OPEN ACCESS

Eco-Shift 2026: International Conference on Global Climate Action
(From Root Causes to Revolutionary Remedies for Sustainable Development)

Int. Jr. of Contemp. Res. in Multi. *PEER-REVIEWED JOURNAL* *Volume 5 [Special Issue 2] Year 2026*



Research Article

Study of Dozer Push Mining Technique and Measures for Controlling Blast Vibration and Flyrock

Sumeet Kishore [1*], Harshit Bhatt [2], Swet Kamal [3], Suraj Chouhan [4], Rahul Kumar [5], Narayan Rabi Das [6], Amit Kumar Roy [7], Veeru Kumar Dey [8]

[1]Assistant Professor, Department of Mining Engineering, Jharkhand Rai University, Ranchi, Jharkhand, India
[2-8] Students, Department of Mining Engineering, Jharkhand Rai University, Ranchi, Jharkhand, India

Corresponding Author: * Sumeet Kishore

DOI: https://doi.org/10.5281/zenodo.23492713

Abstract

Dozer push mining is a widely adopted surface mining technique employed in coal and mineral extraction where overburden or fragmented rock is transported over short distances using bulldozers instead of conventional loading and hauling equipment (Konya & Walter, 1990; Jimeno et al., 1995). The method offers operational simplicity, lower capital investment, and improved productivity in shallow deposits (Bhandari, 1997). However, blasting operations associated with dozer push mining generate environmental concerns such as ground vibration and flyrock, which may threaten worker safety, nearby infrastructure, and mine productivity (Siskind et al., 1980; Singh et al., 2016). This paper reviews the foundational principles of dozer push mining and evaluates an empirical field case study conducted at Mine X in central India to analyze the major factors influencing blast vibration, flyrock generation, and casting efficiency. Various engineering measures—including blast design optimization, electronic delay detonators, stemming improvement, charge distribution, initiation sequencing, and real-time vibration monitoring—are evaluated (Dowding, 1996; Roy, 2005). The study concludes that adaptive blast planning, tailored to site-specific lithological variations, significantly enhances operational safety while maximizing dozer productivity in surface mines.

Manuscript Information

- **ISSN No:** 2583-7397
- **Received:** 10-09-2026
- **Accepted:** 13-10-2026
- **Published:** 18-10-2026
- **IJCRM:**5(SP2); 2026: 34-42
- **©2026, All Rights Reserved**
- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Kishore S, Bhatt H, Kamal S, Chouhan S, Kumar R, Das N R, Roy A K, Dey V K. Study of Dozer Push Mining Technique and Measures for Controlling Blast Vibration and Flyrock. Int J Contemp Res Multidiscip. 2026;5(SP2):34-42.

Access this Article Online

www.multiarticlesjournal.com

KEYWORDS: Dozer push mining, Surface mining, Blast vibration, Flyrock, Controlled blasting, Mine safety, Casting percentage.

© 2026 Sumeet Kishore, Harshit Bhatt, Swet Kamal, Suraj Chouhan, Rahul Kumar, Narayan Rabi Das, Amit Kumar Roy, Veeru Kumar Dey. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by-nc-nd/4.0/

1. INTRODUCTION

Surface mining is the dominant method for extracting coal and other near-surface mineral deposits because of its high production capacity, greater mechanization, and lower operating cost compared to underground mining methods. The widespread use of heavy earth-moving machinery, efficient drilling and blasting techniques, and continuous advancements in mine planning have significantly improved the productivity of surface mines over the past few decades (Jimeno et al., 1995; Bhandari, 1997). Among the various surface mining methods, dozer push mining has emerged as an effective and economical technique for extracting shallow coal seams and removing soft to moderately hard overburden where the material can be transported over relatively short distances. This mining method eliminates the need for large fleets of excavators and dump trucks by employing high-powered crawler dozers to push blasted material directly towards spoil dumps, loading points, or adjacent excavated areas. Consequently, the method offers reduced capital investment, simplified mine operations, and enhanced operational flexibility, making it particularly suitable for small- to medium-scale opencast coal mines.

The success of dozer push mining largely depends on the effectiveness of drilling and blasting operations. Since dozers are capable of efficiently pushing only well-fragmented material, the quality of blast fragmentation directly influences productivity, fuel consumption, equipment wear, and overall mining cost. Poorly fragmented rock increases dozer resistance, extends cycle time, and accelerates blade and undercarriage wear, thereby reducing operational efficiency. Moreover, inadequate blast design can result in excessive ground vibration, flyrock, air overpressure, and back-break, posing serious safety risks to mine personnel, equipment, nearby structures, and surrounding communities (Siskind et al., 1980; Singh et al., 2016). Ground vibrations generated during blasting may cause structural damage and slope instability, while uncontrolled flyrock remains one of the leading causes of blasting-related accidents in surface mines. Therefore, designing blasts that achieve optimum fragmentation while minimizing environmental impacts has become a major objective of modern mining operations.

