkhand State Mineral Development Corporation Limited (JSMDCL), India, could minimize the impacts of surface blasting on structures in nearby sensitive villages to comply with the regulatory requirements leading to resolving the complaints of villagers. Controlled blast design patterns were developed after thorough scientific evaluations using JKSimBlast simulator and blast-compliance software modules to determine the firing pattern, firing sequence and detonation time versus charge mass (kg) detonated for each of the three blast-safety zones. The study enabled the mine management to convince the local people to settle their long-pending disputes.

Keywords: Air overpressure, dominant frequency, flyrock, ground vibration, strategic planning.

WHEN an explosive is detonated inside blastholes, only 15–20% of the total energy generated is estimated to be used for actual rock breakage and the rest 80–85% is wasted in the form of ground vibration, air overpressure/noise and flyrock, among others. These are the main environmental impacts resulting in surface blasting operations. It is revealed that human beings are more sensitive to vibrations, air overpressure/noise, dust and fume than structural damage. In recent years, in India, human response to blast-induced vibrations, flyrock, air blast, dust and fume has been identified as an important feature of any successful mining operation. Numerous complaints due to unoptimized blasts led to many grave unsavoury situations, as a result of which the majority of the mines were either running in loss or were approaching closure. Keeping in mind such unpleasant acts posed by unoptimized blasts, a meticulously framed strategic planning was implemented to successfully evaluate the blast-design parameters to deal with complaints from the neighbouring villages.

Experimental blasts were conducted following strategic planning, like optimization of blast dimension, delay connections, delay optimization, blast sequence, etc., at different mine quarries using varying blast designs and charging patterns. Blast impacts like ground vibration and air overpressure/noise were monitored at various locations within a village near the foundation of various structures and on compacted soil of the approach road of the village in the direction of the structures and behind the free faces of the blasts. Flyrock was observed using digital video cameras. The recorded data were analysed using sophisticated software, which ultimately helped determine the controlled blast design parameters to carry out day-to-day safe blasting operations in the mine. This open-handed approach satisfied the villagers in getting their full support during blasting operations. It also became helpful to the mine owners of other areas for successful mining operations in nearby sensitive regions.

Description of the mine site

The Benti–Bagda Limestone Mine (23°34′55″–23°35′16″N lat. and 85°15′00″E long.) in Ranchi district, Jharkhand, India, consists of five quarries, viz. nos 1–5. The Benti and Bagda villages are located in close proximity to these quarries and the villages have repeatedly raised protests against mining activities with regard to structural damage and blast annoyance. The situation, therefore, necessitated controlled blasting operations for the safe extraction of limestone without compromising the village structures and human annoyance.

The predominant rock type is the Chotanagpur granite gneiss within which bands and enclaves of mica schist, felspathized mica schist, quartzite, calc-silicate rock epidionite, phyllites, etc. occur. Several bands and lenses of metamorphosed and crystalline limestone extend in a belt from Ramgarh westward up to Daltonganj. The area under the limestone mine lies in the above-mentioned belt.

The limestone deposits of the mine, interbanded with phyllites, occur as discontinuous longitudinal bands of 0.5–4.0 m thickness with parting bands varying from 0.5 to 3.0 m thickness. The occurrence of chlorite and dericite is frequent in the limestone of this area and the rock has a phyllitic sheen with well-developed cleavage parallel to the bedding planes. The associated rocks are calc-silicate, amphibolites and ferruginous quartzite. The hardness of

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Table 1. Strategic planning of the work elements

Action no.	Work plan
1	Inspection of rock types in all the quarries (Q1–Q5), understanding their bands, discontinuities and sequence.
2	Assessment of blast design parameters which include initiation schemes; explosive brand and type, strength, density and velocity of detonation.
3	Review of specific charge factor (kg/m^3), degree of fragmentation, displacement and swelling desired. Appraisal of available machinery like drill machine, shovel, dumper, etc.
4	Identification of nearby villages and their minimum distances from all the quarries.
5	Conduction of test blasts and measurements of ground vibration, air overpressure, flyrock, overbreak and charge factor.
6	Rectification of design parameters, charge loading parameters, initiation sequence and blast size.
7	Execution of the second set of trials with modified parameters.
8	Analysis of data using Blastware v10.7 and JKSimBlast v3 for advanced bench blast design and basic analysis.
9	Public hearing and explanation of blast impacts and safety measures to the villagers.
10	Demarcation of three blasting zones.
11	Developing optimum and safe blast design patterns for all the three zones and hands-on training to the blasting personnel for effective implementation of design parameters.

