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Review of Studies on Ground Vibrations and the Future Needs for Research

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Abstract

Fragmentation using Explosives by blasting is the most economical, cheapest and fastest process method of rock fragmentation and the loosening of the material from the host rock, thus making it suitable for excavation. Rock fragmenting makes it ideal for excavation. Blasting performance is generally determined, affected by the structure and Rock Properties of the rock mass characteristics. Volumes of rock blast per blast are increasing as the average size of the mine and the excavation in civil engineering practices is rising. Blasting also produces many undesired outcomes, such as overbreak, ground vibrations, noise, air overpressure, and fumes, which, if not controlled, can be damaging to the neighbourhood and the structures in the vicinity. The objective of this paper is to review the research done on blast-induced ground vibrations till now and broadly identify the research gap. Research so far includes the study of various methods to control ground vibrations and the resulting damage, and formulating allowable limits of ground vibrations. Previous studies aimed at developing empirical formulae for the precise prediction of ground vibrations and enhancing the accuracy of the prediction models. And to improve prediction accuracy. The research gap identified includes the need to study the effects and use of various parameters such as depth of blast from the ground surface, length of the charge, the study of accuracy and inaccuracy of delay detonators and their acceptable limits, effects of geological structures such as jointing pattern, geo-mechanical properties of rock, strata changes and continuous improvement in prediction formulae using cloud computing, IoT (Internet of things) and data mining.

Keywords: *Blasting, Frequency, Model, Peak Particle Velocity PPV, Prediction, Vibration*

1.0 Introduction

Mining is the extraction of minerals from the earth. Mining is the process of extracting valuable geological materials from the Earth's crust. The society uses these minerals for its daily necessities. It includes the movement of massive amounts of both hard and soft rock. Wherever hard rock is encountered, it must be broken into smaller pieces to make it easier to handle during excavation. Size reduction can be accomplished in a variety of ways, including

a) Mechanical processes: cutting, hammering, etc
b) Chemical methods include expanding agents and explosives
c) Other methods include flame cutting

As shown in Figure 1, blasting is the most cost-effective approach for producing large quantities of rock required for current excavation needs.

Blasting has numerous environmental consequences, including ground vibrations, fly rock, poisonous gases, dust, and air overpressure. Because of its potential for

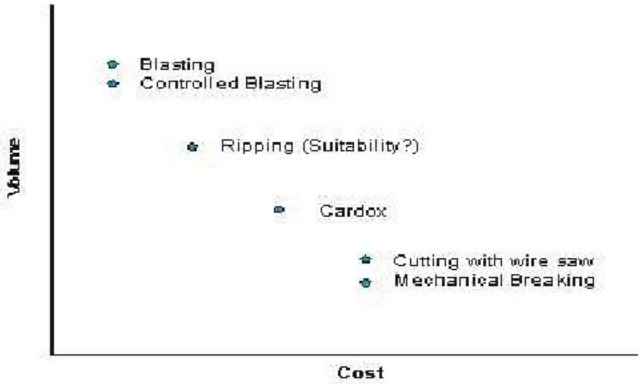

Figure 1. Volume in cubic meters Vs Cost in US dollars (Indicative, not to scale).

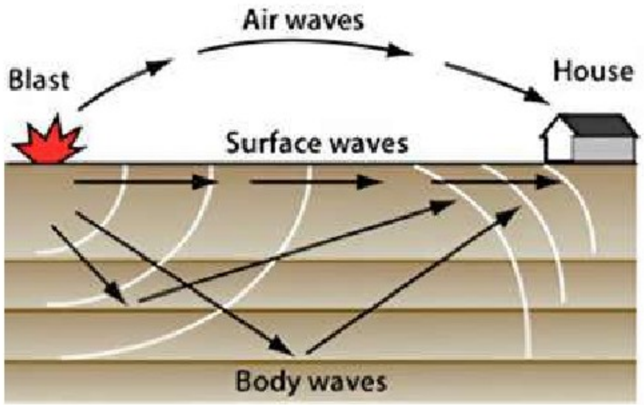

Figure 2. Blast wave and its Propagation.

destruction, it is at risk of being utilised by anti-social groups, necessitating tight manufacturing, transportation, and use protocols.

Among all of the issues, ground vibrations are a key source of concern for blasting engineers because they have the ability to harm structures and cause pain to humans and animals.

As a result, numerous researchers are researching this area to better understand and address the problem, as well as to conduct safe blasts.

1.1 General Characteristics of Blast Vibration

A set of waves is produced when a charge explodes in a solid material, such as rock. There are three primary types of waves produced by explosions: surface, shear, and compressive. Motion needs to be measured in three perpendicular directions, viz, horizontal, radial, and vertical, to fully characterise the motion of the waves. The longitudinal component (L) is usually oriented along a horizontal radius to the explosion. The other two perpendicular components will be vertical (V) and transverse (T) to the radial (R) direction. The three main wave types can be divided into two varieties: body waves, which propagate through the body of the rock and soil, and surface waves, which are transmitted along the upper ground surface (Figure 2).

Further classifications of body waves include compressive waves (shown as P waves) and shear waves (represented as S waves). Body waves are mostly produced at close range by explosions. Until they come into contact with a boundary, such as another layer of rock, soil, or the earth, these body waves spread outward in a spherical pattern. Shear and surface waves are created at this juncture. Rayleigh surface waves become significant when transmission lengths are long.

The more slowly moving shear and surface waves start to split from the compressive wave at long distances, making wave type identification much easier. At small distances, all three wave types will arrive simultaneously and significantly confuse wave type identification. As they pass, the three wave types cause radically distinct patterns of motion in the rock and soil particles. Because of this, each wave will cause a building made of rock or soil to deform differently. Particle motions are produced by the longitudinal (compressive) wave in the same direction as it propagates. As it propagates, the shear wave causes motions that are either vertical or horizontal and perpendicular to its path. Motions are produced by the Rayleigh wave both parallel to and perpendicular to its propagation path.

