-RESEARCH PAPER-

International Journal of Mining and Geo-Engineering

IJMGE

IJMGE 58-3 (2024) 289-294

DOI: 10.22059/IJMGE.2024.355043.595034

Environmental implications on blasting operations in Indian quarry mines

Ajay Kumar [a, *] , Sandeep Prasad [b] , R. Sudhakar Reddy [b]

[a] *Department of Computer Science and Engineering, Manipal University Jaipur, Rajasthan, India.*
[b] *Department of Mining Engineering, AKS University, Satna, Madhya Pradesh, India*

Article History:
Received: 07 February 2023.
Revised: 18 June 2024.
Accepted: 10 July 2024.

ABSTRACT

In conventional opencast mining, blasting plays a significant role in mining activity. Basically, blasting is done in mining activity to create fragmentation. However, the process of fragmentation through blasting results in various side effects. The most prominent side effects include flyrock, airblast, and ground vibration. Also, the desired fragmentation size varies depending on the mineral being extracted. So, the type and quantity of explosive used should be optimized, as they can increase the magnitude of side effects, such as flyrock, airblast, and ground vibrations. actors, including space, burden, stemming material type, and stemming column height also affect all the aforementioned negative impacts. In this article, a case study of Indian mines measures the unfriendly impacts of blasting in opencast mining.

Keywords: *Fly rock, Airblast, Ground vibrations, Sound level, Nonels, and Stemming.*

1. Introduction

Basically, blasting is an inevitable process in conventional opencast mining [1-3]. Safety and the environment are important concerns during blasting. We prominently focus our attention on the environmental impacts of blasting in opencast mining in this paper. Before going in-depth into the environmental impacts of blasting, we should know the routine procedure of blasting in opencast mining. We observed the procedure of blasting in the M/S BRR Enterprises stone quarry located in Telangana state. In this quarry, blasting is carried out under the supervision of a blaster assisted by his crew. In this quarry, blasting happens every alternate day to meet the targeted production. The blasting happens between noon and 2 p.m., because low barometric pressure prevails at that time. It helps localize flyrock and airblast. Mining engineers in charge of blasting should keep in mind the nearness of villages when deciding on fragmentation. Similarly, in India, mining engineers in charge of blasting should have knowledge of regulations guiding blasting in opencast mines as per M.M.R – 2019. (M.M.R. – 2019 is the latest amendment of M.M.R. – 1961).

Throughout open-cast mines, blasting is often thought of as the least costly operation for fragmentation; nevertheless, subsequent blasting is more affordable than primary blasting [4]. Alternative techniques, such as surface miners, rock breakers, and rippers have the potential to fracture rock inside open-cast mines, but their use is restricted, and their cost is prohibitively expensive [5]. A well-experienced drilling and blasting team, along with blasting equipment, such as drill machines, explosives, detonators, and detonating fuses is required for a successful blasting operation in an open-cast mine [6]. The physio-mechanical characteristics of the rocks that need to be broken up determine the type of drill equipment and charges. Prior to blasting operations, it is recommended to drill the rocks with a rotating percussive machine [7]. Furthermore, practically all open-cast mines drill blast holes with down-the-hole hammer (DTH) type drills [8]. The blast holes are drilled in either a straight-line arrangement or a staggered arrangement, depending on the potency of the rock. Also, the location of the holes is determined by the quarry supervisor based on load, spacing, and subgrade. While the holes are being charged and filled, the burden is checked again. If it is confirmed to be incorrect, the quantity of explosive must be amended accordingly [9].

The powder factor, or the ratio of 1 kg of explosive to 1 m^3 of ore or rock, affects how much explosive is used per hole and varies base on the strength of the ore or rock and the objective of the blasting [10]. After placing the specified amount of charge into the blast hole, stemming is carried out using inert material. Explosive is tied to NONEL and slowly put into the blast hole [11]. After stemming, connections are established in series between the holes, and the connection's continuity is verified using a continuity gauge [12]. An important key factor that can influence the cost of blasting and mean fragment size is stemming. Stemming merely refers to the process of adding some inert stemming material to the mouth of the blast hole [13]. Opting for the proper stemming material for the blasting site would aid in accomplishing the optimum blast output.