Recent advances in blasting technology, including electronic delay detonators, computer-aided blast design, numerical modelling, and vibration prediction techniques, have enabled mining engineers to optimize blast performance and reduce adverse environmental effects. Nevertheless, achieving an appropriate balance between fragmentation efficiency and blast-induced hazards **(Rishi, 2026)** remains a significant challenge, particularly in dozer push mining where fragmentation quality directly determines excavation performance. This study therefore reviews the major operational characteristics of dozer push mining and integrates empirical field investigations from Mine X to evaluate how tailored blast geometries, initiation sequences, and stemming controls can simultaneously improve safety and excavation productivity in surface coal mines.

2. Dozer Push Mining Technique

Dozer push mining is a specialized surface mining method in which high-capacity crawler dozers are used to push blasted overburden or coal over relatively short distances instead of transporting the material using excavator–dump truck combinations. The method is particularly suitable for shallow coal deposits where the overburden is soft to moderately hard and the stripping ratio is relatively low. In most mining operations, the economical push distance generally ranges between 60 and 100 metres, beyond which fuel consumption, equipment wear, and operating costs increase significantly (Jimeno et al., 1995). The method is most effective in flat or gently dipping deposits where the terrain allows smooth movement of crawler dozers without excessive resistance or instability.

The mining cycle begins with detailed geological exploration and geotechnical investigations to determine the thickness of the overburden, coal seam characteristics, rock strength, and structural discontinuities. Based on these investigations, benches are designed considering their height, width, and overall slope stability. Drilling operations are then carried out according to the blast design parameters, including burden, spacing, hole diameter, sub-drilling, and stemming length. Explosive charging is performed using suitable explosives and initiation systems designed to produce optimum rock fragmentation while minimizing vibration and flyrock. After blasting, the fragmented overburden is inspected to evaluate fragmentation quality, muck pile profile, and blast performance. High-capacity crawler dozers subsequently push the blasted material towards spoil dumps or designated dumping locations, exposing the underlying coal seam for extraction. The coal is then mined separately and transported for processing or dispatch, while the spoil dumps are systematically managed to ensure long-term slope stability and environmental compliance.

The efficiency of the dozer push mining system depends on several interacting parameters, including fragmentation size distribution, push distance, bench geometry, dozer blade capacity, machine power, ground conditions, and rock mass characteristics (Konya & Walter, 1990). Well-fragmented rock significantly reduces pushing resistance, increases production rates, and lowers fuel consumption. Conversely, oversized boulders or uneven muck piles require secondary breaking or repeated dozer passes, reducing productivity and increasing operating costs. Consequently, effective integration of drilling, blasting, and dozer operations is essential for achieving maximum operational efficiency in dozer push mining.

3. Advantages of Dozer Push Mining

Dozer push mining offers several technical, operational, and economic advantages that make it an attractive mining method for suitable geological conditions. One of its primary benefits is the relatively low initial capital investment compared to conventional shovel–dumper systems because fewer heavy earth-moving machines are required (Jimeno et al., 1995). The

© 2026 Sumeet Kishore, Harshit Bhatt, Swet Kamal, Suraj Chouhan, Rahul Kumar, Narayan Rabi Das, Amit Kumar Roy, Veeru Kumar Dey. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by-nc-nd/4.0/

reduction in equipment fleet size also lowers maintenance costs, spare parts inventory, and manpower requirements, thereby reducing the overall operating cost of mining operations (Bhandari, 1997).

Another significant advantage is its operational flexibility. High-capacity crawler dozers can easily adapt to varying bench conditions and rapidly respond to changing production requirements without requiring extensive infrastructure modifications. The simplicity of the mining cycle enables faster mine development and quicker exposure of coal seams, which improves production scheduling and resource utilization. Since the dozers directly push blasted material without loading and hauling operations, traffic congestion within the mine is minimized, reducing safety risks associated with heavy vehicle movement.

The method is also particularly suitable for selective mining operations where precise removal of overburden is required to minimize coal dilution. Modern crawler dozers equipped with advanced hydraulic systems and GPS-based guidance can achieve accurate material movement, improve ore recovery and reduce waste. Their superior maneuverability allows efficient operation in confined working areas and irregular bench geometries where larger excavation equipment may not be practical. Furthermore, the simplified equipment fleet contributes to lower maintenance downtime, improved equipment availability, and increased operational reliability. These advantages collectively make dozer push mining a cost-effective solution for many shallow opencast coal mines with favourable geological conditions.

4. Limitations of Dozer Push Mining

Despite its numerous advantages, dozer push mining has several operational and economic limitations that restrict its application to specific mining conditions. The most significant limitation is the restricted economical push distance. As the distance over which the blasted material must be pushed increases, dozer productivity decreases rapidly due to increased rolling resistance, longer cycle times, and higher fuel consumption. Beyond approximately 100 metres, the operating cost of dozer pushing generally becomes higher than that of conventional shovel–dump truck systems, making the method economically less attractive (Konya & Walter, 1990).

The performance of dozer push mining is also highly dependent on the mechanical properties of the rock mass and the quality of blast fragmentation. Hard, massive, or poorly fractured rock formations require greater pushing force and often produce oversized boulders that reduce dozer efficiency and increase wear on blades, cutting edges, tracks, and undercarriage components. Excessive equipment wear not only increases maintenance costs but also results in higher machine downtime and reduced equipment availability.