1.2 Factors Affecting Ground Vibration

Ground vibration depends on both uncontrollable and controllable factors. Rock characteristics such as strength, density, and porosity influence seismic wave velocity and frequency, with harder rocks producing higher frequencies. Discontinuities like joints and faults scatter waves, reducing peak amplitudes and modifying frequency content due to reflection and interference. Distance from the blast decreases particle velocity through wave absorption and geometric spreading, while the structural condition and its natural frequency affect response, especially under resonance conditions.

Among controllable factors, blast geometry plays a key role; large hole diameters and excessive burden increase confinement, resulting in higher vibration amplitudes, while proper sub-drilling reduces them. The type and amount of explosive also matter since vibration magnitude is proportional to the charge per delay—ANFO, with low density and detonation pressure, generates lower vibrations compared to gelatinous explosives. Absence of a free face, as in buffer blasting, increases confinement and vibration levels. Proper priming and initiation with adequate delay reduce wave superimposition, as delays create separate wave fronts. Finally, delay timing influences reinforcement; when pulses arrive simultaneously, vibration amplifies, while longer delays produce independent pulses and lower peak amplitudes, as governed by the relation $t_e \times C_m = t_d - S\ cos\Phi$.

2.0 Permissible Limits for Ground Vibration and Predictors

2.1 Permissible Limits for Ground Vibration

It is generally agreed that PPV and frequency play a major role in assessing the damage potential of the ground vibrations.

Many countries have suggested different criteria, as mentioned below, all based on the type of structures and dominant frequencies.

2.1.1 USBM RI: 8507 (1980)– USA[1] (Table 1)

2.1.2 DGMS, Dhanbad, India (Technical Circular 07 of 1997)[2] (Table 2)

2.1.3 ISO - International Standard - 4866 of 1980[3] (Table 3)

2.1.4 British Standard 7385: Part 2, UK (1993)[4](Table 4)

2.1.5 DIN (Deutsches Institute für Normung) - German standards[5] (Table 5)

2.2 Vibration Predictor

Different researchers proposed different relationships between vibrations, explosive charges, and distances. Morris (1950)[6] proposed a relationship given by,

Table 1. USBM standards

`Type of structure	Ground peak particle velocity (mm/sec)	
	High Frequency > 40 Hz	**Low Frequency** < 40 Hz
Modern homes (drywall)	50.8	19.1
Older homes (plaster)	50.8	12.7

Table 2. Permissible Peak Particle Velocity (PPV) at the foundation level of structures in the mining areas in mm/s

TYPE OF STRUCTURES	DOMINANT EXCITATION FREQUENCY		
	< 8 Hz	**8 - 25 Hz**	**> 25 Hz**
A) Buildings/structures do not belong to the owner.			
Domestic Houses / Structures (Kacha, Brick and Cement).	**5 mm/s**	**10 mm/s**	**15 mm/s**
Industrial buildings (RCC and Framed Structure).	**10 mm/s**	**20 mm/s**	**25 mm/s**
Objects of Historical Importance and Sensitive structures.	**2 mm/s**	**5 mm/s**	**10 mm/s**
B) Buildings belonging to the owner with a limited span of life.			
Domestic Houses / Structures (Kacha, Brick and Cement).	**10 mm/s**	**15 mm/s**	**25 mm/s**
Industrial buildings (RCC and Framed Structure).	**15 mm/s**	**25 mm/s**	**50 mm/s**

$$A = K \frac{Q^{0.5}}{R} \quad (1)$$

where,
A is the amplitude of particle displacement
K is a site constant
R is the distance and,
Q is the charge per delay

Table 3. **ISO Standard**

Vibration forcing function	Frequency range Hz	Amplitude range µm	Particle velocity Range mm/s	Particle acceleration Range m/s²	Time characteristic	Measuring quantities
Traffic road, rail, ground-borne	1 to 80	1 to 200	0,2 to 50	0,02 to 1	C/T	pvth
Blasting vibration ground-borne	1 to 300	100 to 2500	0,2 to 500	0,02 to 50	T	pvth
Pile driving ground-borne	1 to 100	10 to 50	0,2 to 50	0,02 to 2	T	pvth
Machinery outside ground-borne	1 to 300	10 to 1000	0,2 to 50	0,02 to 1	C/T	pvth/ath
Acoustic traffic, machinery outside	10 to 250	10 to 1000	0,2 to 30	0,02 to 1	C	pvth/ath
Air over pressure	1 to 40				T	pvth
Machinery inside	1 to 1000	1 to 100	0,2 to 30	0,02 to 1	C/T	pvth/ath
Human activities a) impact b) direct	 0,1 to 100 0,1 to 12	 100 to 500 100 to 5000	 0,2 to 20 0,2 to 5	 0,02 to 5 0,02 to 0,2	T	pvth/ath
Earthquakes	0,1 to 30	10 to 10^5	0,2 to 400	0,02 to 20	T	pvth/ath
Wind	0,1 to 10	10 to 10^5			T	ath
Acoustic inside	5 to 500					

Key
C = continuous
T = transient (simplified categories, see 3.1 and 3.2)
pvth = particle velocity time history
ath = acceleration time history

NOTES

1. The ranges quoted are extremes but indicate the values which may be experienced, and which may have to be measured (see also note 3). Extreme ranges of amplitude of displacement and frequency have not been used to derive particle velocity and acceleration.
2. The frequency range quoted refers to the response of buildings and building elements to the particular type of excitation. It is indicative only.
3. Vibration values within the ranges given may cause concern. There are no standards that cover all varieties of building, condition, and duration of exposure, but many national codes associate the threshold of visible effects with peak particle velocities at the foundation of a building of more than a few millimetres per second. A significant probability of some damage is linked to peak particle velocities of several hundred millimetres per second. Vibration levels below the threshold of human perception (see ISO 2631-2) may be of concern in delicate and industrial processes.