The aim of this work is to assess the impact of blasting in opencast mining, focusing on ground vibration and sound levels, as monitored over five days. The novelty lies in using precise monitoring equipment to measure these parameters, ensuring compliance with Directorate General of Mines Safety (DGMS) regulations. The findings demonstrate that ground vibrations and air blasts remained within safe limits, emphasizing the effectiveness of careful planning and monitoring. This case study highlights the importance of accurate data in minimizing

---

* Corresponding author. *E-mail address:* ajay3789@gmail.com (A. Kumar).

environmental impact, maintaining safety standards, and protecting surrounding communities and mine infrastructure.

1.1. Literature review

In recent years, integrating Artificial Intelligence (AI) and advanced blasting techniques has shown great potential in reducing the environmental impacts associated with quarry mining. This literature review delves into the environmental consequences of blasting operations in Indian quarries and investigates how AI and advanced methods can help mitigate these issues. Noise pollution is a significant environmental concern linked to blasting operations. Research indicates that blasting generates high decibel levels which adversely affect both humans and wildlife. Noise levels in Indian quarries frequently surpass the permissible limits set by regulatory bodies, leading to hearing loss and psychological stress among workers and nearby residents [27]. Ground vibrations caused by blasting can result in structural damage to nearby buildings and infrastructure. An in-depth study on the impact of ground vibrations in Indian quarries reveals that improper blasting practices can produce vibrations exceeding safety thresholds [30]. These vibrations can cause cracks in residential buildings and destabilize slopes. Blasting operations also emit dust and gases, contributing to air pollution. Particulate matter (PM) levels around Indian quarry sites are often significantly above recommended standards. Inhalation of these particulates can lead to respiratory issues and other health problems for local communities [25]. The ecological impact of blasting includes habitat destruction, loss of biodiversity, and disruption of local ecosystems. The ecological consequences of quarrying activities in India found that blasting operations fragmented habitats and negatively affected flora and fauna [29]. AI-driven predictive analytics can enhance the efficiency and environmental sustainability of blasting operations. AI algorithms analyze historical data on blasting outcomes and environmental impacts to predict optimal parameters for future blasts. The application of machine learning models in Indian quarries has reduced ground vibrations and noise levels by optimizing blast designs [26]. Real-time monitoring of blasting operations using AI enables immediate adjustments to minimize environmental impacts. Real-time data collection through sensors and drones, combined with AI analytics, allows for continuous assessment of noise, vibrations, and dust levels. AI-based monitoring systems in Indian quarries have significantly improved regulatory compliance and environmental performance [24]. AI-powered automation in blasting operations can improve precision and reduce the environmental footprint. Automated drilling and blasting systems can execute blasts with high accuracy, minimizing the use of explosives and thereby reducing environmental impacts. The automated blasting techniques in Indian quarries resulted in a 20% decrease in explosive consumption and a corresponding reduction in air and noise pollution [28]. Controlled blasting techniques, such as pre-splitting and cushion blasting, are designed to limit the environmental impact by controlling blast energy and direction. These methods reduce ground vibrations and noise, thus minimizing damage to surrounding structures and habitats. Controlled blasting methods significantly lowered the incidence of structural damage in Indian mining areas [32]. Non-explosive demolition agents (NEDAs) provide an environmentally friendly alternative to traditional explosives. NEDAs expand within drill holes and exert controlled pressure to break the rock, eliminating the noise and vibrations associated with conventional blasting. The use of NEDAs in Indian quarries led to a marked decrease in environmental complaints from local communities [23]. Optimizing blast designs using advanced software tools can enhance the efficiency and environmental compatibility of blasting operations. These tools allow for precise calculation of blast parameters to achieve desired fragmentation while minimizing environmental impacts. The optimized blast designs in Indian quarries resulted in a 15% reduction in dust emissions and improved overall safety [31].

2. Study the geometry of open-cast mines for blasting

The site studied is a quarry near the BRR Enterprises stone quarry located in Telangana state (shown in Fig.1).

Before going in depth about the method of working, we have explored the blast geometry of the mine as summarized in Table 1.

Fig.1: The location map of the BRR Enterprises stone quarry located in Telangana state.

Table. 1. Details of blast geometry.