Another important limitation is the strong dependence of the mining system on effective drilling and blasting practices. Inadequate blast design produces poor fragmentation, irregular muck piles, excessive toe formation, and uneven bench floors, all of which reduce dozer productivity and increase operating costs. Moreover, improper blasting can generate excessive ground vibration, flyrock, air overpressure, and slope damage, creating serious safety hazards and environmental concerns. Weather conditions also influence the effectiveness of dozer push mining. Heavy rainfall, muddy ground, poor visibility, and water accumulation on benches reduce traction, increase machine slippage, and adversely affect operational efficiency. Therefore, successful implementation of dozer push mining requires careful mine planning, optimized blast design, regular equipment maintenance, and continuous monitoring of geological and environmental conditions to ensure safe, productive, and cost-effective mining operations.

5. Blast Vibration

Blast-induced ground vibration is one of the most significant environmental and safety concerns associated with drilling and blasting operations in surface mines. During detonation, only a portion of the explosive energy is utilized for fragmenting and displacing the rock mass, while the remaining energy propagates through the surrounding ground in the form of seismic waves. These waves travel through the rock strata and may cause vibration of nearby structures, mine slopes, equipment, and underground workings (Dowding, 1996). Excessive ground vibration can result in structural damage to buildings, cracking of mine infrastructure, slope instability, discomfort to nearby residents, and interruption of mining operations. Consequently, controlling blast vibration has become an essential aspect of modern blasting practice, particularly in mines located close to villages, industrial installations, highways, railways, or environmentally sensitive areas.

Ground vibration is generally evaluated using Peak Particle Velocity (PPV), which represents the maximum velocity at which a particle of the ground moves during blasting and is widely accepted as the most reliable indicator of potential structural damage. In addition to PPV, the frequency of vibration plays an important role in determining its impact on structures. Low-frequency vibrations tend to cause greater structural response and are therefore considered more damaging than high-frequency vibrations of the same amplitude. Another important parameter is the Vector Sum (Resultant Particle Velocity), which combines vibration components measured in the longitudinal, transverse, and vertical directions to determine the overall vibration intensity experienced at a monitoring location. Modern blasting operations employ tri-axial seismographs to record these vibration parameters, enabling engineers to assess blast performance and ensure compliance with regulatory vibration limits.

The magnitude of blast vibration is influenced by several interrelated geological, explosive, and design parameters. Among these, the maximum explosive charge detonated per delay is considered the most critical factor, as vibration

© 2026 Sumeet Kishore, Harshit Bhatt, Swet Kamal, Suraj Chouhan, Rahul Kumar, Narayan Rabi Das, Amit Kumar Roy, Veeru Kumar Dey. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by-nc-nd/4.0/

intensity generally increases with increasing charge weight. The distance between the blast and the monitoring point also has a significant influence because vibration energy attenuates as seismic waves travel through the rock mass. Geological factors such as rock type, density, elasticity, joint orientation, weathering, and groundwater conditions affect the transmission and attenuation of vibration waves. Blast design parameters, including burden, spacing, bench height, hole diameter, stemming length, and sub-drilling, determine the confinement of explosive energy and consequently influence vibration levels. Furthermore, the initiation sequence and delay timing control the interaction of stress waves generated by individual blast holes. Proper sequencing using millisecond or electronic delay detonators can significantly reduce the effective charge per delay and minimize vibration levels. The type, density, velocity of detonation, and energy characteristics of the explosive also affect the amount of energy transmitted into the surrounding rock mass.

To minimize blast-induced vibration, several engineering measures are adopted in surface mines. These include limiting the maximum charge per delay, optimizing burden and spacing, using precise electronic delay detonators, maintaining adequate stemming length, employing deck charging techniques, and conducting trial blasts to optimize blast design. Continuous vibration monitoring using digital seismographs and the application of empirical vibration prediction equations, such as the scaled distance approach, enable mine engineers to predict vibration levels before blasting and modify blast parameters accordingly. The implementation of these measures not only enhances blasting efficiency but also ensures compliance with environmental regulations, protects nearby structures, and improves the overall safety and sustainability of dozer push mining operations.

The empirical relationship developed by the United States Bureau of Mines (USBM) is commonly used to model vibration attenuation:

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

Were,

PPV = Peak Particle Velocity (mm/s)
D = Distance from the blast face to the monitoring point (m)
W = Maximum explosive charge per delay (kg)
K = Site-specific constant
n = Site-specific attenuation constant

6. Factors Affecting Blast Vibration

Blast-induced ground vibration is governed by a complex interaction of geological conditions, blast design parameters, and explosive characteristics. Understanding these factors is essential for designing safe and efficient blasting operations that achieve the desired fragmentation while minimizing environmental impacts. The magnitude and propagation of vibration waves vary from one mining site to another due to differences in rock mass properties, explosive energy distribution, and initiation sequence. Consequently, a comprehensive assessment of these factors is necessary before finalizing any blast design.