Table 4. British standard

Line	Type of Building	Peak component particle velocity in the frequency range of the predominant pulse 4Hz to 15 Hz 15 Hz and above	
1	Reinforced or framed structures Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	50 mm/s at 4 Hz and above
2	Unreinforced or light-framed structures Residential or light commercial buildings	15 mm/s at 4Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50mm/s at 40 Hz and above

Note 1 —values referred to are at the base of the building.
Note 2 —for line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) is not to be exceeded

Table 5. **German standard**

Type of structure	Peak Particle Velocity (mm/sec)			
	At the foundation level, Frequency range (Hz)			At the floor level of the topmost story (all frequencies)
	<10	10-50	50 - 100	
(i) Building used as offices and industrial structures	20	20-40	40-50	40
(ii) Domestic houses and associated constructions, structures with plaster	5	5-15	15-20	15
Buildings which do not fall under (i) and (ii), and objects of historic interest or other sensitive structures	3	3-8	8-10	8

Table 6. Summary of PPV predictors as proposed by different researchers[9].

Sl. No	Predictor Name	Predictor Equation
1	USBM Predictor (1980)[1]	$v = K[R/\sqrt{Q_{max}}]^{-}B$
2	Langefors and Kihlstrom predictor (1963)[8]	$v = K\left[\sqrt{\left(Q_{max} / R^{2/3}\right)}\right]^{B}$
3	Ambraseys-Hendron predictor (1968)[9]	$v = K[R/(Q_{max})^{1/3}]^{-B}$
4	Indian standard predictor (1973)[10]	$v = K[Q_{max} / R^{2/3}]^{B}$
5	General predictor (1964)[11]	$v = K(R_{max})^{-B}Q^{A}$
6	Ghosh – Daemon predictor (1983) [Surface Mine][12]	$v = K[R/ Q_{max}^{1/2}]^{-B} e^{-\alpha R}$
7	Ghosh – Daemon predictor (1983) [Underground Mine][12]	$v = K[R/(Q_{max})^{1/3}]^{-B} e^{-\alpha R}$
8	CMRI predictor (1993)[13]	$v = n + K [R/ \sqrt{Q_{max}}]^{-1}$
9	Gupta *et al.* (2016)[14]	$v = [R/(Q_{max})^{1/3}]^{-B} e^{-\alpha.(R/Qmax)}$
10	Rai–Singh (2004)[15]	$v = K. R^{-} . Q^{-A} . e^{-\alpha R}$

Where,
v = peak particle velocity (mm/s)
R = distance between blast face and monitoring point (m),
Q_{max} = maximum explosive charge used per delay (kg),
n = site constant, which is influenced by rock properties and geology

Some researchers accept peak particle velocity as a measure of ground vibration. Peak Particle Velocity (PPV) is defined as the highest speed at which an individual earth particle oscillates as the wave passes a particular site. Most of the predictive equations were developed using the PPV and different scaling factors. Some of these predictors are given in Table 6[7].

K, A, B, and α are site constants and are related to rock/rockmass and design parameters. During the establishment of the vibration predictor equation for Indian surface mines and quarries, square root scaling is considered in general.

3.0 Literature Review

A significant amount of research work is carried out by various investigators on various aspects of blast vibrations and is discussed in brief as given below.

Cheng and Huang (2000), using a scaled distance-based predictor equation, proved that vibrations generated at a distance of 5 km by 216 Kg of explosives are very low and don't pose any danger to the structures. Air overhead pressure at 305 meters from the blast was below the USBM recommended limit of 134 dB[16].

Blair and Armstrong (2001) showed that burden doesn't greatly influence the generation of vibrations based on the study of reflected weaves[17]. Brent *et al.* (2001) concluded that the influence of gases on the vibration generation is insignificant[18].

Kahriman (2002) concluded that the higher the data better the prediction[19].

Sastry *et al.* (2003) reported that Shock tube initiation systems, such as NONELs, resulted in better fragmentation, which resulted in reduced loading time for shovels and up to 36% reduction in noise generation[20]. Shock tube uses have also resulted in reduced fly rock when compared to the use of a detonating cord.

Kahriman (2004) concluded that the

1. The predictor equation based on the scaled distance is most suitable for predicting ground vibrations.
2. It's advisable to monitor vibrations in all directions for better predictions.
3. Higher and continuous updating of the equation is needed to improve the quality of predictions[21].

Singh and Singh (2005) emphasised the necessity and criticality of predicting ground vibrations and concluded that statistical models don't predict ground vibrations accurately and recommended the use of ANN (Artificial Neural Network) based models to improve the quality of prediction[22].

Khandelwal and Singh (2006) concluded that ANN produces more accurate predictions than earlier models and could be cheaper[23].

Sivarajan (2007), based on the study in three sites, concluded that presplitting reduced the propagation of ground vibration and generation of Air Blast Over Pressure (ABOP)[24]

Ak and Konuk (2008) reported that PPV measurements from blasts, analysed using the Nicholls *et al.* (1971) model, showed a 66.16% correlation with Scaled Distance (SD), enabling the development of site-specific propagation equations for vibration control. They further observed that while adding discontinuity frequency did not alter the results compared to the Nicholls model, it affected PPV attenuation, being more pronounced at lower SD values (1–4 m/kg^0.5) and smoother at higher SD[25].

Measuring discontinuity frequency when mapped on each bench significantly improved the predictability of Ground Vibrations.

Khandelwal and Singh (2009) reported that estimation of PPV using ANN was close to what was observed in the field and MVRA (Multivariate Regression Analysis)[26].