Parameters	Value/ Configuration
Height of bench	9 metres
Spacing	4 metres
Burden	3 metres
Diameter of drill hole	10 centimetres
Diameter of explosive cartridge	83 millimetres
Subgrade drilling	20 centimetres
Drilling pattern	Straight line
Type of Explosive used	Slurry explosive
Stemming height	3.0 metres
Stemming material used	Clay
Initiation	Nonels

Drilling of 100 mm dia. holes is done in daytime shifts only. Drilling is accomplished with the help of DTH drill machines. DTH drill machines are preferred over other machines due to transfer of impact energy directly to the drill bit [14]. These drill machines are shifted to safe distances before blasting. Air flushing is performed frequently to keep away drill cuttings as well as to increase the drilling rate. Before blasting, blaster once again checks the depth of every drill hole drilled by driller. If any drill hole is choked, it is re-drilled. Spacing generally remains constant, but the burden of front row of holes sometimes varies. These variations sometimes happen because of unskilled excavator operators. In this quarry, the powder factor is generally decided by the mining engineer in charge of blasting, taking into consideration the hardness of mineral as well as the type of explosive [15]. Slurry explosive is used for blasting. The explosive used per hole is 60 kg. Initiation was done by Nonels [16]. Nonels not only provide good fragmentation but also obviate accidental initiation of circuit due to storms, stray current or electrostatic charges. In the BRR stone quarry, with the approval of the mines manager, adjustments were made to the spacing and burden of the holes, the quantity of explosive used, and the height of the stemming column. These adjustments were aimed at ensuring that the magnitude of all side effects, such as vibrations and noise, remained within acceptable threshold limits. Five blasts were conducted consecutively, each on an alternate day, to achieve this goal. In all of the five blasts, the height of the bench, type of explosive, diameter of drill hole and diameter of explosive cartridge remained constant. In each blast, 24 holes were blasted. 24 holes were drilled in two lines. There are two villages, namely kaithapur at 1.5km and koyilagudem at 2km from the quarry leasehold area. There is also a national highway from Hyderabad to Vijayawada at a distance of 750m from the mining site. We collected details of the magnitude of ground vibrations, airblast and distance of flyrock in the direction of two villages and the national highway in all five blasts.

3. Experimental study of air-blast and ground vibration in opencast mines at blasting

We have computed ground vibrations and airblasts using the formulas given as in equations (1-3).

The airblast (P), sound level (Lp), and ground vibrations calculations have used some terminology as follows [15][17][18].

$$P=K\left[\frac{R}{Q^{0.33}}\right]^{-1.2} \quad (1)$$

Where P is pressure in kpa, K is the state of confinement. K=185 (Unconfined), K=3.3 (Fully confined), Q=Maximum charge per delay in kg, R=Plane distance from blasting location to geophone.

$$Lp = 20\log\left[\frac{p}{20\times10^{-9}}\right] \quad (2)$$

Where, P= pressure in kpa.

$$V=K\left[\frac{R}{Q^{0.5}}\right]^{B}$$

Where, V = peak particle velocity in mm/sec, K is a rock and site constant. K=500 (free face-hard or highly structured rock), K=1140 (free face-average hardness), K=5000 (highly confined), Q = Maximum charge per delay in kg, R = Plane distance from blasting location to geophone, B = Rock and site constant (usually -1.6).

3.1. Damage criteria and DGMS regulations

The damage criteria were proposed by many organizations, including USBM, DGMS, Indian Standards, etc., based on the permissible PPV in mm/s and the frequency of ground vibrations for various types of structures [19] [20]. The site blasting is illustrated in Figure 2. Specifically, the Minimate Blaster specifications are based on the channel supports of a microphone and a tri-axial geophone [22]. The monitoring is categorized into two types: vibrational and air overpressure.