6.1 Geological Factors

Geological conditions significantly influence the generation and propagation of blast-induced seismic waves. Rock mass characteristics such as joint orientation, spacing, persistence, and aperture determine the transmission and attenuation of vibration energy through the ground. Closely spaced joints tend to dissipate seismic energy more effectively than massive, intact rock formations. Similarly, the strength and elasticity of the rock influence wave velocity and vibration amplitude. Hard and competent rocks generally transmit vibration over longer distances, whereas fractured or weathered rocks absorb and attenuate a larger portion of the explosive energy. Geological discontinuities such as faults, shear zones, bedding planes, and weathered formations can alter the direction and intensity of vibration waves by reflecting, refracting, or dissipating seismic energy. Therefore, detailed geological and geotechnical investigations are essential for predicting vibration levels and optimizing blast designs in surface mines.

6.2 Blast Design Parameters

The design of the blast pattern plays a crucial role in controlling ground vibration. Parameters such as burden, spacing, hole diameter, bench height, stemming length, and sub-drilling determine how effectively explosive energy is utilized for rock breakage. An insufficient burden may result in excessive rock displacement and flyrock, whereas an excessive burden increases confinement and consequently raises vibration levels. Proper spacing ensures uniform fragmentation and balanced energy distribution throughout the blast. The selection of an appropriate hole diameter influences the explosive charge concentration and energy release, while bench height affects the confinement and movement of blasted material. Similarly, sub-drilling is required to ensure complete breakage at the bench floor, but excessive sub-drilling may unnecessarily increase explosive consumption and vibration intensity. Optimizing these design parameters improves fragmentation efficiency while minimizing undesirable environmental effects.

6.3 Explosive Parameters

The characteristics of the explosives and the initiation system also have a significant impact on blast vibration. The type of explosive, its energy content, density, and velocity of detonation determine the amount of energy released during blasting. High-energy explosives generally produce greater vibration if not properly controlled. The charge concentration or explosive quantity per delay is considered one of the most influential factors affecting Peak Particle Velocity (PPV), with larger charges producing higher vibration levels. Delay timing between blast holes controls the interaction of stress waves generated by successive detonations. Appropriate delay

© 2026 Sumeet Kishore, Harshit Bhatt, Swet Kamal, Suraj Chouhan, Rahul Kumar, Narayan Rabi Das, Amit Kumar Roy, Veeru Kumar Dey. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by-nc-nd/4.0/

intervals prevent constructive interference of seismic waves and reduce the effective charge detonated at any instant. Modern deck charging techniques, in which explosive columns are separated by inert materials, further reduce vibration by dividing the total explosive charge into smaller segments. Careful selection of explosive parameters therefore enables mining engineers to achieve optimum fragmentation while maintaining vibration within permissible limits.

7. Flyrock

Flyrock is one of the most hazardous consequences of blasting operations in surface mines and is defined as the uncontrolled projection of rock fragments beyond the designated blast zone due to excessive explosive energy or inadequate confinement. It remains one of the leading causes of blasting-related accidents worldwide, often resulting in injuries, fatalities, damage to mining equipment, nearby buildings, public infrastructure, and interruptions to mining operations (Roy, 2005; Singh et al., 2016). Since flyrock can travel hundreds of metres from the blast site, effective control measures are essential to ensure the safety of mine personnel and surrounding communities.

Several factors contribute to the occurrence of flyrock. Excessive explosive charge generates more energy than required for rock fragmentation, causing fragments to be projected over long distances. Inadequate stemming allows explosive gases to escape prematurely through the blast hole collar, producing violent rock ejection. Geological conditions such as fractured rock masses, weak zones, cavities, faults, and weathered formations reduce confinement and increase the likelihood of uncontrolled rock projection. Incorrect burden and spacing may either over-confine or under-confine the explosive charge, both of which can generate flyrock. Blast hole deviation, caused by inaccurate drilling, alters the intended explosive distribution and may create localized areas of excessive energy concentration. Additionally, premature initiation or accidental simultaneous detonation of blast holes can significantly increase the energy released at one instant, leading to dangerous flyrock incidents. Therefore, careful blast planning, accurate drilling, and proper explosive loading are essential to minimize flyrock hazards.

8. Measures for Controlling Blast Vibration

Effective control of blast-induced ground vibration requires the integration of appropriate blast design, modern initiation systems, and continuous monitoring. One of the most effective methods of reducing vibration is to limit the maximum explosive charge detonated per delay. Since vibration intensity is directly related to the charge weight per delay, dividing the total explosive quantity into smaller charges significantly reduces Peak Particle Velocity (PPV) while maintaining adequate rock fragmentation.

The adoption of electronic delay detonators has greatly improved vibration control in modern blasting operations. Unlike conventional pyrotechnic detonators, electronic detonators provide highly accurate delay intervals with minimal timing deviations. Precise initiation sequencing minimizes the superposition of seismic waves, resulting in lower vibration levels, improved fragmentation, reduced flyrock, and better muck pile formation. Consequently, electronic initiation systems have become increasingly popular in large-scale surface mining projects where environmental compliance is a major concern.