Khandelwal *et al.* (2009) established that the feed-forward back-propagation neural network approach appears to be a better option for close and accurate prediction of PPV[27].

Fisne *et al.* (2010) used a fuzzy model for predicting ground vibrations. They observed that given two inputs of distance and charge per delay Fuzzy model's predictions were more accurate than statistical model-based predictions[28].

Nateghi (2011) provided guidelines for preconstruction surveys and control of blast-induced structural vibrations. Reza's study showed that in the Aghajari Formation, K varied between 170–660 and b between 0.87–1.71, while in the Bakhtiary Conglomerate, K ranged from 350–420 and b from 0.955–1.63; underground blasting produced nearly three times higher vibrations than bench blasting, mainly due to jointing, bedding thickness, and seam dip rather than explosive properties[29].

Hudaverdi (2012) used multivariate analysis to predict ground vibrations using a large database of various parameters of blasts in a quarry[30].

Dogan *et al.* (2013)

1. Underground Blasts with similar SD produced 47 to 95% less Vibrations, and the dominant frequency was also less by 37 to 78%.
2. Measurement direction is important, as it was observed that PPV values in the southwest directions varied by 20% when compared to the equation developed for the southeast direction[31].

Faramarzi *et al.* (2014)

1. Seismic records indicated that blasts in the southern part of the Mine generated higher vibration, sometimes exceeding the safe limits by 19 mm/s. An unacceptable situation as the Mine was extending towards the major buildings and structures.
2. 94% of the frequencies were in the range of 1 to 14 Hz, very near to the natural frequencies of the structures.
3. AOP was at the average level of 110dB, which can excite windows and is annoying to the persons, but not damaging, as this is less than the allowable limit of 136 dB.[32]

Kumar *et al.* (2014) considerations given the high cost of conducting site-specific blast tests; the study highlighted that using only three fundamental soil parameters allows for a practical and effective estimation of vibration levels even without direct field blast measurements.

They recommended the use of soil properties apart from SD for the prediction of ground vibrations, as their model had a high R^2 value and the least S^2 [33].

In Hasanipanah's (2015) study, the SVM model produced better predictions than the conventional statistical model[34].

Singh (2015) compared data from the use of pyrotechnic delays and Electronic Delay detonators. It was observed that

1. Electronic Detonators reduced ground vibrations by 8 to 10% with a similar hookup pattern.
2. There was a difference in frequencies of ground vibrations recorded with high frequency vibrations recorded in underground and low frequency vibrations observed in underground.[35]

Raymond's (2016)

1. The ANN model demonstrated strong predictive accuracy, achieving a Root Mean Square Error (RMSE) of 0.307 and a coefficient of determination (R^2) of 0.999, ultimately leading to better fragmentation and reduced blast-related disturbances in the field.
2. The scaled distance was the most effective parameter, and the depth of the hole was the least effective parameter for vibration control
3. For AOP Maximum charge per delay was the most effective parameter, and the burden-to-spacing ratio was the least effective parameter[36].

Jayasinghe *et al.* (2016) used the commercial computer program LS-DYNA. The bottom of the pile was first affected by the blast waves as the piles were resting on the Rock. This was due to the higher propagation velocity in the rock.[37]

Kumar *et al.* (2016) concluded that apart from the distance and the charge per delay, other site conditions such as frequency, geological conditions, layering, joint orientation, joint spacings, soil-rock interface, groundwater table, etc., play an important role propagation of vibrations; hence site-specific equation is the only option. They observed that the effect of engineering properties is yet to be studied[38].

Triguerosa *et al.* (2017). The information provided in this study allows fundamental values to be calculated at which mechanical pre-cutting can be substituted for blasting.[39]

Xia *et al.* (2018) observed that, amplifying coefficient first increased to a peak point of approximately 3.5, then decreased with the increasing distance from the tunnel face, indicating the cavity effect only worked within a limited scope on the ground, i.e., 30 m in this study. In Yang's (2012) research, on cavity effect was observed up to 40 meters because of a larger tunnel radius[40]. While in research by Cai *et al.* (2015) and Zhang *et al.* (2005), the cavity effect was observed up to 30 meters[41,42].

The tunnel radius and buried depth influenced the cavity effect. It linearly increased with tunnel radius while decreasing with buried depth in the form of a power function

$$Q = aR - Bd^c \tag{2}$$

Where:

- a and b are constants,
- R is the tunnel radius (linear term),
- D is the buried depth (power term),
- c is the exponent describing the power relationship between Q and D.

1 No amplification was observed when the tunnel was located 60 meters from the surface

2 No PPV was observed at depths more than 60 m from underground, thus indicating that the cavity effect could be ignored[43].

Gui *et al.* (2018)

1 The depth effect in attenuation was observed in both models.

2 Surface measurements of PPV are not a good indicator to assess the impact of safety on underground structures from blast-induced ground vibrations without considering geological conditions[44].

Murmu *et al.* (2018)'s study shows that

1 Their model's prediction was better than other contemporary models

2 Burden was not a significant factor of influence

3 Rock mass quality was not considered

4 The peak particle velocity exhibited a lognormal distribution
5 Measured, predicted, and simulated results showed that the Monte-Carlo simulation can predict PPV better
6 The threat from blasting using a particular blast design could be assessed from probabilistic analysis[45].

Jayasinghe *et al.* (2019)

1 An attenuation formula should be developed for each direction of concern.
2 Further field tests should be done whenever soil-rock interface changes, and a new attenuation formula developed based on numerical modelling or further data[46].

Kumar and Choudhary (2019) showed that ANN (Artificial Neural Network) models are better at vibration prediction[47].

Kumar *et al.* (2020) used a Multivariate Statistical Regression Analysis (MVSRA) based model to predict dominant frequency and components of frequency in three directions[48].