Table 2. Ranges of charge factor for bench blasting in surface mines[4]

Rock type	Charge factor (kg/m^3)
Highly fissured rocks, weathered or soft	0.10–0.30
Medium-strength rock	0.30–0.60
Massive and high-strength rock	0.60–1.50

the limestone is 3.5 and *in situ* density is 2.7 t/m^3. The limestone is medium- to coarse-grained and grey in colour. The limestone zones of the deposits are trending differently but dipping 65° northward.

Basic blast design parameters

In strategic planning, it is required to follow a systematic approach to understand the parameters having the most significant influence on the rock breakage process (Table 1). These parameters are of two categories, namely uncontrollable and controllable. The uncontrollable parameters include the geology and nature of the rock deposits comprising rock and rock mass properties such as lithology, joint spacing, dip, dip-direction, stress field, water content and different physico-mechanical properties[1]. The controllable factors are the basic blast design parameters, including explosive properties. A brief description of some parameters is given below:

(i) Bench height: Its selection depends on the thickness of the formation and drilling and loading equipment to be deployed.

(ii) Blasthole diameter: The choice of blasthole diameter depends mainly on the required fragmentation size.

(iii) Blasthole depth: The required blasthole depth depends on the bench height, inclination of the hole and subgrade drilling.

(iv) Burden and spacing: Burden is the minimum distance from the axis of a blasthole to the face of the excavation, whereas spacing denotes the lateral distance between consecutive blastholes in the same row. Burden generally varies between 25 and 40 times the hole diameter, while spacing varies between 1.2 and 2.0 times the burden.

The two most commonly used equations for the calculation of burden are as follows[2,3]

$$B=\left[\frac{2\rho_{\mathrm{e}}}{\rho_{\mathrm{r}}}+1.5\right]\times D_{\mathrm{e}}, \tag{1}$$

where B is the burden (ft), ρ_{e} the specific gravity of the explosive, ρ_{r} the specific gravity of the rock and D_{e} is the diameter of the explosive (inch) (for bulk explosives, it is the diameter of the drill hole).

$$B=H\left[\frac{D_{\mathrm{e}}}{D_{\mathrm{h}}}\right]\cdot\left[\frac{5.93}{\mathrm{RQD}}\right]+(0.37)\sqrt{(L/C)}, \tag{2}$$

where B is the burden (m), H the bench height (m), D_{e} the diameter of the explosive (mm), D_{h} the diameter of the blasthole (mm), RQD the rock quality designation; L the loading density of the explosive (kg/m) and C the charge factor (kg/m^3) or the inverse of the powder factor (m^3/kg).

(v) Charge factor: The quantity of explosive (kg) required to fragment one cubic metre of rock is known as the charge factor (kg/m^3) or specific charge. The charge factor rises as the blasthole diameter, rock strength, fragmentation, displacement and desired swelling increase. Table 2 gives a wide range of charge factors for different rock types in case of surface bench blasting[4].

Blast-induced ground vibration

Detonation of explosive charge inside a blasthole creates two types of useful energy components – shock energy and gas energy. The partitioning of gas and shock energy depends on the explosive, its suitability for a particular application and the surrounding rocks. On detonation, hot gas is produced at intense pressure and a steep wavefront travels into the rock, which depending upon the resistance of the rock, crushes roughly 2–4 times the radius of the original blasthole. Within this (zone 1), the rock behaves hydrologically (Figure 1, ref. 5). The borehole pressure spontaneously loads the surrounding rocks and generates a compressive shock pulse that rapidly moves away from the borehole at a velocity that may initially exceed the sonic velocity of the rock. The expanding gases (gas energy) continue to work on the rock, extending the cracks and moving the rock upwards and outwards. This activity takes place in the zone of intended work on the rock, breaking it and moving it forward for excavation.

Beyond the fracture zone, the pulse travels as an elastic wave until it reaches the free face, where it is reflected as a tensile wave. The amount of energy transferred to a given rock is a linear function of the product of density and the rate of detonation, commonly known as characteristic impedance.

Beyond the fractured zone, seismic waves travel in all directions and give rise to the particles of the medium in motion called vibration. At any instant of time, the velocity of a particle during vibration disturbance is called particle velocity. The maximum velocity from the position of rest (zero motion) is the peak particle velocity (PPV). This has been traditionally used as a means to establish the degree of blast damage. Unfortunately, most explosives are detonated as a series of smaller explosions which are delayed by milliseconds, and differences in travel paths and delay times result in overlapping arrival of both wavefronts and wave types[3].

Factors affecting vibration intensity and characteristics

The intensity and characteristics of ground vibration generated from a blasting source depend upon different parameters such as local geology, charge weight per delay, distance from the blasting source (the central point of a multiple hole blasting), delay period, spatial distribution of explosive charge, confinement and type of explosive.