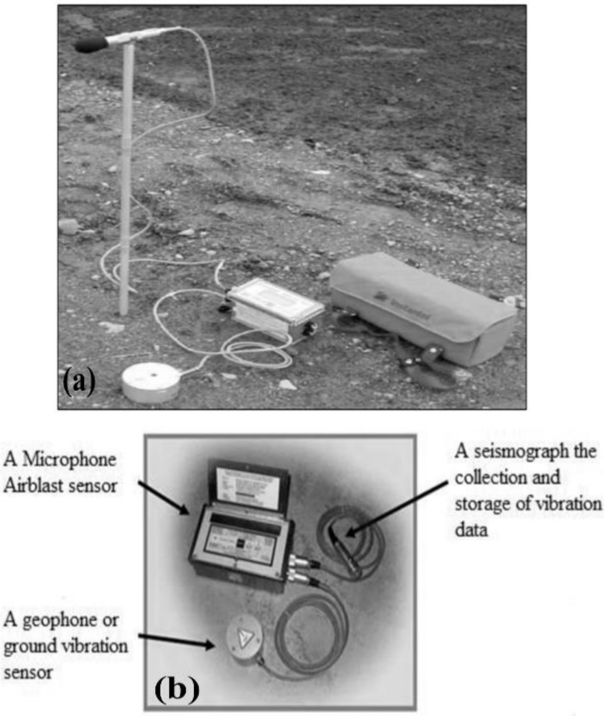

Fig. 2: The illustration of layout in site (a) view of blasting, and (b) mini mate blaster [22].

Vibrational monitoring covers various aspects, including range, resolution, accuracy, transducer density, and frequency range. The specifications are as follows: a range of up to 254 mm/s (10 in/s), a resolution of 0.127 mm/s (0.005 in/s) with a built-in preamp, an accuracy of ±5% (whichever is greater, between 4 and 124 Hz), a transducer density of 2.13 g/cc, and a frequency range of 2 to 250 Hz (within zero to -3 dB of an ideal flat response).

Similarly, the air overpressure monitoring specifications include range, resolution, accuracy, and frequency range. These are defined as follows: a linear range of 88 to 148 dB (500 Pa peak), a resolution of 0.25 Pa (0.0000363 PSI), an accuracy of ±10% (whichever is greater, between 4 and 125 Hz), and a frequency range of 2 to 250 Hz (between -3 dB roll-off points).

These specifications ensure that the monitoring equipment accurately measures the vibrations and air overpressure generated by the blasting operations, providing essential data to maintain safety and compliance with regulatory standards. The precise monitoring of these parameters is crucial for minimizing the environmental impact and ensuring the safety of the surrounding area during blasting activities.

The criteria based on the Permissible PPV in mm/s and the frequency of the ground vibrations for various types of structures as per DGMS (1997) are shown in Table 2.

Table. 2. DGMS criteria for blasting.

Type of structure	Dominant excitation frequency (Hz)		
	<8 Hz	8-25 Hz	>25Hz
(a) Buildings/structures not belonging to the owner			
(i) Domestic houses/structure (kuccha, brick, and cement)	5	10	15
(ii) Industrial building (RCC and framed structures)	10	20	25
(iii) Objects of historical importance and sensitive structures	2	5	10
(b) Building belonging to owner with limited span of life			
(i) Domestic houses/structure (kuccha, brick, and cement)	10	15	25
(ii) Industrial building (RCC and framed structures)	15	25	50

3.2. Outcome of the blasting sequences at the location

Extensive blasting was conducted at the site, and three key measurement parameters were selected as the outcomes. These results are detailed in Table 3.

Furthermore, we have five days of studies on ground vibration and sound levels. The results are summarized in Figures 3and 4.

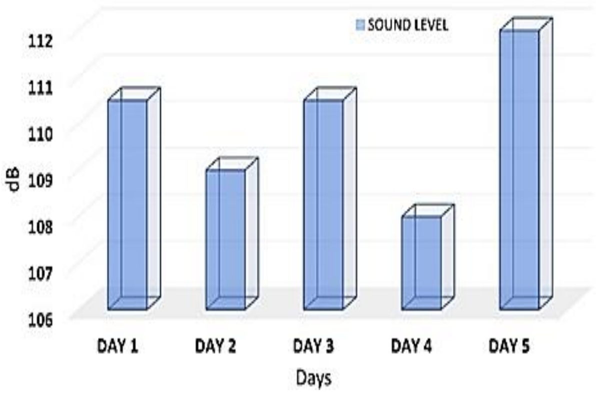

Fig. 3: During five days blasting study of sound level.

Table 3. Blasting Patterns.