Pradeep *et al.* (2020) reported the following from their study:

1 Peak particle velocity is directly proportional to the compressive strength of the rock.
2 PPV was also directly proportional to the tensile strength of the rock[49].

Lawal *et al.* (2021)

1 Among the models, the Sine Cosine Algorithm optimised ANN (SCA-ANN) and the ANFIS model achieved the highest performance, with GEP following closely[50].

Kumar *et al.* (2021)

Peak Ground Acceleration (PGA) is estimated using an ANN-based approach of non-linear dynamic analysis was carried out for a structure with different natural periods. A distributed spring was used to study the effect of soil flexibility.

Their conclusions are

1 Low-rise structures constructed beyond 1 km are safe

Table 7. Conclusion

Model	R^2 Value
CRANFIS-PSO	0.997
CRANFIS	0.967
RANFIS	0.958
ANFIS	0.822
ANN	0.775

2 For medium and high-rise structures, strengthening of columns at lower floors is needed[51].

Wei *et al.* (2021) concluded as in Table 7

Burden was the most influential factor for PPV prediction than other parameters[52].

Gou *et al.* (2021) Theil-Sen regression is better at vibration prediction[53].

Chrzan (2022)

1 In the near field, different vibration readings were observed in left and right directions.
2 Around 20% higher vibration velocity in the direction of imitation was observed than in the opposite direction
3 Change in direction of initiation has a significant influence on the generation of vibrations
4 Contouring of vibrations helps in determining the direction of concern
5 Lesser vibrations were recorded in the front of the blasting face compared to the other direction[54].

Sonkar *et al.* (2022) Boosted Regression Trees (BRT) model's prediction was compared with various empirical models, including the USBM recommended model, and was found to outperform the USBM model[55].

Guan *et al.* (2023) Amongst all the factors, diameter and spacing of damping holes are the greatest influencing factors, followed by coverage area, number of rows, arrangement type, and row distance of damping holes[56].

4.0 Research Gap

4.1 Influence of Vertical Depth on the Attenuation Propagation of Vibration

Siskind *et al.* (1980) suggested a USBM equation for predicting ground vibration based on the charge per delay and the distance[57].

$$V = D/\sqrt{C} \quad (2)$$

Where:

- V represents the ground vibration.
- C represents the charge per delay.
- D represents the distance from the blast.

However, this formula did not take into account the influence of the total charge in a round and the influence of the vertical distance of the place of blasting to the instrument.

The formula also does not specify whether to consider horizontal or radial distance. The formula does not specify the source of the distance or the place from which the distance is to be considered. In big opencast mines where faces measuring 100s of meters are being blasted at once, this can make a huge difference and needs to be studied in detail.

With the increasing depth of open-cast mines, this is essential as some mines are already working at depths of more than 300 meters below the ground level.

4.2 Influence of Repeated Blasting on Rock Properties and Propagation of Ground Vibrations

Research so far has not been done on the effect of geo-mechanical properties on ground vibrations. The study by Ramulu (2008) investigated the impact of repeated blasts on rock mass damage in two types of basalt[58]. They used a method called the charge weight scaling law to predict damage levels and compared them with actual measurements. They found that repeated blasting weakened the rock mass significantly, causing more damage than single blasts alone. The research emphasises the importance of considering repeated blasting when assessing damage in underground excavations.

There is a need to study the effects of repeated blasting on the Rock Properties in the surrounding areas and its impact on the propagation of ground vibrations.

4.3 Influence of Rock Soil Interface

Jayasinghe (2018) has researched the soil-rock interface in the tunnel. The effect of soil soil-rock interface on the propagation characteristics and generation of ground vibrations is still not well studied[37].

Influence of Rock Mass Rating (RMR): It is well-studied that the waves propagate longer distances in hard rock; the influence of RMR, which is a better overall indicator of rock properties than Uniaxial Compressive Strength (UCS) alone, needs to be studied in detail.

Influence of Jointing Pattern: It is generally understood that waves attenuate faster in vertically jointed rocks when compared to horizontally or inclinedly jointed rocks due to the presence of softer materials in the joints, the phenomenon is not well studied.

4.4 Influence of Hole Depth

It's generally accepted that increased hole depth leads to higher ground vibrations due to the increased volume of space to accommodate explosives. However, if a lesser quantity of explosives is accommodated in the hole by reducing the density of explosives, it is a topic that is still not well-researched.

4.5 Influence of Scatter of Delay Detonators

While detonator scatter is a major cause of concern for blasting engineers, no data exists for tolerance limits for each type of delay.

Mahdiyar *et al.* (2019) conducted research aiming to predict peak particle velocity (PPV) resulting from blasting operations in four Malaysian quarry sites[59]. They employed Genetic Programming (GEP) to develop a predictive model and utilised Monte Carlo (MC) simulation to analyse a wide range of PPV outcomes. The simulation revealed that PPV values ranged from 1.13 mm/s to 34.58 mm/s, with a mean of approximately 18.28 mm/s. The distribution function of the 10,000 outputs was identified as 'logistic'. With 90% confidence, the PPV was determined to be less than 25.25 mm/s, and 99% of the results were less than 30.86 mm/s.

These variations are due to improper delays. Further research is needed to establish tolerance limits for each delay and acceptable limits for burden distances, the number of rows, and the total number of holes in a blast.

4.6 Influence of Frequency

DGMS (circular 07 of 1997) suggested higher allowable PPVs for higher frequencies[2].

Factors that influence the generation of frequencies are not well-researched yet. Research on this may lead to a correlation of the geo-mechanical properties of rock based on the frequency generated in the blast and recorded by the seismograph.

4.7 PPV at Different Vertical Points of a Structure

In today's world, when foundations are deeper, there is a necessity to understand the effects of vibrations on the various vertical points of the structure.