Local geology has a major influence on the intensity and characteristics of ground vibration. The frequency of seismic waves produced from blasting mainly depends on the nature of the transmitting medium and distance of the measuring point. If geological formation of the rock strata is massive with shallow soil cover or if the strata consist of hard and soft formations or if the topsoil is black cotton, the blast vibration will be characterized by relatively low frequencies. However, if the propagating medium comprises a deep covering of soil and jointed rock formations, the vibration will be characterized by relatively high frequencies and larger displacement. Also, with increasing distance, high-frequency waves attenuate and only low-frequency waves can travel over a larger distance. The magnitude of ground vibration decreases with an increase in distance of observation from the blasting source and vice versa.

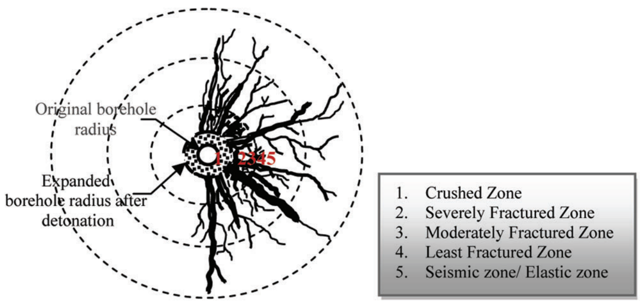

Figure 1. Different zones of rock deformation around a blasthole[5].

In a blast where multiple detonators are used, the maximum charge per delay has the most significant direct influence on vibration intensity and not the total charge used for the blast, as long as the delay interval is adequate to avoid constructive interferences between the waves generated by different groups of holes connected with the same number of delays[4]. A delay interval of 8 ms had been suggested by researchers to eliminate the constructive interferences of different seismic waves generated from blasting[6,7]. For the same charge weight per delay, vibrations produced from a single large hole diameter would be more than those generated from a larger number of holes with a smaller diameter due to the spatial distribution of explosive charge, which results in the geometrical spreading of explosive energy[7].

The cases, viz. confinement of explosive charges such as more burden and spacing, deeply buried charge (excessive stemming length) and the presence of blasted material at the face (choked face) generally increase the level of ground vibration. Explosives having low borehole pressure also produce low vibration than those of high-strength explosives with more detonation pressure.

Ground vibration and air overpressure standards followed in India

PPV is mainly used to evaluate the blast damage criteria for different types of structures. Table 3 gives the prescribed limits of the Directorate General of Mines Safety (DGMS), Government of India (GoI), on ground vibrations for different types of structures depending upon the frequency of blast waves[8]. The Bureau of Indian Standards has also prescribed a separate vibration standard, generally applicable to normal structures like buildings, elevated structures, bridges, retaining walls, concrete and masonry dams constructed using materials like brick walls, stone masonry and concrete[9] (Table 4). Table 5 gives the typical air overpressure limits given by Oriard[10] for surface mine blasting.

Field investigations

Experimental blasts

Experimental blasts were conducted at different mine quarries by varying the charge loading parameters and

Table 3. Ground vibration limits (mm/s) prescribed by Directorate General of Mines Safety (DGMS), Government of India[8]

Type of structure	Dominant excitation frequency (Hz) < 8	8–25	>25
Buildings/structures not belonging to the mine owner			
Domestic houses/structures (Kuchcha, brick and cement)	5	10	15
Industrial buildings	10	20	25
Objects of historical importance and sensitive structures	2	5	10
Buildings/structures with limited life span and belonging to the mine owner			
Domestic houses/structures	10	15	25
Industrial buildings	15	25	50

Table 4. Bureau of Indian Standards prescribed damage criteria[9]

Type of rock/soil	PPV (mm/s)
Soil, weathered or soft rock conditions	70
Hard rock conditions	100

Table 5. Typical air overpressure (AOP) criteria[10]

Type of breakage	AOP dB(L)
General window breakage	171
Occasional window breakage	151
Long-term history of application as a safe project specification	140
Bureau of Mines recommendation following a study of large-scale surface mine blasting	134

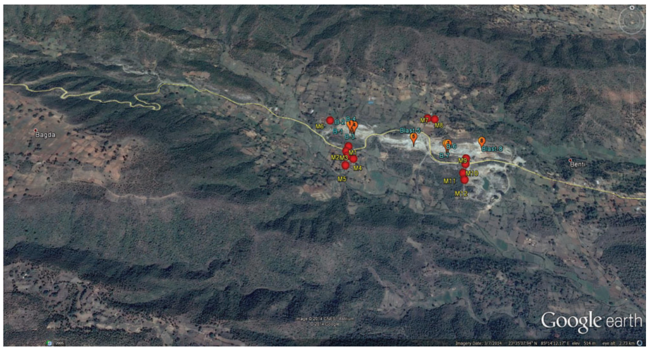

Figure 2. Google Earth view of the trial blasts and monitoring stations.