	Recording Points	At Mine Office	National Highway	Kaithapur	Koyilagudem
	Distance from blasting site to recording point	510m	750m	1.5km	2km
Blasting Pattern 1	Air blast (kpa)	0.01520	0.00825	0.00755	0.00625
	Sound level	110.500	100.250	98.500	92.750
	Ground vibrations (mm/s), K=500	20.000	19.250	17.100	16.500
Blasting Pattern 2	Air blast (kpa)	0.01550	0.00950	0.00850	0.00700
	Sound level	109.000	102.250	98.700	94.750
	Ground vibrations (mm/s), K=500	20.500	17.500	16.000	15.500
Blasting Pattern 3	Air blast (kpa)	0.01500	0.00850	0.00750	0.00700
	Sound level	110.500	100.250	97.500	93.750
	Ground vibrations (mm/s), K=500	19.500	17.500	15.500	15.000
Blasting Pattern 4	Air blast (kpa)	0.01450	0.00800	0.00725	0.00625
	Sound level	108.000	98.250	97.500	95.750
	Ground vibrations (mm/s), K=500	19.500	18.000	17.000	16.500
Blasting Pattern 5	Air blast (kpa)	0.01650	0.00975	0.00725	0.00525
	Sound level	112.000	99.250	98.500	97.750
	Ground vibrations (mm/s), K=500	19.500	17.500	16.000	15.500

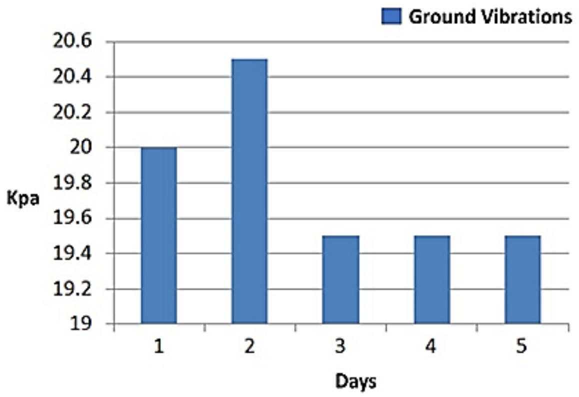

Fig. 4: Ground vibrations during five days blasting study.

4. Discussion and results

The outcomes demonstrate the effectiveness of the monitoring equipment in accurately measuring the vibrations and air overpressure generated by the blasting operations, providing essential data for maintaining safety and compliance with regulatory standards. The precise monitoring of these parameters is crucial for minimizing the environmental impact and ensuring the safety of the surrounding area during blasting activities.

In all trial blasts, the monitored ground vibrations did not exceed the threshold limit values set by the DGMS in India. In Kaitapur Village (1.5 km) and Koyilagudem Village (2 km), the observed ground vibrations were approximately 15 mm/second with a frequency of 50 Hz, which is within the vibration limits prescribed by the DGMS. At the mine office, which is constructed of brick, the vibrations were nearly 20 mm/second. Since the mine office is within the mine premises, the vibration needs to remain below 25 mm/second, with the frequency measured at 30 Hz. In this case, too, the ground vibrations never exceeded the DGMS's threshold limit values.

In all observed sites, no fly rock was detected beyond 300 meters. The airblast and sound levels observed were within permissible limits during all trial blasts. However, on the fifth day, the airblast and sound levels observed in the direction of the mine office were slightly higher, but still below the threshold limit values. The increase in air blast and sound levels on this day was attributed to strong winds blowing during the blasting.

provided accurate measurements of the vibrations and air overpressure, which is essential for maintaining safety standards and minimizing the environmental impact of the blasting operations. The consistent compliance with DGMS regulations across all trial blasts highlights the reliability and effectiveness of the monitoring system. The data collected ensures that all safety measures are met and helps in making informed decisions to further mitigate any potential risks associated with blasting activities.

In Kaitapur Village and Koyilagudem Village, the ground vibrations were well within acceptable limits, indicating that the blasting operations did not pose a threat to the structural integrity of buildings or the safety of the residents. The mine office also remained within safe vibration levels, ensuring the safety of the mine's infrastructure. The absence of fly rock beyond 300 meters confirms that the blasting was controlled and did not pose a risk to the surrounding environment.

Despite the slightly higher air blast and sound levels observed on the fifth day, the values remained within safe limits, demonstrating that the monitoring equipment can accurately detect even minor variations in blasting conditions. This capability is crucial for maintaining continuous safety and compliance with regulatory standards.

The successful management of airblasts and ground vibrations throughout the trial blasts emphasizes the importance of precise monitoring in ensuring the safety of both the mine site and the surrounding areas. By adhering to DGMS guidelines and using accurate monitoring equipment, the environmental impact of blasting operations can be minimized, and the safety of nearby communities and mine personnel can be safeguarded.