5.0 Futuristic Approach Vs Traditional or Current Approach

The futuristic approach to Research needs to focus on improving the accuracy of prediction by considering more factors other than the distance and the charge per delay, along with the help of online monitoring and work towards online reporting and predictive strategies for damage mitigation.

Present prediction models are based on a one-time study and assume that the same parameters continue to prevail throughout the life of the mine, which usually is not the case. Strata changes within the mine with varying geomechanical properties are very common; structures that do not exist today may be constructed, and explosive properties are bound to change and are rarely constant in countries such as Indian.

All the modes used today for the prediction don't consider the impact of the increasing depth of the work as the mine progresses. Blasts need to be conducted at various levels, and their impact on other levels needs to be assessed accurately. In many civil engineering applications, impacted structures could be at a lesser elevation than the blating level. Because of the elevation difference, the impact is likely to vary, and such needs to be studied.

Hence, there is a need to develop continuous prediction models based on the Internet of Things (IoT), cloud computing, and data mining. There is also a need to understand the effects of vertical separation between the place of blasting to the place of monitoring. Apart from this greater number of factors other than just charge per delay and the distance need to be considered to improve the accuracy of the prediction with the help of machine learning and other computational models. There is also a necessity to review the damage criteria as mandated by the various regulations, as there has been a considerable improvement in structural engineering since the time this phenomenon was studied. And understand the damage potential of the Air Overhead Pressure (AOP), as larger blasts very near the residential premises have become a common thing throughout the world.

6.0 Modelling And Prediction Techniques for Ground Vibrations

Most of the present models for the prediction of ground vibrations are based on empirical formulae. For more precise predictions, the help of data mining, AI-based models based on cloud computing needs to be developed.

7.0 Conclusions

In this paper, an attempt has been made at an in-depth analysis of various factors influencing ground vibration, such as blast design parameters, geological conditions, and predictive techniques. This review consolidates existing knowledge and highlights the complexities inherent in mitigating the effects of ground vibration

The paper underscores the importance of understanding blast damage not only for the safety of nearby structures, infrastructure, and the environment but also for the well-being of communities surrounding blasting operations. Effective mitigation strategies discussed within the paper, including the use of predictive models, proper blast design modifications, and advanced monitoring technologies, demonstrate promising avenues for reducing the impact of ground vibration.

However, despite advancements in research and technology, challenges persist in accurately predicting and controlling ground vibration due to the changing dynamics and the inability to accurately predict the properties of the Rock. This necessitates further interdisciplinary research, collaboration between industry and academia, and innovative approaches to develop more robust solutions for minimising the adverse effects due to blasting.

Overall, this review paper consolidates existing knowledge, identifies areas for further investigation, and emphasises the significance of continued research efforts in mitigating blast-induced ground vibration, thereby contributing to safer and more sustainable blasting practices in various industries.

8.0 References

1. Siskind DE, Stagg MS, Kopp JW, Dowding CH. Structure response and damage produced by ground vibration from surface mine blasting. Washington, DC: U.S. Bureau of Mines; 1980. Report No.: RI 8507.
2. Directorate General of Mines Safety (DGMS). Damage to structures due to blast-induced ground vibrations in the mining areas. Dhanbad: DGMS; 1997. (Tech) (SandT) Circular No. 7.
3. International Organization for Standardization. ISO 4866:1980. Mechanical vibration and shock - vibration of buildings - guidelines for the measurement of vibrations and evaluation of their effects on buildings. Geneva: ISO; 1980.
4. British Standards Institution. BS 7385-2:1993. Evaluation and measurement for vibration in buildings - part 2: guide to damage levels from groundborne vibration. London: BSI; 1993.
5. German Standards Organisation (GSO). DIN 4150:1984. Vibrations in building construction. Berlin: GSO; 1984.
6. Morris G. Vibrations due to blasting and their effects on building structure. Engineer. 1950; 190:394-5.
7. Bhagwat VP, Mishra D, Pathak K, Dey K. Vibration predictor equation - some issues. J Mines Met Fuels [Internet]. 2015; 63(7):151-6. Available from: https://www.researchgate.net/publication/279847566_Vibration_predictor_equation_-_Some_issues
8. Langefors U, Kihlström B. The modern technique of rock blasting. 2nd ed. New York: Wiley; 1978.
9. Ambraseys NN, Hendron AJ. Dynamic behaviour of rock masses. In: Stagg KG, Zienkiewicz OC, editors. Rock mechanics in engineering practice. London: Wiley; 1968. p. 203-36.
10. Bureau of Indian Standards. IS 6922:1973. Criteria for safety and design of structures subject to underground blasts. New Delhi: BIS, 1973.
11. Davies B, Farmer IW, Attewell PB. Ground vibration from shallow subsurface blasts. Engineer. 1964; 217(5644):654-9.
12. Ghosh A, Daemen JK. A simple new blast vibration predictor. In: Proceedings of the 24th US Symposium on Rock Mechanics; 1983 Jun 20-23; College Station, TX. College Station: Texas A&M University; 1983. p. 151-61.
13. Pal RP. Putting ground vibration predictions into practice. Colliery Guard. 1993; 241(2):63-7.
14. Kumar R, Choudhury D, Bhargava K. Determination of blast-induced ground vibration equations for rocks using mechanical and geological properties. J Rock Mech Geotech Eng. 2016; 8(3):341-9. https://doi.org/10.1016/j.jrmge.2015.10.009
15. Rai R, Singh TN. A new predictor for ground vibration prediction and its comparison with other predictors. Indian J Eng Mater Sci. 2004; 11(3):178-84.
16. Chen G, Huang SL. Analysis of ground vibrations caused by open-pit production blasts - a case study. Fragblast. 2001; 5(1-2):91-107. https://doi.org/10.1076/frag.5.1.91.3316
17. Blair DP, Armstrong LW. The influence of burden on blast vibration. Fragblast. 2001; 5(1-2):108-29. https://doi.org/10.1076/frag.5.1.108.3315
18. Brent GF, Smith GE, Lye G. Studies on the effect of burden on blast damage and the implementation of new blasting practices at KCGM's Fimiston Mine. In: EXPLO 2001; 2001; Hunter Valley, NSW, Australia. Carlton: AusIMM; 2001. p. 189-94. https://doi.org/10.1076/frag.6.2.189.8665
19. Kahriman A. Analysis of ground vibrations caused by bench blasting at Can open-pit lignite mine in Turkey. Environ Geol. 2002; 41(6):653-61. https://doi.org/10.1007/s00254-001-0446-2
20. Sastry VR, Teggi V, Chander KR. Shock tube initiation for eco-friendly blasting: a few case studies. J Inst Eng India Ser D. 2003; 83:41-6.
21. Kahriman A. Analysis of parameters of ground vibration produced from bench blasting at a limestone quarry. Soil Dyn Earthquake Eng. 2004; 24(11):887-92. https://doi.org/10.1016/j.soildyn.2004.06.018
22. Singh T, Singh V. An intelligent approach to prediction and control of ground vibration in mines. Geotech Geol Eng. 2005; 23(3):249-62. https://doi.org/10.1007/s10706-004-7068-x
23. Khandelwal M, Singh TN. Prediction of blast-induced ground vibrations and frequency in opencast mine: a neural network approach. J Sound Vib. 2006; 289(4-5):711-25. https://doi.org/10.1016/j.jsv.2005.02.044
24. Sivarajan V, Kumara K, Hearath H, Nanayakare N, Welideniya H, Weerawarnakula S. Ground vibration and air blast overpressure assessment using scaled distance [Internet]. Moratuwa: University of Moratuwa, Department of Earth Resources Engineering; 2007 [cited 2025 Jun 9]. Available from: http://dl.lib.uom.lk/handle/123/18342
25. Ak H, Konuk A. The effect of discontinuity frequency on ground vibrations produced from bench blasting: a