Figure 3. View of explosive charging of holes with Handydet 400/25 ms delays.

Figure 4. Near a house in Benti village, Ranchi district in Jharkhand (216 m from B-2).

using JkSimBlast-simulated design patterns. Out of the eight trial blasts, one each was conducted at quarry nos 1 and 3, two at quarry no. 2 and four blasts were conducted at quarry no. 5. Figure 2 is a Google Earth image providing a complete view of the mine along with surrounding villages showing locations of the trial blasts and the concerned ground vibration monitoring points.

The depth of holes varied from 3.5 to 5.2 m using a blasthole diameter of 100 mm. The average burden and spacing were 2.0 m and 2.5 m respectively, in all the blasts. Holes were drilled in staggered patterns. The total number of holes in all the trial blasts was five, drilled in one or two rows. Cartridge diameter was 83 mm, with each cartridge weighing 2.78 kg. All the holes were charged with the shock tube (Nonel) initiation system of Handydet 400/25 ms (Figure 3). All the holes were stemmed properly using a tamping rod. They were then connected for firing using the Handydet 400/25 ms detonators. The top stemming column in all the holes varied between 2.5 and 2.8 m, while the explosive charge per hole varied between 8.34 and 18.07 kg. The total explosive charge in the blasting round varied from 41.70 to 90.35 kg in all the blasts, whereas the maximum explosive charge per delay varied between 8.34 and 19.46 kg.

Monitoring of ground vibration and air overpressure

Six seismographs were used to measure the ground vibration and air over pressure levels at different locations. In the first four trial blasts, i.e. B1–B4 at quarry no. 5, five seismographs were placed adjacent to the concerned residential and other important structures in Benti village at the back of the free faces of the blasts (Figures 4 and 5). For the remaining four trial blasts, i.e. B5–B8 at quarry nos 3, 2 and 1, four seismographs were placed at the back of the free faces of blasts in quarry nos 2 and 3, behind the OB dump of the mine (Figures 6 and 7), whereas two seismographs were placed near two structures of Benti village, situated on the other side of the mine. The distance of the monitoring stations from the blasting sites varied between 100 and 315 m.

Figure 5. Near a school in Benti village (170 m from B-3).

Figure 6. Near another school of Benti village (170 m from B-5).

Figure 7. Near the road connecting Benti village and Bagda villages (100 m from B-7).

Results of ground vibration, air overpressure and flyrock

In all, 29 ground vibration data were recorded in and around Benti village. No ground vibration data could be recorded at 19 instances where the triggering level of the seismograph was set as 0.5 mm/s.

The magnitude of ground vibration measured at different locations varied between 0.622 and 3.40 mm/s. The highest magnitude of ground vibration recorded was 3.40 mm/s at a distance of 107 m from the blasting face on the compactted ground near the approach road of the village. The maximum explosive charge per delay was 19.46 kg and the total explosive charge fired in the blasting round was 90.35 kg. The highest magnitude of ground vibration recorded in Benti village was 2.56 mm/s, with a dominant peak frequency of 20.6 Hz. This was recorded from B2 at quarry no. 5. The monitoring point was 103 m away from the blasting face, the maximum charge per delay was 12.51 kg and the total explosive charge fired in the blasting round was 62.55 kg.

Table 6. Air overpressure recorded at different locations of the mine

Blast no.	Total charge (kg)	Maximum charge/ delay (kg)	Distance (m)	AOP dB(L)
B-1	62.55	12.51	105	105.5
			135	109.5
			160	109.5
			177	106.0
			218	106.0
			122	118.3
B-2	62.55	12.51	103	109.5
			133	106.5
			158	109.5
			173	107.5
			216	100.0
			130	113.1
B-3	41.70	8.34	100	106.0
			132	105.5
			156	106.0
			170	104.9
			140	110.2
B-4	41.70	8.34	100	91.5
B-5	54.21	12.51	274	103.5
			280	106.0
B-6	90.35	19.46	107	106.0
			120	109.5
			150	103.5
			184	106.0
B-7	90.35	19.46	100	109.9
			112	109.5
			145	101.9
			180	106.0
B-8	90.35	18.07	113	112.6

