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DESIGNING CONTROLLED BLASTING IN THE VICINITY OF SENSITIVE STRUCTURES IN AN IRON MINE IN INDIA - A CASE STUDY

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Abstract

This paper presents a case study at an Indian iron ore mine where controlled blast patterns were meticulously planned after conducting a few trial blasts for conducting blasts near numerous sensitive structures. A new screening plant for the mine had to be constructed on a hilly terrain in the vicinity of many sensitive structures such as residential huts, gas stations, gas storage facilities, structures of the existing screening plant, mine water reservoirs, etc. The test blasts were conducted at selected locations of the hilly terrain with varying geometric parameters in order to understand the results of the interaction between rock and explosives in the area. The effects of blasting, i.e., ground vibration, air overpressure, rock flight, etc., were evaluated and measured. Based on the results the results of test blasting and vibration data analyses from various iron ore mines in India with similar topographic conditions, three blasting zones were distinguished: critical, semi-critical and non-critical have been defined considering the nearness and sensitiveness of different structures. For each zone, the blasting parameters were developed, i.e., load, spacing, number of holes, blast charge per delay, type of explosive, etc. Using the developed controlled blasting patterns, development work near sensitive structures progresses safely. The developed controlled blasting patterns and methods can be used as aids for similar work in the absence of adequate scientific evaluation results.

Key words: *controlled blasting, screening plant, iron mine, hard rock, excavation, blast vibration, explosive, drilling and blasting, damage.*

1. Introduction

Kirandul Iron Ore Mine complex is one of the important production projects of National Mineral Development Corporation (NMDC) Limited situated in the Bailadila Iron Ore range in India and containing a good quantity of high-grade iron ore with an iron content of more than 66%. The iron ore is distributed over 14 deposits. In order to augment its present production capacity in the Bailadila sector, NMDC has embarked upon an ambitious plan to modernize and expand its existing crushing and screening equipment and streamline the present system of iron ore handling, storage, dispatch and rail loading within the Bailadila sector, with a special focus at the Kirandul complex. Therefore, a new screening plant (SP-III) is being constructed at Kirandul Complex Mine in order to enhance their crushing, screening, stacking, and loading facilities of iron ore fines and calibrated lumpy ores to process 12 MTPA of ROM iron ore to generate calibrated lumps of size (-) 40 mm to (+) 10 mm and iron ore fines of (-)10 mm [1].

The iron ore handling and processing plants of the new Screening Plant-III were planned on a hilly terrain with high undulations. The project was planned on an area graded at different heights to optimize cutting-filling, conveyor lengths and to accommodate the handling houses and processing plants with all the ancillary equipment. The initial development works of a very large hilly site required the excavation of hard rock by drilling and blasting. As the proposed facility was in close proximity to the residential hutments and other important structures such as the old screening plant, mine water reservoirs, conveyor belts, gas godown, gas pumps, etc., careful planning of controlled blasting for the development work and its proper execution were prerequisites for completing the work without risk to life and property. This paper presents the case study of the Kirandul iron ore mine where controlled blasting techniques were developed according to scientific

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knowledge evaluating the test blasts results. The developed blasting parameters and methodology were implemented for hard rock excavation in area development works for construction of the new Screening Plant in the vicinity of various sensitive structures and residential hutments.

2. Site description

The proposed new screening plant had to be constructed after land-development work of a small hillock. The highest altitude of the hillock is 740 m, whereas it is required to be excavated up to 660-645 m at different places. The area is surrounded by different structures in three directions; residential hutments in the north-western direction, two water storage reservoirs in the southern direction, a conveyor belt passing through the northern and western areas along the periphery of the excavation boundary, different structures of the old screening plant in the south-western direction. A petrol pump and an LPG gas godown are also present in the northwestern side of the excavation area. The Google Earth view of the proposed area for the new screening plant, along with different structures present in the vicinity, is shown in Figure 1. A schematic layout of the proposed screening plant-III area along with its proximity to various sensitive structures is shown in Figure 2.

Figure 1 Google Earth view of new screening plant area along with important structures present at nearby locations (Map data: Google, ©2021 CNES/Airbus)

3. Damage to structures due to blasting

To breakrock in mining and civil construction projects, the use of explosives is widespread. With the use of technology-controlled blasting techniques, the results of blasting have been greatly improved through the use of maximum blasting energy. Nevertheless, these blasts usually generate ground vibrations that, if they exceed certain limits, can cause damage to buildings in the surrounding area [2-6]. There are two important parameters that characterize ground vibration: first, the peak particle velocity (PPV) and second, its frequency. Some researchers have quantified the damage potential of ground vibrations using only PPV [7-11], while many researchers have determined the damage potential for both the PPV and the associated frequency [12-16].

There are many factors that affect the extent of damage to a structure caused by blast vibrations. These include total the amount of blast charge, the maximum charge per delay (MCPD), the distance of the structure from the blast site, the characteristics of the propagating media, and various other blast design parameters as well as the characteristic properties of the structure [12,13]. Higher vibration intensities can cause direct structural damage without producing a resonance effect in the structures, whereas lower vibration intensities can cause structural damage due to resonance effects if the natural frequency of the structure matches the frequency of the vibration waves. The low-intensity ground vibration waves can also cause soil and foundation settlement in loose soils, cohesionless sands and silts [17].

