Indian Journal of
Modern Research and Reviews
This Journal is a member of the *'Committee on Publication Ethics'*
Online ISSN:2584-184X

Research Article

Evaluation of Controlled Blasting Techniques for Reducing Ground Vibrations in Surface Mining

Kamakhya Narayan [1*], Sunny S Prasad [2], Guddu Kumar [3], Shubham Kumar [4]
[1] Assistant Professor Department of Mining Engineering, Jharkhand Rai University, Ranchi, Jharkhand, India
[2,3,4] Student Department of Mining Engineering, Jharkhand Rai University, Ranchi, Jharkhand, India

Corresponding Author: * Kamakhya Narayan

DOI: https://doi.org/10.5281/zenodo.20258270

Abstract

Blasting is an indispensable operation in surface mining, primarily employed for rock fragmentation and excavation. However, blast-induced ground vibration (BIGV) remains one of the most critical environmental and geotechnical challenges associated with mining activities. Excessive ground vibration may cause structural damage to nearby buildings, destabilisation of mine slopes, and social disturbances in surrounding communities. The present study evaluates the effectiveness of various controlled blasting techniques in minimising ground vibration while maintaining operational efficiency and acceptable fragmentation characteristics. Field investigations were conducted by analysing major blasting parameters such as charge per delay, burden, spacing, delay timing, and blast geometry. Controlled blasting techniques, including reduced charge per delay, optimised delay sequencing, deck charging, air decking, and pre-splitting, were systematically examined. Ground vibration was monitored using seismographic instruments, and vibration intensity was assessed in terms of Peak Particle Velocity (PPV). The measured values were compared with regulatory standards prescribed by the Directorate General of Mines Safety (DGMS) and the United States Bureau of Mines (USBM). The results demonstrate that controlled blasting significantly reduces vibration levels in comparison with conventional blasting methods. Among the investigated techniques, deck charging and delay timing optimization produced the highest reduction in PPV, achieving approximately 40–50% reduction in vibration intensity. The study further emphasizes that the integration of controlled blasting with real-time monitoring systems and predictive analytical models can substantially improve environmental sustainability, operational safety, and regulatory compliance in surface mining operations.

Manuscript Information

- **ISSN No:** 2584-184X
- **Received:** 06-04-2026
- **Accepted:** 08-05-2026
- **Published:** 17-05-2026
- **MRR:**4(5); 2026: 125-128
- **©2026, All Rights Reserved**
- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Narayan K, Prasad S S, Kumar G, Kumar S. Evaluation of controlled blasting techniques for reducing ground vibrations in surface mining. Indian J Mod Res Rev. 2026;4(5):125-128.

Access this Article Online

www.mrrjournal.in

KEYWORDS: Controlled Blasting, Blast-Induced Ground Vibration, Peak Particle Velocity, Surface Mining, Deck Charging, Delay Optimization, Air Decking, Environmental Management.

1. INTRODUCTION

Blasting constitutes one of the most important unit operations in surface mining and civil excavation projects. The effectiveness of blasting directly influences excavation efficiency, fragmentation quality, equipment productivity, and overall mining economics. In hard rock mining operations, explosives are extensively utilized to fragment rock masses into manageable sizes for loading and transportation. Despite its operational advantages, blasting generates several undesirable environmental impacts including fly rock, air overpressure, noise pollution, dust generation, and blast-induced ground vibration (BIGV). Among these environmental consequences, ground vibration is considered the most significant because of its potential to damage nearby structures, affect slope stability, and create social concerns among surrounding populations.

Blast-induced ground vibration occurs when a portion of the explosive energy propagates through the rock mass in the form of seismic waves. These waves include primary waves (P-waves), secondary waves (S-waves), and surface waves, each contributing differently to vibration transmission and structural response. Only a limited fraction of the explosive energy is effectively utilized for rock fragmentation, while the remaining energy dissipates in the form of vibration, heat, noise, and air blast. Excessive vibration may adversely affect residential buildings, industrial structures, underground workings, and sensitive installations located near mining operations. According to USBM recommendations, PPV values beyond permissible limits may cause structural damage and public complaints (USBM, 1980).