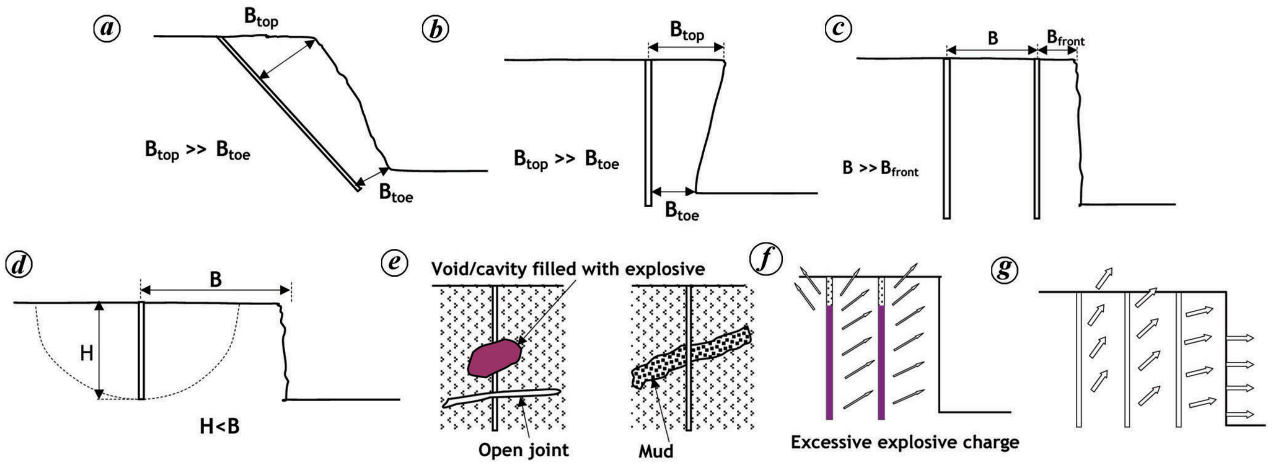

Figure 8. Common causes of flyrock in surface bench blasting. ***a***, Incline hole causing less toe burden. ***b***, Under-confined at the toe. ***c***, Too less front burden. ***d***, Too large front burden. ***e***, Cavity, open joint and mud seam. ***f***, Excessive charge and very small top stemming. ***g***, Inadequate delay timing (back rows).

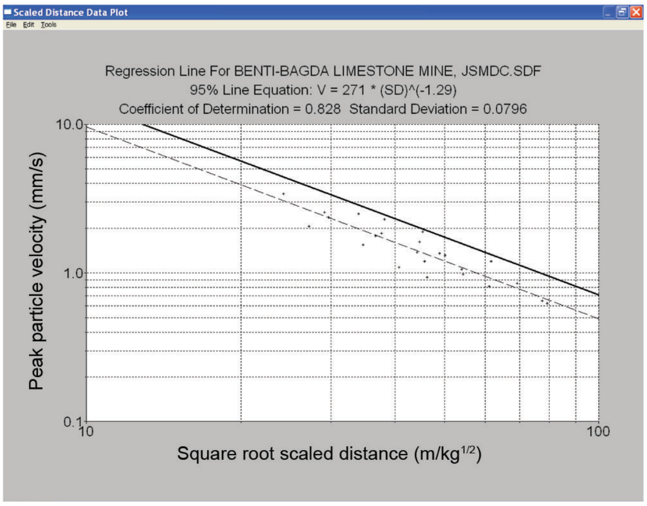

Figure 9. Regression plot of vibration at different locations of Benti–Bagda Limestone Mine, JSMDC Limited, Jharkhand.

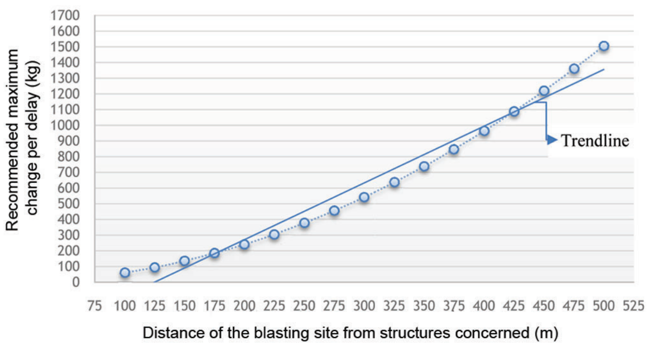

Figure 10. Safe maximum charge per delay to be fired in a round of blast.

The overall dominant frequency of vibration varied widely between 12.0 and 72.6 Hz, while the fast Fourier transform (FFT) analyses revealed that in majority of the blasts, the maximum concentration of dominant energy ranged between 12 and 40 Hz.

It was further observed that most of the residential structures/houses in Benti village were made of bricks and mud (kuchcha houses). Table 3 gives the ground vibration standards prescribed by DGMS; GoI. Therefore, based on the dominant excitation frequencies of the ground vibration, the threshold value of PPV was taken as 10 mm/s, following the regulatory guidelines.