Another effective vibration control technique is deck charging, in which explosive columns within a blast hole are separated by inert stemming material. This arrangement reduces the amount of explosive detonated simultaneously, thereby lowering vibration intensity without significantly affecting fragmentation performance. Similarly, optimization of blast hole geometry, including burden, spacing, bench height, hole diameter, and stemming length, ensures efficient distribution of explosive energy throughout the rock mass. Properly designed blast patterns minimize excessive confinement and improve energy utilization.

The use of sequential firing with appropriate delay intervals further reduces blast vibration by preventing constructive interference of stress waves generated by adjacent blast holes. Modern blasting practices also emphasize continuous vibration monitoring using digital tri-axial seismographs capable of recording Peak Particle Velocity (PPV), vibration frequency, and complete waveform characteristics. The recorded data enable mining engineers to validate blast designs, compare measured values with predicted results, and refine future blasting operations for improved safety, productivity, and environmental compliance (Singh et al., 2016).

9. Measures for Controlling Flyrock

Preventing flyrock requires careful attention to blast design, drilling accuracy, explosive loading, and safety management. One of the most important preventive measures is the proper design of burden and spacing, ensuring that explosive energy is adequately confined within the rock mass. Appropriate burden prevents excessive rock displacement and minimizes the projection of fragments beyond the intended blast area.

The quality of stemming plays a crucial role in controlling flyrock. Well-compacted angular crushed stone provides significantly better confinement than drill cuttings, allowing explosive gases to remain within the blast hole for a longer duration and improving fragmentation while reducing rock ejection. In blasting operations conducted near sensitive structures or populated areas, blast mats made of rubber, steel wire mesh, or heavy chains are commonly placed over the blast area to physically restrain flying rock fragments and enhance safety.

Strict implementation of blast safety procedures is equally important. All personnel, vehicles, and equipment should be evacuated from the designated blast danger zone before initiation, and properly designed blast shelters should be used wherever necessary. Prior to charging, detailed geological

© 2026 Sumeet Kishore, Harshit Bhatt, Swet Kamal, Suraj Chouhan, Rahul Kumar, Narayan Rabi Das, Amit Kumar Roy, Veeru Kumar Dey. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by-nc-nd/4.0/

mapping should be undertaken to identify faults, weak zones, cavities, and highly fractured rock that may increase the risk of flyrock. Recent advancements in blast simulation software enable engineers to predict fragmentation patterns, vibration levels, and potential flyrock distances before blasting, allowing necessary modifications to the blast design. The integration of these engineering and safety measures significantly reduces the probability of flyrock accidents while improving overall blasting efficiency (Bhandari, 1997; Roy, 2005).

10. Modern Technologies in Blast Design and Control

Rapid technological advancements have transformed drilling and blasting practices in the mining industry by improving precision, safety, productivity, and environmental performance. Electronic delay detonators provide millisecond-level timing accuracy, enabling precise control over explosive energy release and reducing both blast vibration and flyrock. Drone-based blast inspection and Unmanned Aerial Vehicle (UAV) photogrammetry are increasingly used for pre-blast surveying, post-blast fragmentation analysis, volumetric measurements, and assessment of muck pile characteristics without exposing personnel to hazardous conditions.

High-speed blast imaging systems capture the detonation process in real time, allowing engineers to study explosive behaviour, rock movement, and fragmentation mechanisms in detail. The application of Artificial Intelligence (AI) and machine learning algorithms has further enhanced blast optimization by analysing historical blasting data and recommending optimal drilling and charging parameters for different geological conditions. Modern GPS-enabled drilling systems improve drilling accuracy by ensuring precise hole positioning, inclination, and depth, thereby reducing blast design errors and improving fragmentation consistency.

In addition, real-time vibration monitoring systems equipped with wireless sensors provide immediate feedback on blast performance, enabling engineers to verify compliance with permissible vibration limits and make timely adjustments for subsequent blasts. Integrated digital blast management systems combine geological data, drill plans, explosive loading records, initiation sequencing, and monitoring results into a centralized platform for efficient planning and decision-making. Collectively, these advanced technologies have significantly improved blast precision, fragmentation quality, operational safety, environmental compliance, and the overall efficiency of dozer push mining operations (Singh et al., 2016).

11. Case Study: Field Investigations at Mine X Open Cast Mine

To validate the operational and environmental blast control measures reviewed in the preceding sections, an empirical field investigation was conducted at the Mine X open cast coal mine. The objective of the field trials was to evaluate the direct interaction between blast hole inclination, stemming length, delay sequencing, and subsequent dozer-push productivity in varying lithological conditions.

11.1 Study Area and Geological Setting

The Mine X open cast coal mine is located in the Hasdo-Arand coalfield of central India in northern Chhattisgarh. The coalfield is associated with the Mahanadi Valley Gondwana basin and contains three workable coal seams: Seam IV, Seam V, and Seam VI, with Seam IV identified as the most significant in terms of both quality and reserves.