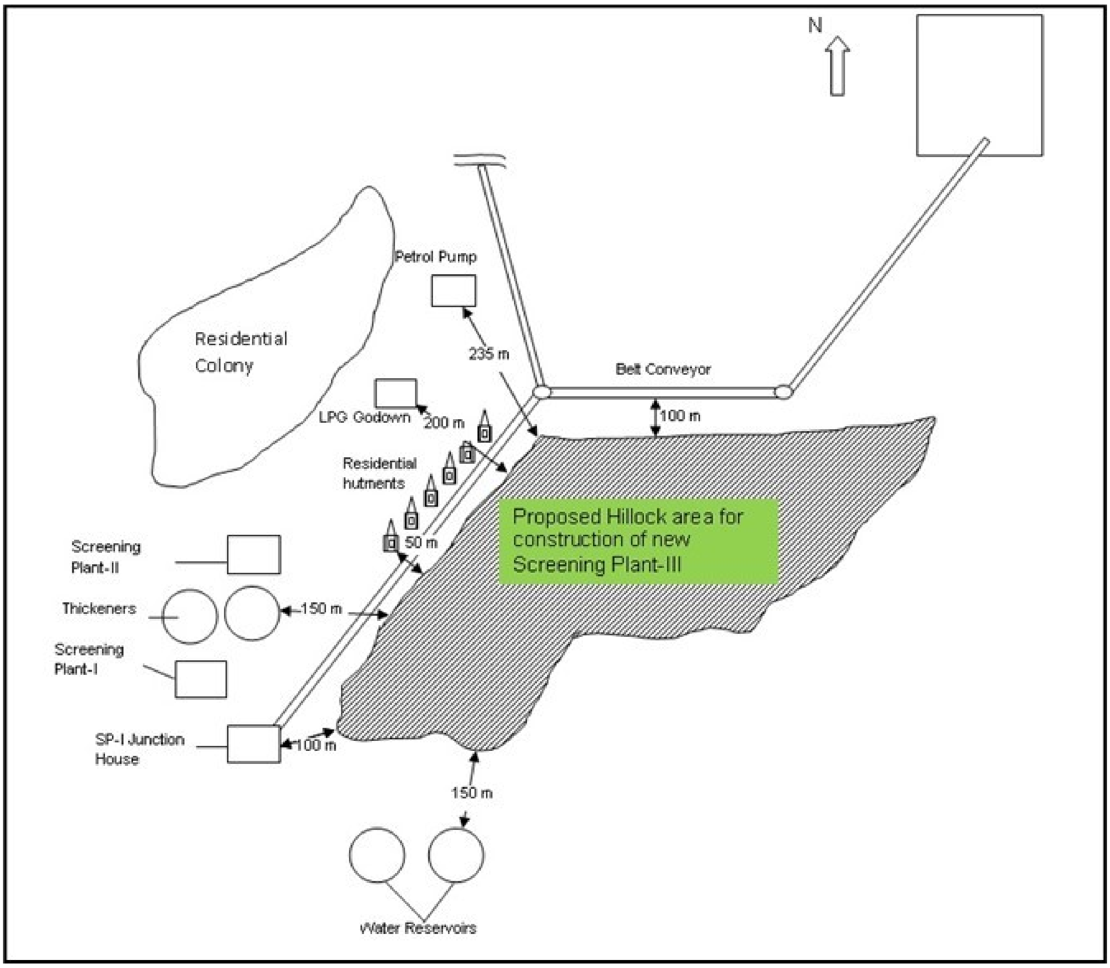

Figure 2 Schematic layout of the proposed area for new screening plant-III along with important structures present in nearby area (Not to Scale)

Excavation of hard rock as part of development works for the construction of a new screening plant-III (SP-III) must be carried out by means of drilling and blasting in combination with the shovel method and dumpers of matching capacity in the vicinity of the residential hutments and other sensitive industrial structures. Therefore, it was essential to develop a controlled blasting technique and proper scientific methodology for the excavation work and the parameters of controlled blasting were required to be formulated cautiously after conducting test blasts and assessing their results under different explosive loading conditions [18].

3.1. Determination of safe vibration levels for different structures

Numerous standards and guidelines have been developed and proposed by various researchers and authorities for blasting-induced ground vibrations. Vibration wave frequencies have also been incorporated in many vibration standards various researchers to determine safe vibration levels [12,14,19-21]. In India, the Directorate General of Mines Safety (DGMS), the

Central Mining Research Institute (CMRI) and the Indian Standard Institute (ISI) have developed vibration standards. The DGMS and CMRI vibration standards have also included dominant frequencies in determining safe vibration levels. These are listed in Tables 1 and 2. However, the vibration criteria established by ISI are based on the foundation conditions of the structures (Table 3).