Peak Particle Velocity (PPV) is widely recognized as the most reliable parameter for assessing blast vibration intensity and evaluating the potential for structural damage. PPV is influenced by several factors including explosive charge per delay, distance from the blast site, geological conditions, rock mass properties, burden-spacing ratio, initiation sequence, and delay timing. Therefore, optimizing blasting parameters becomes essential for minimizing environmental impacts while maintaining desired fragmentation efficiency.

Controlled blasting techniques have emerged as effective solutions for reducing blast vibration and improving environmental performance in mining operations. Techniques such as reduced charge per delay, deck charging, air decking, pre-splitting, and delay optimization enable controlled energy release and reduce wave superposition effects. Modern electronic detonators have further improved blasting precision through highly accurate delay intervals. The adoption of such advanced blasting approaches has become increasingly important in environmentally sensitive mining regions and densely populated areas near mines. Previous studies conducted by Bauer and Calder (1971), Hoek and Bray (1981), and Singh (2010) emphasized the importance of scientific blast design for minimizing environmental disturbances and ensuring mine safety [1,6,7].

The present study investigates the effectiveness of controlled blasting techniques in reducing ground vibration in surface mining operations. Field experimentation and vibration monitoring were carried out to compare conventional blasting with various controlled blasting approaches. The research aims to identify the most effective techniques for vibration reduction while ensuring operational efficiency and compliance with environmental regulations.

2. LITERATURE REVIEW

Ground vibration generated during blasting operations has been extensively investigated due to its environmental, geotechnical, and safety implications. Researchers worldwide have identified PPV as the principal parameter for evaluating vibration severity and potential structural damage. According to the USBM vibration criteria, PPV values exceeding 10–12 mm/s may cause noticeable damage to residential structures and discomfort to nearby communities (USBM, 1980) [8].

Conventional blasting practices generally involve the detonation of large explosive charges with limited control over timing and energy distribution. Such blasting methods often generate excessive instantaneous energy release, resulting in high vibration intensity and poor environmental performance. Studies by Bauer and Calder (1971) reported that uncontrolled blasting significantly affects slope stability and structural safety in mining regions [1].

Reduced charge per delay has been recognized as one of the most effective techniques for vibration control. By limiting the amount of explosive detonated at a particular instant, the energy transmitted into the surrounding rock mass decreases substantially. Several investigations reported vibration reductions of nearly 30–40% using optimized charge distribution techniques.

Delay timing optimization is another important vibration control strategy. Improper delay intervals may lead to constructive interference and wave superposition, thereby amplifying vibration intensity. Electronic detonators provide millisecond-level precision and help achieve controlled energy release. Brown et al. (2020) demonstrated that optimized delay sequencing significantly reduces PPV values while improving fragmentation efficiency [2].

Deck charging involves dividing the explosive column into separate segments using inert materials between explosive decks. This technique distributes explosive energy over multiple intervals, thereby minimizing vibration intensity and improving fragmentation uniformity. Air decking further enhances blasting performance by introducing air gaps within boreholes, which absorb part of the shock energy and reduce stress wave transmission.

Pre-splitting techniques are widely employed to create controlled fractures along excavation boundaries. These fractures act as barriers to stress wave propagation, thereby reducing vibration transmission beyond the blast zone. Hoek and Bray (1981) highlighted the importance of controlled fracturing methods for maintaining slope stability and reducing environmental disturbances in mining operations [6].

Recent research has focused on integrating predictive modeling and machine learning techniques into blast vibration analysis. Chen et al. (2022) developed machine learning-based predictive models capable of accurately estimating vibration intensity under varying blasting conditions [3]. Although such technologies offer promising results, challenges remain regarding data availability, implementation cost, and real-time adaptability.