The dozer-push application evaluated in this study was implemented within the inter-burden strata between Seam IV and Seam V. The host rock mass was highly heterogeneous and comprised the following distinct lithological units:

- Carbonaceous shale
- Fine- to medium-grained sandstone
- Medium-grained sandstone
- Friable sandstone
- Medium- to coarse-grained friable sandstone
- Coarse-grained friable sandstone

This lithological variation is critical from an operational perspective, as a blast design that produces satisfactory fragmentation and directional movement in one rock type may fail to achieve the same efficacy in another. The Mine X field investigation underscores a foundational principle of dozer-push mining: fixed blast patterns are ineffective across an entire mining block; instead, continuous field adjustments must be made to adapt blast geometry to real-time face conditions.

11.2 Field Trials and Blast Configuration Adjustments

A series of eleven experimental field trials were executed within the inter-burden to optimize casting percentage, muckpile profiling, backbreak, and environmental impacts (ground vibration and flyrock). Throughout the trials, blast hole inclinations were systematically modified to account for changing face geometries and rock mass structures.

In the seventh trial, a uniform 20° inclination across the entire blast block achieved a casting percentage of 14% with no observable backbreak during post-blast inspections. However, during the eighth trial, the inclination was reduced to 10° for the first seven rows and 15° for the final row. This geometric modification was necessitated by a vertical face present near the free face, demonstrating that blast design must actively adapt to local structural constraints to avoid puncturing the face or generating uncontrolled rock projection.

Subsequent attempts to further reduce inclination in the ninth trial—utilizing 5° in the first six rows, followed by 10° and 15° in the final rows—resulted in localized flyrock and a wide dispersion of recorded ground vibration. Field investigations revealed that this instability was largely linked to inconsistent stemming lengths, where reduced stemming columns allowed premature gas venting and rock ejection.

Synthesizing these findings, the tenth trial implemented an optimized configuration of 20° inclination in the first two rows

© 2026 Sumeet Kishore, Harshit Bhatt, Swet Kamal, Suraj Chouhan, Rahul Kumar, Narayan Rabi Das, Amit Kumar Roy, Veeru Kumar Dey. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by-nc-nd/4.0/

and 15° in the remaining rows. This arrangement produced an improved muckpile profile with superior cast characteristics compared to earlier trials. With an average hole depth of approximately 19.4 m, the recorded Peak Particle Velocity (PPV) ranged safely between 2.953 mm/s and 5.074 mm/s at designated monitoring stations. The eleventh trial acted as a confirmatory test, retaining the 20° to 15° inclination concept while enforcing strict stemming control, successfully verifying its suitability for continuous production.

11.3 Results and Analysis of Field Trials

The operational and environmental outcomes of all eleven field trials are synthesized in **Table 1**, illustrating the progressive optimization of the blast architecture.

Table 1: Summary of Field Blast Trials and Operational Observations at Mine X

Trial No.	General Inclination Arrangement	Casting (%)	Primary Field Observation
1	10° to vertical	6.8	Toe burden formation; minor break
2	15°–10°–5° to vertical	4.8	Reduced sidebreak
3	20°	12.5	Higher cast percentage; larger fragments
4	20°	16.3	Good cast and perimeter control
5	25° / 20°	13.67	Lower backbreak observed
6	25° / 20°	16.4	High cast; no sidebreak
7	20°	14.0	No backbreak
8	10° / 15°	—	Adjusted for face protection
9	5° / 10° / 15°	—	Flyrock observed; wide vibration range
10	20° / 15°	—	Improved muckpile profile; PPV 2.953–5.074 mm/s
11	20° / 15°	—	Confirmatory trial; stable cast and containment

11.3.1 Influence of Blasthole Inclination

The field data indicates a distinct relationship between blast hole inclination and casting performance, with cast percentages generally increasing as inclinations were adjusted from near-vertical (10° to vertical) to angled configurations (20° and 25°). However, the results demonstrate that higher inclination does not unilaterally equate to superior blast performance. For example, while the sixth trial (25°/20°) achieved a high casting percentage of 16.4%, it also produced larger, oversized rock fragments that impeded smooth dozer operation. In contrast, the tenth trial (20°/15° combination) yielded a more balanced muckpile profile that optimized both fragmentation sizing and horizontal displacement. Consequently, effective dozer-push blasting requires selecting a balanced *inclination pattern* tailored to local geology rather than maximizing a single inclination angle.

11.3.2 Importance of Stemming

Stemming column integrity emerged as a critical determinant of both safety and explosive energy utilization. A short stemming column allowed premature escape of high-pressure detonation gases, directly correlating with the flyrock incidents observed in the ninth trial. Conversely, excessive stemming reduced explosive energy distribution in the upper bench strata, leading to poor fragmentation and boulder formation.