Table 1 DGMS Vibration Standard (Technical Circular No. 7 of 1997) [22]

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

Table 2 CMRI Vibration Standard [23]

Type of structures	Permissible level of peak particle velocity (mm/s)	
	<24 Hz	>24 Hz
Domestic houses, dry wall interior, construction structures with plasters, bridge	5.0	10.0
Industrial buildings, steel or reinforced concrete structures	12.5	25.5
Object of historical importance, very sensitive structures, more than 50 years old construction and structures in poor state condition	2.0	5.0

Table 3 Permissible level of ground vibration based on Indian Standard Institute [24]

Medium of the foundation	Permissible level of peak particle velocity in mm/s
Soil, weathered or soft rock conditions	70
Hard rock conditions	100

The residential hutments and other industrial structures such as conveyor belts, their rollers, struts, other steel elements, old screening plants and their various parts located near the excavation area of the new screening plant require a minimum level of ground vibration to prevent them from being damaged. All of these types of structures have been considered in the ground vibration limits established by the DGMS threshold levels of ground vibrations. In the DGMS standard, both PPV and dominant frequency both were considered in establishing damage thresholds. The ownership of the structures and their type, significance and sensitivity were also considered. The highest PPV values were set for industrial buildings made of RCC elements. But, the allowable vibration values for multi-story structures and buildings of historical significance are the lowest because they can be damaged even at low vibration levels.

Considering these aspects, the DGMS vibration standards were used in determining the safe ground vibration levels for the complete safety of the structures near the site of the new screening plant.

4. Experimental works

In order to design and develop the different controlled blasting parameters for the excavation, it was first necessary to evaluate the results of the interaction between rock and explosives by performing some test blasts and assessing their effects on the surrounding structures. The new screening plant is to be constructed by excavating a small hill and most of the important structures such as the residential houses, conveyor belts, the existing screening plant, water reservoirs, etc. are located at the foot of the hill. The highest elevation of the hill is 745 m while the for construction of various structural components of the SP-III, requires excavation from 715 m EL to 654 m EL. The EL of the ground on which residential buildings and other important structures are situated, is 645 m. The plan and sectional views of the proposed screening plant is shown in Figure 3. Keeping in mind the difference in altitudes of the structures and blasting locations, the blasting tests were planned at different elevation of the hill to assess the impact of ground vibrations on the structures situated at the foot of the hill.

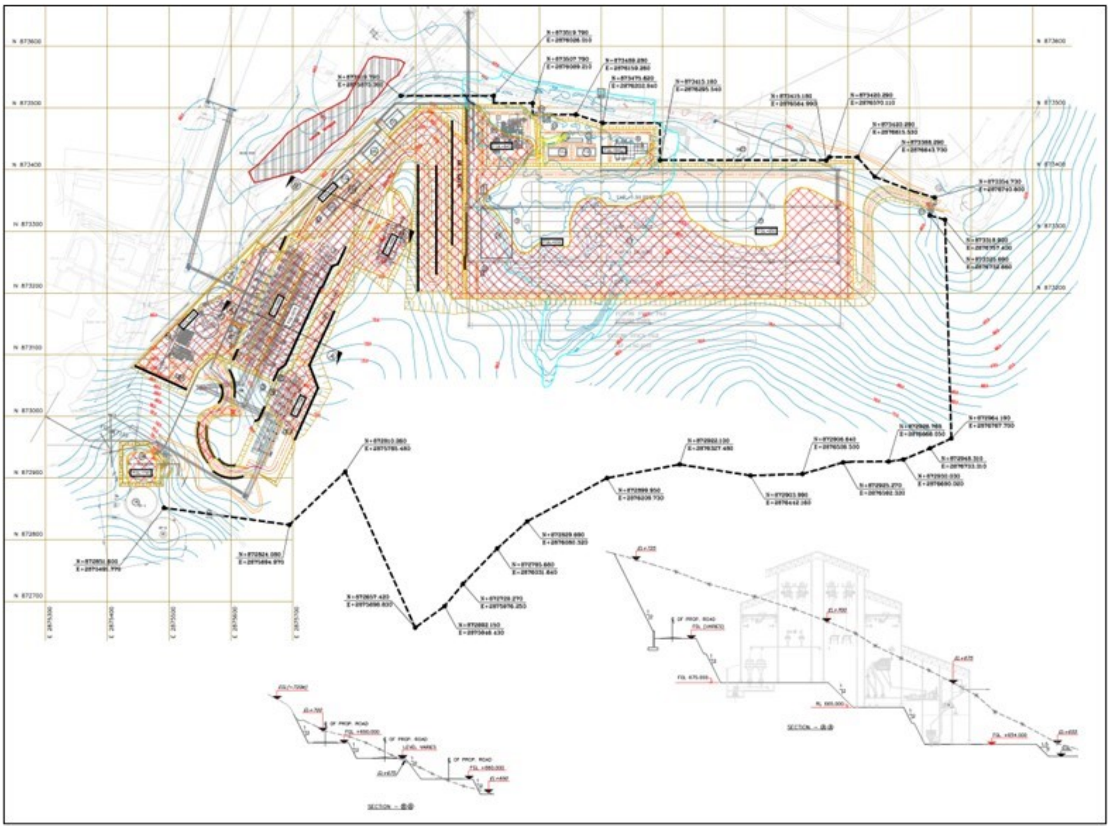

Figure 3 Plan and sectional views of the proposed area for construction of new screening plant