Air overpressure is formed either by the direct action of the explosion products from an unconfined explosive in the air, or by the direction of a confining material subjected to blast loading. The maximum excess pressure in this wave is known as the peak air overpressure, generally measured in decibels (dB) using linear frequency-weighting (L). Table 6 gives the air overpressure levels recorded from different blasts, which varied between 91.5 and 118.3 dB(L). Based on the United States Bureau of Mines standard for surface mining (Table 5), the air overpressure level of 134 dB(L) was considered a safe limit for large-scale surface-mine blasting[10]. Therefore, the air overpressure levels recorded at the Benti–Bagda Limestone Mine were within the safe limit.

Figure 8 reveals the possible causes of flyrock as prescribed by various researchers, which are commonly encountered during any bench blasting in a surface mine[2,4]. It was observed through a high-speed video camera that in none of the trial blasts, the flying fragments travelled beyond 50 m distance from the blasting face. This was achieved due to a larger top stemming column, proper blast design, firing patterns using the Nonel system of initiation, and the precise implementation and supervision of the blasting operations.

Therefore, through the intended planning and scientific approach, it was possible to control all side effects of blasting at the Benti–Bagda Limestone Mine, which ultimately

Table 7. Suggested controlled blast design parameters

	Blasting zone from HT line and road		
Blast design parameters	100–200 m	200–300 m	>300 m
Blasthole diameter	100–115 mm	100–115 mm	100–115 mm
Blasthole depth	6.0 m	6.5 m	6.5 m
Total number of holes	20–30	30–40	40–50
No. of rows	Two or three	Three	Three or more
Burden	2.5 m	2.5–3.0 m	2.5–3.0 m
Spacing	3.0 m	3.0–3.5 m	3.0–3.5 m
Top stemming length	2.5–2.8 m	2.5 m	2.5 m
Drilling pattern	Staggered	Staggered	Staggered
Sub-grade drilling length	<0.5 m	0.5 m	0.5 m
No. of deck charge	Nil	Nil	Nil
Explosive charge/hole	22.24 kg	22.24–28.35 kg	22.24–28.35 kg
Maximum charge/delay	22.24 kg	45.00–57.00 kg	45.00–57.00 kg
Total charge	445.00–667.00 kg	890.00–1134.00 kg	1112.00–1418.00 kg
Surface firing patterns	Diagonal	Diagonal	Diagonal
Explosive type	83 mm diameter cartridge explosive, 2.78 kg per cartridge or ANFO explosive	83 mm diameter cartridge explosive, 2.78 kg per cartridge or ANFO explosive	83 mm diameter cartridge explosive, 2.78 kg per cartridge or ANFO explosive
Initiation type	Non-electric (Nonel) system: DTH: 200/450 ms TLD: 17/25/42 ms	Non-electric (Nonel) system: DTH: 200/450 ms TLD: 17/25/42 ms	Non-electric (Nonel) system: DTH: 200/450 ms TLD: 17/25/42 ms

Figure 11. Blast fragmentation of quarry no. 2.

Figure 12. Blast fragmentation of quarry no. 3.

Figure 13. Blast fragmentation of quarry no. 5.

helped the mine management excavate minerals without further hindrance.

Analysis of ground vibration

The recorded ground vibration data were grouped for statistical analysis correlating the maximum charge weight per delay (Q_{max}, kg), distance of the vibration measuring transducer from the blasting source (D, m) and recorded peak particle velocity (V, mm/s). The predictor equation is given below

$$V = 271 \times \left[\frac{D}{\sqrt{Q_{max}}} \right]^{-1.29}, \tag{3}$$

where the coefficient of determination = 0.828 and standard deviation = 0.0796.

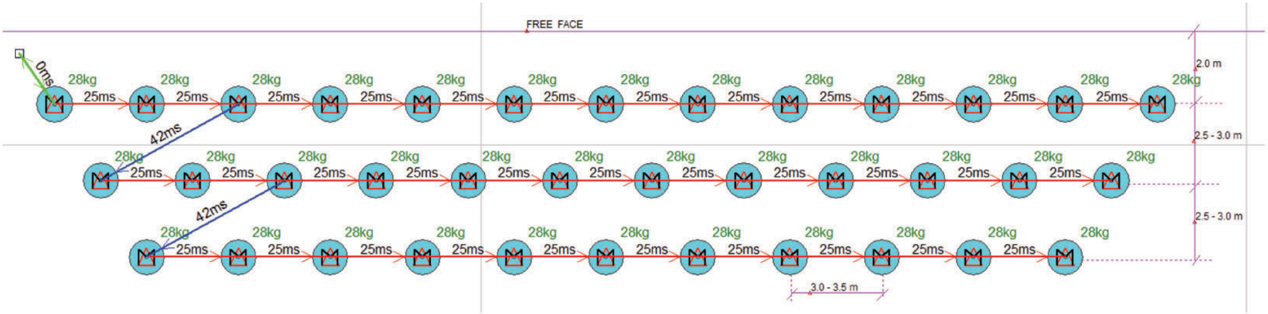

Figure 14. Suggested surface firing pattern of holes for blasting zone of 200–300 m.