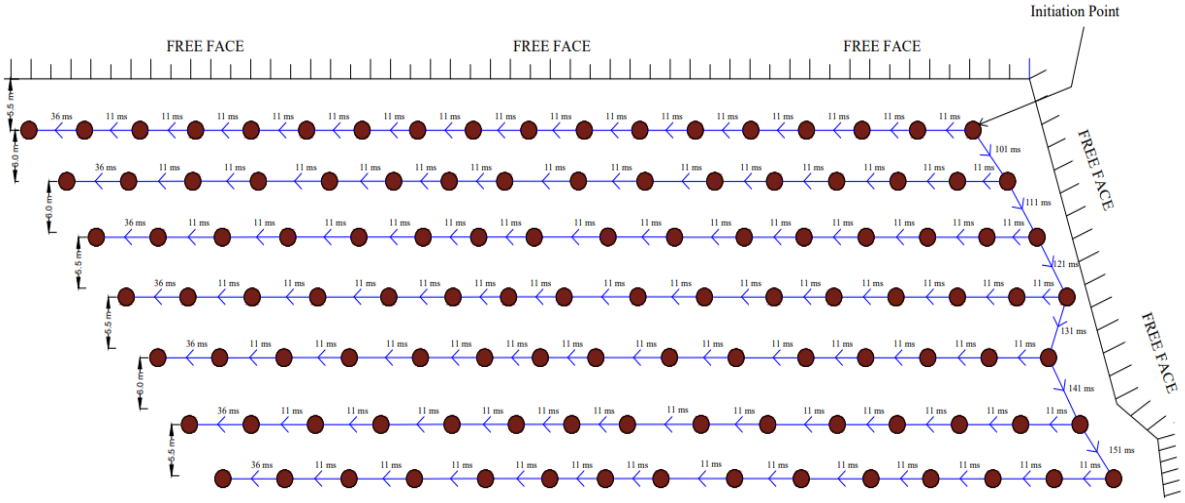
Under the heterogeneous sandstone and shale conditions of the Mine X inter-burden, an optimized stemming column of approximately 4.5 m provided the ideal operational balance between energy containment and rock fragmentation. Because the primary objective of dozer-push mining is controlled, predictable material displacement, maintaining rigorous stemming standards is vital to prevent uncontrolled vertical rock ejection and preserve horizontal casting energy.

11.3.3 Delay Sequencing and Directional Movement

The field trials confirmed that initiation delay sequencing acts as a primary movement-control parameter. The Mine X trials utilized short millisecond delays between holes within a given row, combined with a progressively extended inter-row firing sequence.

Crucially, the incorporation of a "jump delay" at the final hole of each row consistently reduced sidebreak across the trials. This confirms that where perimeter control and bench wall stability are required, the terminal hole in a row should not detonate in immediate sequence with adjacent holes. By utilizing delay timing to govern stress-wave interaction and gas expansion paths, engineers can actively shape the resulting muckpile to suit crawler dozer push geometries while mitigating ground vibration amplitudes.

© 2026 Sumeet Kishore, Harshit Bhatt, Swet Kamal, Suraj Chouhan, Rahul Kumar, Narayan Rabi Das, Amit Kumar Roy, Veeru Kumar Dey. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by-nc-nd/4.0/



11.3.4 Operational Compatibility Between Blasting and Dozer Equipment

An overarching finding of the Mine X investigation is that drilling/blasting operations and crawler dozer performance cannot be evaluated as independent operational silos. A blast that achieves maximum casting distance is counterproductive if it generates oversized boulders that increase dozer blade resistance, mechanical wear, and cycle times. Similarly, a blast that achieves exceptionally fine fragmentation without providing adequate forward displacement increases the required dozer push distance, elevating fuel consumption and operating costs.

Based on the empirical findings at Mine X, the optimal blast design for dozer-push mining must simultaneously satisfy five criteria:

- **Acceptable Fragmentation:** Consistent rock sizing without oversized boulders to minimize dozer pushing resistance.
- **Controlled Cast Movement:** Maximum horizontal displacement of material toward the spoil dump to shorten mechanical push distances.
- **Limited Backbreak:** Preservation of highwall and bench stability for subsequent mining cycles.
- **Minimal Flyrock:** Strict containment of explosive energy within the bench to protect personnel and machinery.
- **Compatible Muckpile Profile:** A gently sloped, evenly distributed muckpile that allows immediate dozer deployment without requiring secondary leveling passes.

12. DISCUSSION

Efficient dozer push mining depends largely on optimum fragmentation produced through scientific blast design (Jimeno et al., 1995). The integration of theoretical principles with empirical field evidence from Mine X demonstrates that while general literature emphasizes the economic benefits of reducing excavator fleets in shallow surface deposits, the practical execution of dozer pushing is entirely governed by the physical characteristics of the post-blast muckpile. Proper fragmentation reduces dozer cycle time, equipment wear, and fuel consumption while improving overall productivity (Konya & Walter, 1990).

The Mine X case study illustrates that standardizing blast parameters across heterogeneous stratigraphies—such as transitioning from carbonaceous shale to friable sandstones—can lead to operational failures, including flyrock hazards, excessive ground vibration, and poor fragmentation. The empirical data confirms that blast hole inclination is a primary driver of casting percentage; however, as shown in the comparison between the sixth (16.4% cast with larger fragments) and tenth (improved overall profile) trials, casting volume must be balanced against fragmentation sizing.