5. Conclusion

Blasting is a critical component of conventional opencast mining, primarily used for fragmentation. However, this process often results in side effects, such as flyrock, airblast, and ground vibrations. The desired size of fragmentation varies with different minerals, necessitating the optimal use of explosive type and quantity to minimize these adverse effects. Factors, such as spacing, burden, stemming material type, and stemming column height also significantly influence these side effects. This article presents a case study of Indian mines, highlighting the adverse impacts of blasting in opencast mining and emphasizing the importance of careful planning and monitoring to mitigate these effects. The consistent adherence to DGMS regulations across all trial blasts underscores the reliability and effectiveness of the monitoring system. The data collected are essential for verifying that all safety measures are observed and for making informed decisions to mitigate potential risks associated with blasting activities.

Future recommendations include the continued use of accurate monitoring equipment and strict adherence to DGMS guidelines. Additionally, assessing weather conditions prior to blasting can further reduce variations in airblasts and sound levels. Ongoing monitoring and evaluation will ensure the sustained safety of nearby communities and mine personnel, as well as the continued minimal environmental impact of blasting operations.

REFERENCES

[1] Crandell, F. J. (1949). *Ground vibration due to blasting and its effect upon structures*. Boston Society of Civil Engineers.

[2] Nicholls, H. R., Johnson, C. F., & Duvall, W. I. (1971). *Blasting vibrations and their effects on structures* (p. 656). Washington: US Government Printers.

[3] Rockwell, E. H. (1927). *Vibrations caused by quarry blasting and their effect on structures*. Rock Products, 30(3), 58-61.

[4] Choi, B. H., Ryu, C. H., Deb, D., Jung, Y. B., & Jeong, J. H. (2013). *Case study of establishing a safe blasting criterion for the pit slopes of an open-pit coal mine*. International Journal of Rock Mechanics and Mining Sciences, 57, 1-10. https://doi.org/10.1016/j.ijrmms.2012.07.014.

[5] Reddy, S., Tripathi, A. K., & Parida, S. (2020). *Influence of stemming material on performance of blasting*. PalArch's Journal of Archaeology of Egypt/Egyptology, 17(7), 9797-9809.

[6] Young, O. E., & Lenon, R. (2016). *Black powder and hand steel: Miners and machines on the old Western frontier*. University of Oklahoma Press.

[7] Manzoor, S., Liaghat, S., Gustafson, A., Johansson, D., & Schunnesson, H. (2020). *Establishing relationships between structural data from close-range terrestrial digital photogrammetry and measurement while drilling data*. Engineering Geology, 267, 105480. https://doi.org/10.1016/j.enggeo.2020.105480

[8] Pathak, J., & Dias, M. F. (1987). *Microprocessor-controlled down-the-hole drill for enhancing productivity and accuracy in underground hardrock bulk mining methods*. IEEE transactions on industry applications, (6), 1099-1104. DOI: 10.1109/TIA.1987.4505038.

[9] Liu, K., Yang, J., Li, X., Hao, H., Li, Q., Liu, Z., & Wang, C. (2018). *Study on the long hole raising technique using one blast based on vertical crater retreat multiple deck shots*. International Journal of Rock Mechanics and Mining Sciences, 109, 52-67. https://doi.org/10.1016/j.ijrmms.2018. 06.020

[10] Michaux, S., & Djordjevic, N. (2005). *Influence of explosive energy on the strength of the rock fragments and SAG mill throughput*. Minerals engineering, 18(4), 439-448. https://doi.org/10.1016/j.mineng. 2004.07.003

[11] Mandal, S. K., Singh, M. M., & Dasgupta, S. (2008). *Theoretical concept to understand plan and design smooth blasting pattern*. Geotechnical and Geological Engineering, 26(4), 399-416. https://doi.org/10.1007/s10706-008-9177-4.

[12] Reddy, S., Tripathi, A. K., & Parida, S. (2020). *Influence of stemming material on performance of blasting*. PalArch's Journal of Archaeology of Egypt/Egyptology, 17(7), 9797-9809.