4.1. Blast tests

Three blast tests (TB-1 to TB-3) were carried out at different elevations of the hill to be excavated. The first two blasts took place side-by-side in the southern part of the hill at 705 m EL and 695 m EL while the third test blast was carried out at 675 m EL in the northern part of the hill. The test blasts were carried out with a blasthole diameter of 110 mm. Cartridge explosives (83 mm diameter) weighing 2.78 kg per cartridge were used. Non-electric shock tube detonation systems were used for detonation of the explosive in the borehole and detonation at the surface. Down-the-hole delay (DTH) detonators with a delay of 200 milliseconds (ms) were used to detonate the explosives inside the borehole, while trunk-line delay (TLD) detonators with a delay of of 25 and 42 ms were used to connect the holes at the surface. The test blasts were specifically planned so that the number of holes, the depth of the holes and the values for their loading and spacing were the same for all three explosions. However, in order to quantify the optimal amount of explosive required to break the rock easily, the charge factor or specific charge, i.e., the amount of explosive required to break per cubic meter of rock was varied from 0.56-0.65 kg/m^3. Details of blasting patterns and explosives used in the test blasts are summarized in Table 4.

Table 4 Details of blasting patterns and explosives used

Test Blast & Location	No. of holes & rows	Hole Depth [m]	Burden x Spacing [m x m]	Explosive quantity in each hole [kg]	Total explosive in the blast [kg]	Max. explosive charge per delay [kg]	Specific charge used [kg/m^3]	Type of initiating system used
TB-1 N18^{0}37'18.07" E81^{0}15'18.5" (705 m EL)	30 & 3 rows	6.0 - 6.8	2.5 x 2.5	19.46 - 25.00	670.00	50.00	0.560	DTH - 200 ms TLD - 25 & 42 ms
TB-2 N18^{0}37'22.5" E81^{0}15'14.7" (695 m EL)	30 & 3 rows	6.0 - 6.8	2.5 x 2.5	22.24 - 27.80	710.00	66.72	0.625	DTH - 200 ms TLD - 25 & 42 ms
TB-3 N18^{0}37'31.2" E81^{0}15'31.6" (675 m EL)	30 & 3 rows	6.0 - 6.8	2.5 x 2.5	22.24 - 33.36	750.00	66.72	0.650	DTH - 200 ms TLD - 25 & 42 ms

The view of blasting faces in one of the test blasts TB-1 along with muffling arrangement is shown in Figure 4. The explosive loading pattern in the holes, drilling and detonation sequence of holes in TB-1 are also shown in Figure 5 (a) and (b), respectively.

The ground vibrations generated from these test blasts were monitored near the various structures located near the construction site of the new screening plant. Vibrations were recorded by digital seismographs near the residential hutments, petrol pump and gas godown. The view of the monitoring station in the petrol pump is shown in Figure 6. The monitoring distances from the blast faces varied from 210 to 685 m. Details of different monitoring points used in the test blasts are given in Table 5.

Figure 4 View of blasting face covered with conveyor belts and sand bags (Blast TB-1)

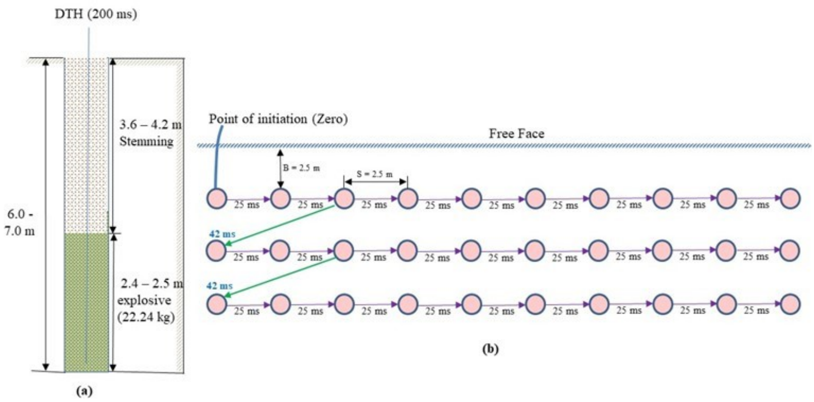

Figure 5 (a) Explosive loading pattern, and (b) drilling and detonation sequence of holes in one of the blasts TB-1