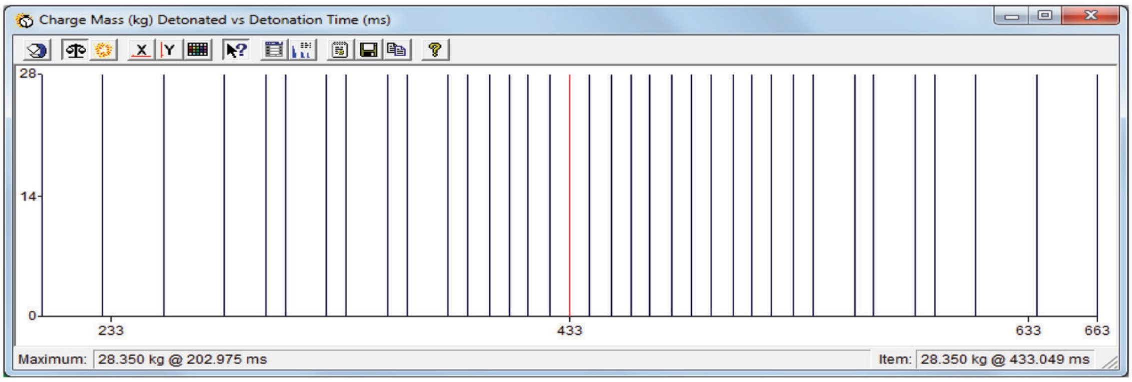

Figure 15. No. of holes (decks) detonated versus detonation time obtained from Figure 14.

Figure 9 shows the regression plot of the recorded vibration data. Equation (3) is site-specific and may be used to compute the safe maximum explosive charge to be detonated in a delay for various distances of concern (Figure 10).

Suggested controlled blast design patterns

The residential structures of Benti village were more than 100 m away from different quarries of the limestone mine. Field measurements showed that when the blast was conducted with a maximum explosive charge per delay of 19.49 kg and a total explosive charge per round of 90.35 kg, the induced maximum PPV was 3.40 mm/s at a distance of 107 m from the blasting source. However, as calculated from eq. (3), or as can be seen from Figure 10, the safe value of maximum charge per delay at a distance of 100 m from the blasting site is 60.30 kg, considering 10 mm/s as the admissible limit of PPV. For operational ease, therefore, it was considered necessary to demarcate the following three blasting zones for controlled deep-hole blasting operations in different quarries of the Benti–Bagda Limestone Mine: (A) 100–200 m zone from the residential structures, (B) 200–300 m zone and (C) Beyond 300 m zone from the residential structures.

Table 7 shows the suggested controlled blast design parameters for different blasting zones. Although the safe values of maximum charge per delay determined from the predictor eq. (3) for zones A–C are at a higher range, it was recommended that less number of holes should be used in a blasting round, particularly within the blasting zone of 100–300 m from the residential structures. Considering the sensitivity of the area, in-hole as well as surface hole-to-hole initiations, Nonel (shock tube system) was strictly recommended in order to control the ground vibration, air overpressure and flyrock. The explosives might be ANFO or 83 mm diameter cartridges weighing 2.78 kg each. The maximum explosive charge per delay was determined from eq. (3) for the three different blasting zones and a directive was given for its compliance.

The specific charge or charge factor (i.e. the amount of explosive charge (kg) to break/fragment one cubic metre of rock) varied between 0.60 and 0.63 kg/m^3. With this range of charge factors, good fragmentation was obtained (Figures 11–13). Figures 14–17 show a few suggested surface firing patterns for different blasting zones.

Table 8 provides the final output parameters from this study.

Conclusion and recommendations

Strategic planning is of utmost importance when blasting is carried out in sensitive places where local villagers are socially conscious, violent and politically polarized. In such a situation, in addition to cautious blasting with proper