Despite considerable advancements in blasting science, several research gaps persist. There is still a lack of universally applicable predictive models capable of accounting for complex geological conditions and varying blast designs. Furthermore, real-time vibration monitoring and adaptive blast design systems are not widely implemented in many developing mining regions. The high cost of advanced detonator systems and monitoring technologies also limits their large-scale adoption.

3. METHODOLOGY

3.1 Research Design

The present study adopted a quantitative experimental research methodology involving field blasting trials in surface mining operations. Conventional blasting practices were compared with different controlled blasting techniques to evaluate their effectiveness in reducing ground vibration.

3.2 Data Collection

Field data were collected during blasting operations using systematic monitoring procedures. Important blast design parameters recorded during experimentation included hole diameter, bench height, burden, spacing, stemming length, charge per delay, explosive type, and delay interval. Geological characteristics of the rock mass and the distance between blast location and monitoring stations were also documented.

3.3 Ground Vibration Measurement

Ground vibration measurements were conducted using portable digital seismographs installed at different distances from the blast site. The instruments recorded Peak Particle Velocity (PPV) values along three orthogonal directions. The maximum vector sum of vibration components was considered for analysis and comparison with regulatory standards.

3.4 Experimental Procedure

Initially, baseline data were obtained using conventional blasting methods commonly practiced in the mine. Subsequently, controlled blasting techniques such as reduced charge per delay, delay optimization, deck charging, and air decking were implemented individually and in combination. Each blast was carefully monitored, and vibration data were systematically recorded for analysis.

3.5 Data Analysis

The collected vibration data were analyzed using the scaled distance approach, which is widely used for blast vibration prediction. The relationship between PPV and scaled distance was evaluated using the following empirical equation:

$$PPV = K\left(\frac{D}{\sqrt{W}}\right)^{-n}$$

Where:

- **PPV** = Peak Particle Velocity (mm/s)
- **D** = Distance from blast site (m)
- **W** = Maximum charge per delay (kg)
- **K and n** = Site-specific constants

Regression analysis was performed to determine site constants and evaluate the effectiveness of different blasting techniques.

4. RESULTS AND DISCUSSION

4.1 Conventional Blasting Performance

The conventional blasting trials generated relatively high vibration levels due to larger charge concentrations and limited control over detonation sequencing. Recorded PPV values ranged between 9.8 mm/s and 12.5 mm/s, approaching the upper permissible vibration limits prescribed for residential structures. High vibration intensity was primarily attributed to excessive charge per delay and inadequate timing control.

4.2 Controlled Blasting Performance

The implementation of controlled blasting techniques produced substantial reductions in vibration intensity. Reduced charge per delay decreased PPV values to approximately 6.8–9.2 mm/s, corresponding to nearly 30% vibration reduction. The reduction occurred because smaller explosive quantities released less instantaneous seismic energy into the surrounding rock mass.

Delay timing optimisation further improved vibration control by minimising wave superposition effects. The use of accurate delay intervals significantly reduced PPV values to approximately 6.6–8.8 mm/s, corresponding to nearly 35% vibration reduction. Electronic detonators provided superior timing accuracy compared with conventional initiation systems.

Deck charging emerged as the most effective individual vibration control technique. By dividing explosive charges into separate decks, the energy release became more distributed and controlled. PPV values decreased to approximately 6.3–8.5 mm/s, representing nearly 40% reduction in vibration intensity.

Air decking also produced noticeable improvements in vibration control. The introduction of air gaps within boreholes absorbed part of the explosive shock energy and reduced stress wave transmission. Vibration reduction achieved through air decking ranged between 20–25%, with PPV values varying between 6.5 mm/s and 8.9 mm/s.

The combined application of multiple controlled blasting techniques produced the best overall performance. Simultaneous implementation of deck charging, optimized delay timing, and reduced charge per delay resulted in vibration reductions approaching 50%. These findings indicate that multi-technique blasting approaches are more effective than isolated methods.