Table 5 Details of vibration monitoring points

Test Blast (Location with altitude)	Details about vibration monitoring points			
	Location of seismographs	Altitude of the monitoring location [m EL]	Difference in altitude with respect to blast location (- or +)	Radial distance from blasting face [m]
TB-1	North side of the hutment, near SP-II	638	(-) 67	622
N18^{0}37'18.07"	South side of the hutment	644	(-) 61	400
E81^{0}15'18.5"	In the Petrol Pump	636	(-) 69	685
(705 m EL)	Near Gas Godown	640	(-) 65	600
TB-2	North side of the hutment, near SP-II	638	(-) 57	580
N18^{0}37'22.5"	South side of the hutment	644	(-) 51	325
E81^{0}15'14.7"	In the Petrol Pump	636	(-) 59	620
(695 m EL)	Near Gas Godown	640	(-) 55	535
TB-3	North side of the hutment, near SP-II	638	(-) 37	210
N18^{0}37'31.2"	South side of the hutment	644	(-) 31	275
E81^{0}15'31.6"	In the Petrol Pump	636	(-) 39	330
(675 m EL)	Near Gas Godown	640	(-) 35	280

Note: (-) sign represents that the altitude of monitoring point is lesser than that of blasting point.

Figure 6 Monitoring of ground vibration in the petrol pump during test blasts

4.2. Results and discussions

The amount of explosive needed to crush one cubic meter of rock (specific charge or charge factor) is one of the key parameters for the industry to determine the break-even point of its business. The average fragment size and rock profile of the blasted rock are highly influenced by the optimum amount of explosive to break a cubic meter of rock. With different rock types and geological conditions, the presence of joints and other weak points, the specific charge varies considerably. Therefore, great importance was given to this parameter in the test blasts, and the amount of blast charge per hole was varied in all three test blasts to determine the optimum specific charge to break a cubic meter of rock. All other parameters such as hole depth, charge, and spacing were kept the same for the test blasts. The 1st blast was performed with a charge factor of 0.560 kg/m^3 while the 2nd and 3rd blasts were performed with charge factors of 0.625 kg/m^3 and 0.650 kg/^{3}, respectively. All blasting resulted in proper demolition of the rock mass. However, the mud profile was somewhat narrow during the 1st blast making it difficult to remove the material with the hydraulic excavators. However, in the 2nd and 3rd blasts, the mud profile was loose but not scattered, so the mechanical excavators could be used optimally. Therefore, it was decided that a charge factor between 0.60-0.65 kg/m^3 would be sufficient to break the rock and obtain a good mud profile.

No vibration data were recorded during any of the test blasts at any of the monitoring locations that were established near the sensitive structures in the vicinity area. Although, the monitoring distance was also 210 m during the 3rd test blast, the seismograph did not record any vibration trace. The seismograph trigger level was maintained at 0.5 mm/s. The reason that no vibration data was recorded could be the large height difference between the monitoring instruments which were located near the sensitive locations with respect to the altitude of blasting faces. The blast areas were at much higher elevations than the residential structures, gas station and gas storage facility. The height differences varied between (-) 69 m and (-) 31 m. Another reason could be use of a smaller number of holes with a smaller amount of explosives in the blast.

There was no suitable location to record vibrations at a lesser distance i.e., within 100 m of the blast areas .However, the results of the test blasts and monitoring of the ground vibrations conducted during the test blasts confirmed that 30 holes with a depth of 6.0 - 6.8 m, an explosive charge of 19.46 - 33.36 kg per hole and a total amount of explosive of 670 - 750 kg in the charge would not cause any damage to the residences and other sensitive structures near the excavation area, but at a distance of more than 100 m from the blast areas . No flying rock was observed or recorded on the video camera during any of the test blasts. In all test blasts, the stem column of the holes exceeded 3.5 m after loading the explosive. The use of conveyor belts and sandbags also prevented the blasted material from remaining directly on the blast wall. The results of the test blasts helped in the development-controlled blasting patterns and in the determination of safe blasting zones for regulating blasting operations required to be conducted during the excavation works.

5. Blasting zones and development of controlled blasting patterns

5.1. Determination of blasting zones

After seeing the results of the test blasts and considering the various structures present nearby the required excavation area, the total excavation area of the new screening plant is divided into three zones for conducting safe blasting operations. These zones are:

(1) Critical Zone: Within 50-100 m from the structures,

(2) Semi-critical Zone: Within 100-200 m from the structures and,

(3) Non-critical Zone: Beyond 200 m from the structures.

A view of the controlled blasting zones along with structures present and area of excavation falling in different zones are given in Figure 7.