Furthermore, the field findings validate that ground vibration and flyrock can be substantially controlled by optimizing burden, spacing, charge per delay, stemming quality, and initiation sequence (Siskind et al., 1980; Singh et al., 2016). Maintaining a 4.5 m stemming column and introducing jump delays at row terminuses effectively prevented explosive gas venting, eliminated flyrock, controlled sidebreak, and maintained Peak Particle Velocities (PPV) well within safe operational limits (2.953–5.074 mm/s). The adoption of electronic detonators, vibration monitoring systems, drones, and blast simulation software further enhances operational safety and environmental performance (Roy, 2005). Ultimately, blasting in a dozer-push system must be treated as the primary material-handling process, where explosives are utilized not merely to fracture rock, but to shape and displace the overburden into a profile that minimizes crawler dozer cycle times and mechanical wear.

13. CONCLUSIONS

Dozer push mining is an economical surface mining technique for shallow deposits with limited haul distances (Jimeno et al., 1995). Its effectiveness depends primarily on well-designed

© 2026 Sumeet Kishore, Harshit Bhatt, Swet Kamal, Suraj Chouhan, Rahul Kumar, Narayan Rabi Das, Amit Kumar Roy, Veeru Kumar Dey. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by-nc-nd/4.0/

drilling and blasting operations that produce adequate fragmentation while minimizing environmental impacts (Konya & Walter, 1990). Ground vibration and flyrock remain significant concerns affecting mine safety and nearby infrastructure (Siskind et al., 1980). Scientific blast design, optimized explosive distribution, electronic initiation systems, and continuous vibration monitoring effectively reduce these adverse impacts (Singh et al., 2016).

The empirical investigations conducted at the Mine X open cast mine provide concrete operational guidelines for optimizing dozer-push blasting in heterogeneous overburden:

1. **Adaptive Blast Geometry:** Fixed blast patterns should be avoided. Blast hole inclinations must be dynamically adjusted (e.g., utilizing combined 20°/15° profiles) to accommodate geological variations and protect exposed face geometries.
2. **Balanced Energy Allocation:** Maximizing casting percentage must not come at the expense of fragmentation quality. Blast designs must balance forward displacement with uniform rock sizing to prevent high dozer blade resistance and equipment wear.
3. **Rigorous Stemming Control:** An optimized stemming column (such as the 4.5 m standard established at Mine X) is essential to contain detonation energy, prevent flyrock, and ensure explosive energy is utilized for horizontal displacement rather than vertical ejection.
4. **Strategic Delay Sequencing:** Firing patterns must be leveraged as movement-control parameters. The application of inter-row timing adjustments and terminal jump delays effectively minimizes sidebreak, shapes the muckpile for dozer accessibility, and keeps ground vibration (PPV) within regulatory environmental limits.

By treating blast design as an integrated component of mechanical excavation, surface mining operations can successfully mitigate environmental hazards such as ground vibration and flyrock while maximizing the productivity, safety, and profitability of dozer-push mining systems. Future research should focus on AI-based blast optimization, machine learning models for vibration prediction, and digital twin technologies to further improve blasting efficiency and environmental sustainability.

REFERENCES

1. Jimeno CL, Jimeno EL, Carcedo FJA. Drilling and blasting of rocks. Rotterdam: A.A. Balkema; 1995.
2. Konya CJ, Walter EJ. Surface blast design. Englewood Cliffs (NJ): Prentice Hall; 1990.
3. Singh PK, Roy MP, Paswan RK, Sarim MD, Kumar S, Jha RR. Blast vibration analysis in surface mines. J Rock Mech Geotech Eng. 2016;8(3):341-349.
4. Siskind DE, Stagg MS, Kopp JW, Dowding CH. Structure response and damage produced by ground vibration from surface my blasting. Washington (DC): U.S. Bureau of Mines; 1980. Report No. RI 8507.
5. Dowding CH. Construction vibrations. Englewood Cliffs (NJ): Prentice Hall; 1996.
6. Langefors U, Kihlström B. The modern technique of rock blasting. New York: John Wiley & Sons; 1978.
7. Bhandari S. Engineering rock blasting operations. Rotterdam: A.A. Balkema; 1997.
8. Roy PP. Rock blasting: effects and operations. Boca Raton (FL): CRC Press; 2005.
9. Rishi SK. An integrated assessment of occupational disease prevalence among coal mine workers in India. Indian J Mod Res Rev. 2026 May 18. p. 152-155. ISSN 2584-184X.

Creative Commons (CC) License

This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution–Non-Commercial–No Derivatives 4.0 International (CC BY-NC-ND 4.0) license. This license permits sharing and redistribution of the article in any medium or format for non-commercial purposes only, provided that appropriate credit is given to the original author(s) and source. No modifications, adaptations, or derivative works are permitted under this license.

© 2026 Sumeet Kishore, Harshit Bhatt, Swet Kamal, Suraj Chouhan, Rahul Kumar, Narayan Rabi Das, Amit Kumar Roy, Veeru Kumar Dey. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY NC ND).https://creativecommons.org/licenses/by-nc-nd/4.0/