case study. Soil Dyn Earthquake Eng. 2008; 28(9):686-94. https://doi.org/10.1016/j.soildyn.2007.11.006

26. Khandelwal M, Singh TN. Prediction of blast-induced ground vibration using an artificial neural network. Int J Rock Mech Min Sci. 2009; 46(7):1214-22. https://doi.org/10.1016/j.ijrmms.2009.03.004
27. Khandelwal M, Kumar DL, Yellishetty M. Application of soft computing to predict blast-induced ground vibration. Eng Comput. 2009; 27(2):117-25. https://doi.org/10.1007/s00366-009-0157-y
28. Fişne A, Kuzu C, Hüdaverdi T. Prediction of environmental impacts of quarry blasting operation using fuzzy logic. Environ Monit Assess. 2011; 174(1-4):461-70. https://doi.org/10.1007/s10661-010-1470-z
29. Nateghi R. Prediction of ground vibration level induced by blasting at different rock units. Int J Rock Mech Min Sci. 2011; 48(6):899-908. https://doi.org/10.1016/j.ijrmms.2011.04.014
30. Hudaverdi T. Application of multivariate analysis for prediction of blast-induced ground vibrations. Soil Dyn Earthquake Eng. 2012; 43:300-8. https://doi.org/10.1016/j.soildyn.2012.08.002
31. Dogan O, Anil Ö, Akbas SO, Kantar E, Erdem RT. Evaluation of blast-induced ground vibration effects in a new residential zone. Soil Dyn Earthquake Eng. 2013; 50:168-81. https://doi.org/10.1016/j.soildyn.2013.03.005
32. Faramarzi F, Ebrahimi Farsangi MA, Mansouri H. Simultaneous investigation of blast-induced ground vibration and airblast effects on the safety level of structures and humans in surface blasting. Int J Min Sci Technol. 2014; 24(5):663-9. https://doi.org/10.1016/j.ijmst.2014.07.006
33. Kumar R, Choudhury D, Bhargava K. Prediction of blast-induced vibration parameters for soil sites. Int J Geomech. 2014; 14(3):04014007. https://doi.org/10.1061/(ASCE)GM.1943-5622.0000355
34. Hasanipanah M, Monjezi M, Shahnazar A, Jahed Armaghani D, Farazmand A. Feasibility of indirect determination of blast-induced ground vibration based on support vector machine. Measurement. 2015; 75:289-97. https://doi.org/10.1016/j.measurement.2015.07.019
35. Singh PK, Roy MP, Paswan RK, Dubey RK, Drebenstedt C. Blast vibration effects in an underground mine caused by open-pit mining. Int J Rock Mech Min Sci. 2015; 80:79-88. https://doi.org/10.1016/j.ijrmms.2015.09.009
36. Tiile RN. Artificial neural network approach to predict blast-induced ground vibration, airblast and rock fragmentation [master's thesis]. Rolla: Missouri University of Science and Technology; 2016 [cited 2025 Jun 9]. Available from: https://scholarsmine.mst.edu/masters_theses/7571/
37. Jayasinghe LB, Zhou H, Goh ATC, Zhao Z, Gui Y. Pile response subjected to rock blasting induced ground vibration near soil-rock interface. Comput Geotech. 2017; 82:1-15. https://doi.org/10.1016/j.compgeo.2016.09.015
38. Kumar R, Choudhury D, Bhargava K. Determination of blast-induced ground vibration equations for rocks using mechanical and geological properties. J Rock Mech Geotech Eng. 2016; 8(3):341-9. https://doi.org/10.1016/j.jrmge.2015.10.009
39. Trigueros E, Cánovas M, Muñoz J, Cospedal J. A methodology based on geomechanical and geophysical techniques to avoid ornamental stone damage caused by blast-induced ground vibrations. Int J Rock Mech Min Sci. 2017; 93:196-200. https://doi.org/10.1016/j.ijrmms.2016.12.013
40. Yun-ling Y. Hollow effect induced by blasting vibration in shallow tunnels. Blasting. 2012; 29(1):1-5.
41. Cai J, He Z, Lin Z, Huang Z. Numerical simulation of blasting vibration effect for tunnel excavation. Min Metall Eng. 2015; 35(1):5-8.
42. Zhang JC, Cao XJ, Zheng SY, Guo XB. Experimental study on vibration effects of the ground due to shallow tunnel blasting. Chin J Rock Mech Eng. 2005; 24(22):4158-63.
43. Xia X, Li H, Liu Y, Yu C. A case study on the cavity effect of a water tunnel on the ground vibrations induced by excavating blasts. Tunn Undergr Space Technol. 2018; 71:292-7. https://doi.org/10.1016/j.tust.2017.08.026
44. Gui YL, Zhao ZY, Jayasinghe LB, Zhou HY, Goh ATC, Tao M. Blast wave-induced spatial variation of ground vibration considering field geological conditions. Int J Rock Mech Min Sci. 2018; 101:63-8. https://doi.org/10.1016/j.ijrmms.2017.11.016
45. Murmu S, Maheshwari P, Verma HK. Empirical and probabilistic analysis of blast-induced ground vibrations. Int J Rock Mech Min Sci. 2018; 103:267-74. https://doi.org/10.1016/j.ijrmms.2018.01.038
46. Jayasinghe B, Zhao Z, Goh ATC, Zhou H, Gui Y. Attenuation of rock blasting-induced ground vibration in rock-soil interface. J Rock Mech Geotech Eng. 2019; 11(4):770-8. https://doi.org/10.1016/j.jrmge.2018.12.009
47. Kumar S, Choudhary BS. Prediction of blast-induced ground vibration by ANN, USBM and CMRI formulae for the safety of the structures near surface coal mines. J Mines Met Fuels [Internet]. 2019; 67(7):351-6. Available from: https://www.researchgate.net/publication/334250543_Prediction_of_blast-induced_ground_vibration_by_ANN_USBM_and_CMRI_