[13] Qiu, X., Shi, X., Zhang, S., Liu, B., & Zhou, J. (2018). Experimental study on the blasting performance of water-soil composite stemming in underground mines. Advances in Materials Science and Engineering, 2018. https://doi.org/10.1155 /2018/3523509

[14] Singh, P. K., & Roy, M. P. (2010). *Damage to surface structures due to blast vibration*. International Journal of Rock Mechanics and Mining Sciences, 47(6), 949-961. https://doi.org/10.1016/j.ijrmms. 2010.06.010

[15] Singh, P.K., Vogt, W., Singh, R.B. and Singh, D.P. (1996) *Blasting Side Effects—Investigations in an Opencast Coal Mine in India*. International Journal of Surface Mining Reclamation and Environment, 10, 155-159. http://dx.doi.org/10.1080/09208119608964824

[16] Faramarzi Farhad, E.F. (2014) *Simultaneous Investigation of Blast Induced Ground Vibration and Airblast Effects on Safety Level of Structures and Human in Surface Blasting*. International Journal of Mining Science and Technology, 663-669. http://dx.doi.org/10.1016/j.ijmst. 2014.07.006

[17] Aler, J., Du Mouza, J., & Arnould, M. (1996). *Measurement of the fragmentation efficiency of rock mass blasting and its mining applications*. In International journal of rock mechanics and mining sciences & geomechanics abstracts (Vol. 33, No. 2, pp. 125-139). Pergamon. https://doi.org/10.1016/0148-9062(95)00054-2

[18] Roy, P. P. (1991). *Prediction and control of ground vibration due to blasting*. Colliery Guardian;(United Kingdom), 239(7).

[19] Mandal, B. B. (2014). *Implementation of DGMS guidelines for ergonomics risk assessment of mining operations*. In national workshop on applied ergonomics for mining. National Institute of miners (pp. 36-43).

[20] Choudhary, B. S., & Agrawal, A. (2019). *Blast assessment to improve productivity and safety of habitats in dolomitestone quarry using artificial intelligence*. In National Seminar Digitization and e-Governance in Mining Industry, Udaipur.

[21] Rudenko, D. (2002). *An analytical approach for diagnosing and solving blasting complaints*. Journal of Explosives Engineering, 19(4), 36-41.

[22] Minimate Blaster Operator manual (*1990-2013 XMARK Corp. Instantel, the Instantel logo, Auto Call Home, Blastmate, Blastware, Micromate, Minimate and Histogram Combo are trademarks of Stanley Black & Decker, Inc., or its affiliates. trademarks of Microsoft Corporation 716U3001 Rev 03*). https://www.geonor.com/brochures/minimate-blaster.pdf

[23] Das, R., Sharma, P., & Singh, R. (2019). Use of Non-explosive Demolition Agents in Indian Quarry Mines. Journal of Sustainable Mining, 8(2), 45-54.

[24] Gupta, A., & Sharma, V. (2021). AI-based Real-time Monitoring Systems in Quarry Mines: Case Studies from India. Mining Technology, 12(3), 67-78.

[25] Jain, S., Patel, A., & Kumar, V. (2018). Air Pollution from Blasting Operations in Indian Quarry Mines. Environmental Monitoring and Assessment, 190(11), 657.

[26] Kumar, S., Singh, N., & Das, A. (2020). Predictive Analytics in Blasting Operations: Enhancing Efficiency and Sustainability. International Journal of Mining Science and Technology, 30(4), 493-502.

[27] Mishra, R., Verma, S., & Roy, P. (2016). Noise Pollution and Its Control in Quarry Mines of India. Environmental Science and Pollution Research, 23(12), 12245-12253.

[28] Patel, K., Kumar, S., & Gupta, N. (2022). Automation in Blasting Operations: Environmental and Operational Benefits. Journal of Mining Engineering, 15(1), 34-49.

[29] Sharma, P., Thakur, J., & Singh, R. (2019). Ecological Impacts of Quarry Mining: A Case Study from India. Journal of Environmental Management, 233, 318-328.

[30] Singh, R., & Roy, S. (2017). Ground Vibrations Due to Blasting in Quarry Mines: A Case Study from India. Bulletin of Engineering Geology and the Environment, 76(1), 177-185.

[31] Singh, V., Verma, M., & Rao, K. (2021). Optimized Blast Design for Environmental Sustainability in Indian Quarries. Rock Mechanics and Rock Engineering, 54(6), 3015-3029.

[32] Verma, P., & Rao, S. (2018). Controlled Blasting Techniques in Indian Quarry Mines. Journal of Mining Science, 54(4), 675-684.