Table 1: Comparative Analysis of Controlled Blasting Techniques

Blasting Technique	PPV Range (mm/s)	Approximate Reduction
Conventional Blasting	9.8 – 12.5	—
Reduced Charge per Delay	6.8 – 9.2	~30%
Delay Timing Optimization	6.6 – 8.8	~35%
Deck Charging	6.3 – 8.5	~40%
Air Decking	6.5 – 8.9	~25%

The results clearly indicate that charge per delay is the most influential parameter affecting blast vibration intensity. The findings of the present investigation are consistent with earlier studies conducted by Brown et al. (2020) and Singh (2010), which emphasized the importance of optimized blast design for environmental control [2,7].

5. Regulatory Compliance

The measured vibration values were compared with vibration standards prescribed by the Directorate General of Mines Safety (DGMS) and the United States Bureau of Mines (USBM). The controlled blasting trials successfully maintained PPV values within permissible limits for nearby structures and inhabited areas. Air overpressure levels remained below the USBM-recommended limit of 134 dB, thereby minimizing the risk of air blast-related disturbances [4,8].

Noise levels generated during blasting operations also complied with the guidelines prescribed by the Central Pollution Control Board (CPCB), Government of India [9]. The results confirm that controlled blasting techniques not only improve operational efficiency but also ensure environmental sustainability and regulatory compliance.

6. CONCLUSION

The present study demonstrates that controlled blasting techniques significantly reduce blast-induced ground vibration in surface mining operations while maintaining acceptable fragmentation efficiency. Conventional blasting methods generated relatively high PPV values due to excessive instantaneous energy release, whereas controlled blasting approaches effectively minimized vibration intensity through optimized energy distribution.

Among the investigated techniques, deck charging and delay timing optimization emerged as the most effective methods for vibration control. Combined blasting approaches achieved vibration reductions of nearly 50%, thereby substantially improving environmental performance and operational safety. Reduced charge per delay and air decking also contributed significantly to vibration mitigation.

The study confirms that scientific blast design, accurate delay sequencing, and controlled explosive distribution are essential for sustainable mining operations. The integration of real-time vibration monitoring systems, electronic detonators, and predictive analytical tools can further improve blasting efficiency and environmental management in modern mining practices.

7. Recommendations and Future Scope

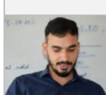
Future research should focus on the development of machine learning-based predictive models for accurate vibration estimation under varying geological and operational conditions. Artificial intelligence and IoT-enabled monitoring systems can facilitate real-time adaptive blast design and automated vibration control. Cost optimization of advanced detonator systems and monitoring technologies should also be explored to enhance their practical applicability in developing mining regions.

The adoption of integrated digital blasting systems, coupled with continuous environmental monitoring, can significantly contribute to sustainable and socially responsible mining operations in the future.

REFERENCES

1. Bauer A, Calder PN. The influence of blasting on stability. SME; 1971.
2. Brown T, et al. Ground vibration analysis in surface mining. Int J Min Sci. 2020;45(3):210-225.
3. Chen X, et al. Machine learning models for blast vibration prediction. Eng Geol. 2022; 298:106543.
4. Directorate General of Mines Safety. Technical Circular No. 7. Government of India; 1997.
5. Kishore S. Enhancing blasting efficiency and environmental performance through chamber blasting in opencast mining. Indian J Mod Res Rev. 2025:100-102.
6. Hoek E, Bray J. Rock slope engineering. IMM; 1981.
7. Singh RD. Principles and practices of modern coal mining. New Age International Publishers; 2010.
8. United States Bureau of Mines (USBM). RI 8485: Structure response and airblast limits. USBM; 1980.
9. Central Pollution Control Board (CPCB). Noise Pollution Rules. Government of India; 2000.

About the Corresponding Author



Kamakhya Narayan is an Assistant Professor in the Department of Mining Engineering at Jharkhand Rai University. His academic and research interests include blasting technology, mine safety, rock mechanics, and sustainable mining practices. He actively contributes to teaching, technical research, and the professional development of students in the field of mining engineering.