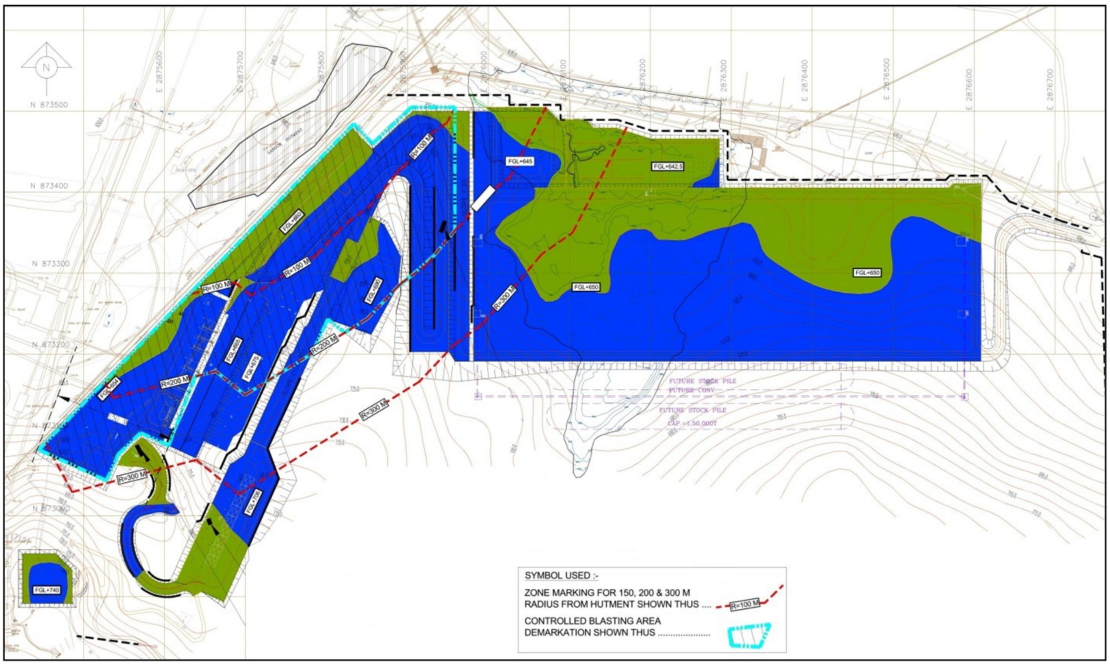

Figure 7 Controlled blasting zones along with area of excavation and surrounding structures

The various blast zones were determined based on the results of the test blasting, the distances of dwellings and other structures from the required blast areas, the orientation of the blast areas (toward or/away from the structures) and the direction of the slope profile. In the critical blast zone, the residences are located 50-100 m away and the mine's existing conveyor belt is also very close to the mining boundary. However, from the mining boundary, the nearest residential development is more than 75 m away. This zone was given the greatest importance. Within the semi-critical zone of 100-200 m from residences, careful blasting must be used during excavation, with adequate protection from flying rock in the form of silencers. The blast zone beyond 200 m is considered a non-critical zone because blast faces are oriented in opposite directions due to the slope of the terrain.

It has been proposed to attenuate loaded holes using conveyor belts and sandbags up to 200 m from the huts, if the blast benches are aligned with the hut area. However, if the blast benches are oriented in the opposite direction of the huts or if blasting is performed on the opposite side of the hills, sound attenuation measures are only required within a 150 m zone.

5.2. Development of controlled blasting patterns

The various blasting parameters and methodology for conducting safe blasting in the development of the area developed based on the results of test blasting at various locations on the hill. The data collected from CSIR-CIMFR during numerous scientific studies on controlled blasting in various iron ore mines in India were also used to determine the safe blasting patterns for the present work. The blasting patterns for safe excavations are given in Table 6.

Table 6 Suggested blast design patterns for different hole depths

Hole diameter [mm]	Hole depth [m]	Burden [m]	Spacing [m]	Number of holes for different zones			Type of Explosive & initiation system
				50-100 m	100-200 m	>200 m	
100-115	3.0-4.0	1.25-1.50	1.50-1.75	8-10		>30	Cartridge explosive (83 mm dia., 2.78 kg wt.), Non-electric (Nonel)/ shock tube initiation system for down the hole and surface connections
	4.0-5.0	1.50-1.75	1.75-2.25				
	5.0-6.0	2.0	2.5		10-30		
	6.0-7.0	2.0-2.25	2.5-2.75				
	7.0-8.0	2.5-3.0	3.0-3.5				

During the test blasts, the specific charge varied from 0.56 to 0.65 kg/m^3. Based on the results of the test blasts, a specific charge between 0.60 and 0.65 kg/m^3 is sufficient to achieve optimum blasting results. Sufficient length of the upper punch column should be maintained for all holes. The length of the upper punch column may vary depending on the depth of the hole. In any case, the length of the upper punch column should not be less than 2.75 m, especially within the specified controlled blast zone where a silencer is required. In addition, suitable clearances should be provided for all blastings to ensure that the blasted material is projected toward the bench face and does not form a crater fracture.

5.2.1. Development of controlled blasting patterns

During the test blasts, vibration data could not be recorded at any of the vibration monitoring points. The nearest vibration monitoring point was 210 m from the location of the test blasts. Therefore, to evaluate the maximum blast charge per delay for different distances, the database of CSIR-CIMFR was used. CSIR-CIMFR has conducted blast vibration studies in various iron ore mines in India. In order to obtain an equation for predicting ground vibrations, the blasts conducted in various iron ore mines in India with blast hole diameter of 110-115 mm and 83 mm diameter explosive cartridge were selected. The vibration data recorded from these blasts were summarised to establish an empirical equation.