formulae_for_safety_of_the_structures_near_surface_coal_mines/citations

48. Kumar MA, Kumar MS, Kumar S, Singh S, Kishore DN. Assessment of blast-induced ground vibration frequency in opencast coal mine: a multivariate statistical regression model. Int J Recent Technol Eng. 2020; 8(5):3233-7. https://doi.org/10.35940/ijrte.E6346.018520
49. Pradeep G, Ramulu M, Budi G, Murthy VMSR. Smart software assessment of effects of rock properties on blast-induced ground vibrations. Int J Recent Technol Eng. 2020; 9(2):393-7. https://doi.org/10.35940/ijrte.B3542.079220
50. Lawal AI, Kwon S, Hammed OS, Idris MA. Blast-induced ground vibration prediction in granite quarries: an application of gene expression programming, ANFIS, and sine cosine algorithm optimised ANN. Int J Min Sci Technol. 2021; 31(2):265-77. https://doi.org/10.1016/j.ijmst.2021.01.007
51. Kumar S, Dutta SC, Goswami K, Mandal P. Vulnerability assessment of building structures due to underground blasts using ANN and non-linear dynamic analysis. J Build Eng. 2021; 44:102674. https://doi.org/10.1016/j.jobe.2021.102674
52. Zhu W, Rad HN, Hasanipanah M. A chaos recurrent ANFIS optimised by PSO to predict ground vibration generated in rock blasting. Appl Soft Comput. 2021; 108:107434. https://doi.org/10.1016/j.asoc.2021.107434
53. Gou Y, Shi X, Qiu X, Huo X, Yu Z. Assessment of induced vibrations derived from the wave superposition in time-delay blasts. Int J Rock Mech Min Sci. 2021; 144:104814. https://doi.org/10.1016/j.ijrmms.2021.104814
54. Chrzan T. Discussion on "Impact of orientation of blast initiation on ground vibrations" [J Rock Mech Geotech Eng 15 (2022) 255-261]. J Rock Mech Geotech Eng. 2023; 15(1):262-8. https://doi.org/10.1016/j.jrmge.2022.10.012
55. Sonkar R, Dhekne PY, Londhe ND. Prediction of peak particle velocity of blast-induced ground vibrations using boosted regression trees. J Mines Met Fuels. 2022; 70(4):203-10. https://doi.org/10.18311/jmmf/2022/30057
56. Guan X, Yao Y, Yang N, Xu H, Xin B, Li B. Analysis of factors influencing vibration reduction and design optimisation of damping holes in adjacent tunnel blasting. Case Stud Constr Mater. 2023; 19:e02448. https://doi.org/10.1016/j.cscm.2023.e02448
57. Siskind DE, Stagg MS, Kopp JW, Dowding CH. Structure response and damage produced by ground vibration from surface mine blasting. Washington, DC: U.S. Bureau of Mines; 1980.
58. Ramulu M, Chakraborty AK, Sitharam TG. Damage assessment of basaltic rock mass due to repeated blasting in a railway tunnelling project - a case study. Tunn Undergr Space Technol. 2009; 24(2):208-21. https://doi.org/10.1016/j.tust.2008.08.002
59. Mahdiyar A, Jahed Armaghani D, Koopialipoor M, Hedayat A, Abdullah A, Yahya K. Practical risk assessment of ground vibrations resulting from blasting, using gene expression programming and Monte Carlo simulation techniques. Appl Sci. 2020; 10(2):472. https://doi.org/10.3390/app10020472