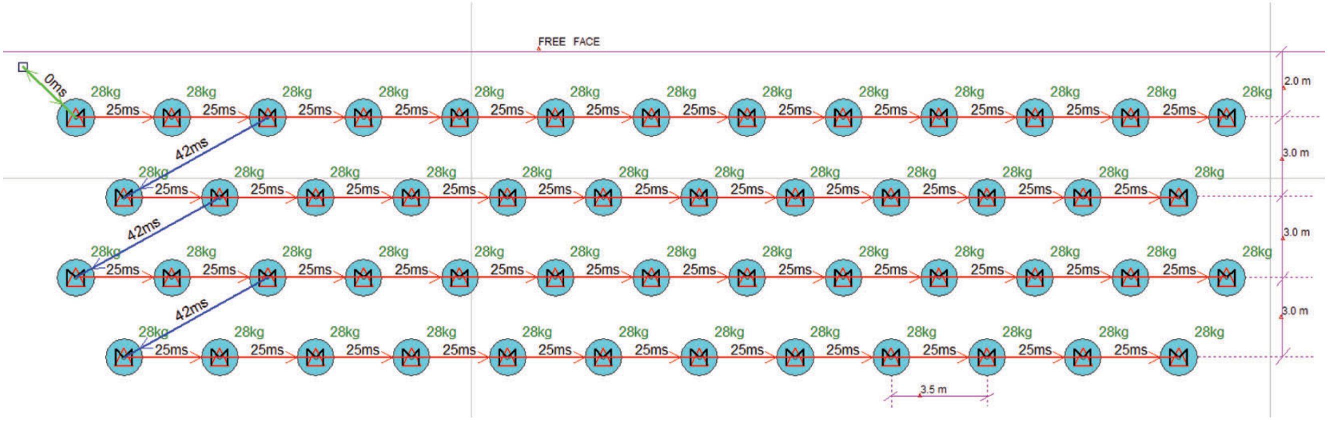

Figure 16. Suggested surface firing pattern of holes for the blasting zone beyond 300 m.

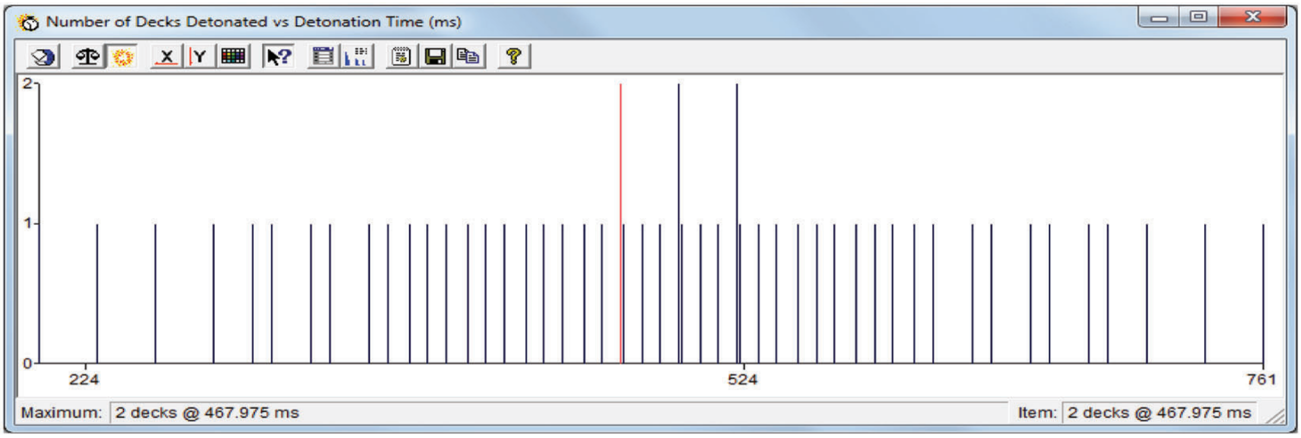

Figure 17. No. of holes (decks) detonated versus detonation time obtained from Figure 16.

Table 8. Output parameters obtained from the study

Output parameters	Result
Dominant frequency range	12–40 Hz
Ground vibration level	0.622–3.40 mm/s
Air overpressure level	91.5–118.3 dB(L)
Charge factor	0.60–0.63 kg/m^3
Range of flying fragments	Within 50 m distance

planning, human understanding, good liaising and appropriate supervision are essential to convince the local people.

Trial blasts were conducted at quarry nos 1, 2, 3 and 5 by meticulously following the standard rock breakage mechanism, as well as suitable software and advanced computer-aided design parameters to contain blast impacts to the barest minimum. In 19 instances, ground vibration data could not be recorded by the seismographs as the magnitude was less than the preset triggering level of the instruments, i.e. 0.5 mm/s. The Nonel initiation system (Handydet 400/25 ms) was used in all the blasts. The seismographs were placed on the compacted ground at the back of the free faces, i.e. towards the direction of Benti village, near different residential and important public buildings. The distance of the monitoring stations varied between 100 and 315 m. The FFT analyses of vibration data revealed that in most blasts, the maximum concentration of dominant energy ranged between 12 and 40 Hz, which helped in determining the safety levels of ground vibration for different residential structures as 10 mm/s, according to regulatory guidelines. The recorded levels of air overpressure varied between 91.5 and 118.3 dB(L), which were well within the safe limits. The safe and optimum controlled blast design patterns for the mine were suggested for different blasting zones, enabling the mine management to carry out safe and economic mineral extraction without causing any damage to the neighbouring villages.

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