The maximum blast charge per delay (Q_{max} in kg), the distance of the blast site from the monitoring points (D in m) and the recorded vibration values (V in mm/s) were used to generate the empirical equation. The obtained regression curve is shown in Figure 8. The obtained equation with a confidence level of 95% is as follows:

$$v = 131.06 \times \left[\frac{D}{\sqrt{Q_{max}}}\right]^{-1.113} \tag{1}$$

The houses in the hutment area, near the proposed screening plant consist mainly of adobe walls with tiled roofs. The other buildings are industrial facilities such as the existing screening plant, conveyor belts, etc. The gas storage facility and petrol pump are located at a greater distance from the residential hutments. The vibration standards prescribed by the Indian regulatory authority (DGMS) are given in Table 1.

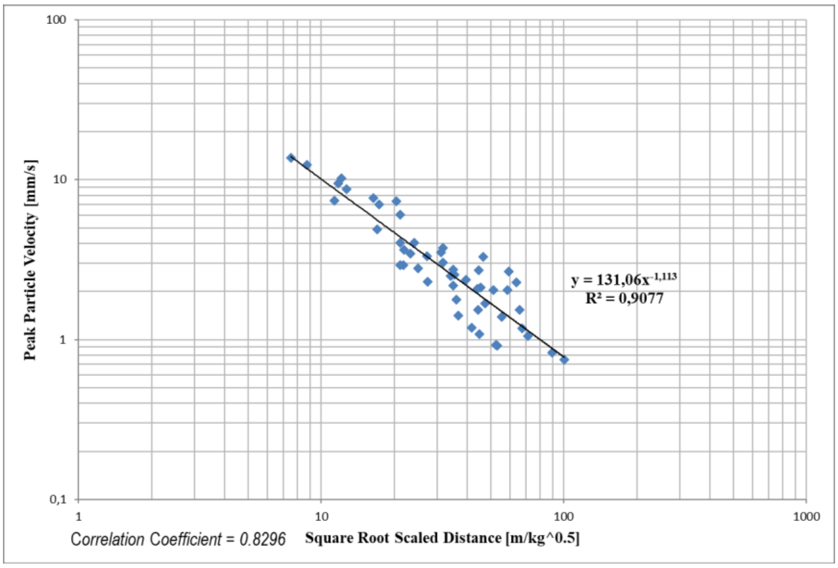

Figure 8 Regression plot of vibration data recorded in various iron ore mines

The distribution pattern of frequency content of ground vibration recorded from various iron ore mines is shown in Figure 9. From the frequency distribution pattern, it is clear that the low frequency values below12 Hz are predominant in most of the recorded vibration data. In addition, more than 50% of the frequency values are below 8 Hz. It is expected that the ground vibration caused by blasting in the present study area will have lower frequency values i.e., less than 8 Hz. Therefore, the safe value of PPV according to the DGMS standard is considered to be 5 mm/s. Based on this threshold PPV, the maximum blast charge per delay to be fired during blasting is calculated and (see Figure 10).

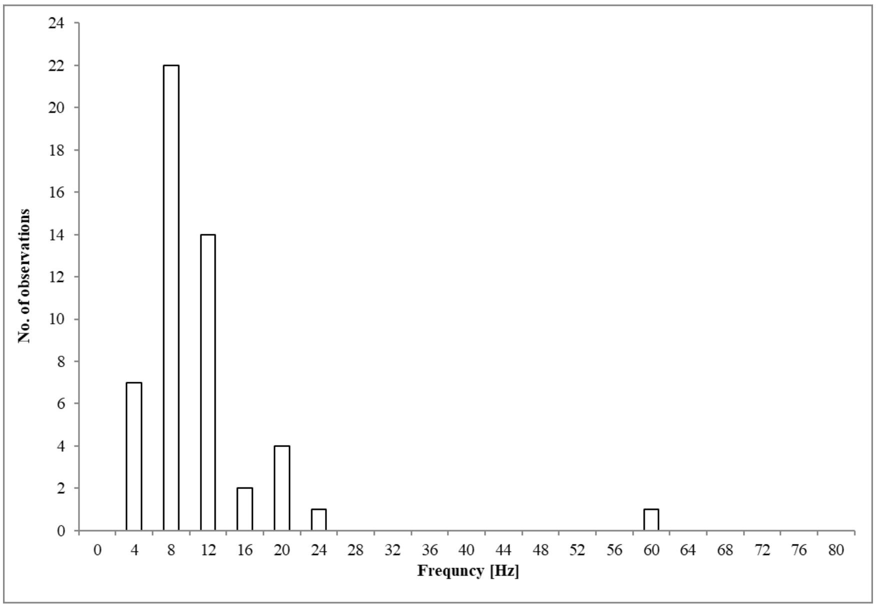

Figure 9 Frequency distribution of vibration waves recorded in different Iron Ore Mines

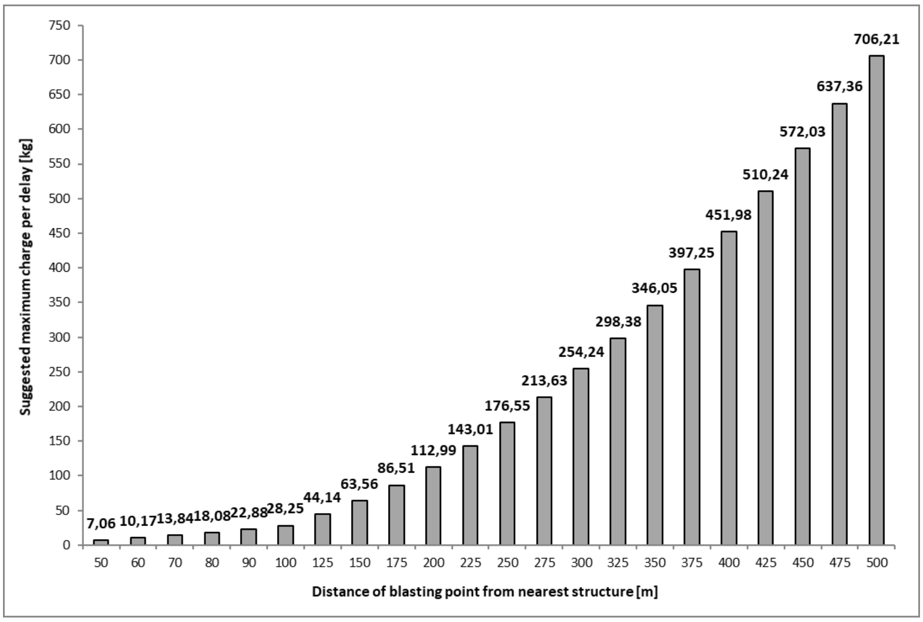

Figure 10 Safe values of maximum explosive charge per delay [Threshold ground vibration value - 5 mm/s]

6. Conclusions

Drilling and blasting operations near sensitive structures require careful planning and design of controlled blasting parameters to avoid damage to these structures from blasting-induced ground motion, air overpressure and rockfall. The extent of damage depends on the ground motion parameters, various blasting parameters, and the type of geologic strata and their inherent strength and other dynamic properties. Due to the inclusion of numerous scientific parameters in the development of appropriate blasting patterns near sensitive structures, the target industry is seeking other mechanical options for cutting and fracturing hard rock in sensitive areas. However, these options may not be easy to manage and may prove uneconomical. Under those conditions, the controlled blasting patterns developed in this research for different mining zones can be very useful to perform safe blasting for hard rock mining operations under similar geological conditions when site-specific blasting studies are not available.

In the present research, vibration data could not be recorded during the test blasts near the structures due to the large height differences (-69 to -31 m) between the measurement points and the blasting areas. Therefore, the controlled blasting patterns were developed based on the vibration data available at CSIR-CIMFR when conducting scientific studies in similar rock types and blasting conditions. The proposed blasting parameters can be further modified the actual blasting operations begin and excavation progresses toward the structures. For further research, the data collected during the controlled blasting operations at the excavation site would be used in developing more precise and result-oriented controlled blasting parameters for safe excavation operations under such sensitive conditions.

Acknowledgments

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PROJEKTOVANJE KONTROLISANOG MINIRANJA U BLIZINI OSETLJIVIH STRUKTURA U RUDNIKU GVOŽĐA U INDIJI – STUDIJA SLUČAJA

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Izvod

Ovaj rad predstavlja studiju slučaja u indijskom rudniku gvožđa gde su kontrolisani obrasci eksplozija bili pažljivo planirani nakon sprovođenja nekoliko probnih eksplozija u blizini brojnih osetljivih struktura. Novo postrojenje za prosejavanje je moralo biti izgrađeno na brdovitom terenu u blizini mnogih osetljivih objekata kao što su barake za stanovanje, benzinske pumpe, objekti za skladištenje gasa, objekti postojećeg postrojenja za prosejavanje, rezervoari rudničke vode, itd. Probne eksplozije sprovedene su na odabranim lokacijama brdovitog terena sa različitim geometrijskim parametrima kako bi se razumeli rezultati interakcije između stena i eksploziva u tom području. Ocenjeni su i izmereni efekti miniranja, tj. vibracije tla, natpritisak vazduha, let kamenja itd. Na osnovu rezultata analize podataka o probnom miniranju i vibracijama iz različitih rudnika gvozdene rude u Indiji sa sličnim topografskim uslovima, izdvojene su tri zone miniranja: kritična, polukritična i nekritična, s obzirom na blizinu i osetljivost različitih strukture. Za svaku zonu su razvijeni parametri miniranja, odnosno opterećenje, razmak, broj rupa, eksplozivno punjenje po kašnjenju, vrsta eksploziva, itd. Koristeći razvijene kontrolisane šeme miniranja, razvojni radovi u blizini osetljivih struktura odvijaju se bezbedno. Razvijene kontrolisane šeme i metode miniranja mogu se koristiti kao pomoćna sredstva za sličan rad u nedostatku adekvatnih rezultata naučne evaluacije.

Ključne reči: *kontrolisano miniranje, postrojenje za prosejavanje, rudnik gvožđa, tvrda stena, iskopavanje, vibracije pri miniranju, eksploziv, bušenje i miniranje, šteta.*