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Review Paper

Estimation of near-field peak particle velocity: A mathematical model

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Peak particle velocity (PPV) is an important parameter in estimation of rock and structural damage. In general, ground vibration is measured using a seismograph at a distance from the blast face to keep the instrument safe. However, rock damage due to blasting occurs very close to the blast hole and thus, PPV at the damaged zone can not be measured directly. In the far-field observations charge is considered as point source because the distance of measurement is significantly longer than the charge column length. However, in near-field PPV estimation charge length can not be ignored. Thus, a mathematical model is developed for estimation of near-field PPV. In the proposed model, effect of an elemental charge in the charge column is calculated and then summed up for the whole charge column. Thus, it is assumed that blast waves from all the elemental charges of charge column reached at the point of interest at same time. This can be helpful in assessing the extent of blast-induced rock damage.

Key words: Near-field PPV, rock damage, blasting.

INTRODUCTION

Drilling and blasting is an integral operation in any excavation project. This is largely due to the fact that fragmentation of rock using explosives is much more economical over other existing techniques. However, energy of an explosive can not be fully utilised for fragmentation and displacement of *in-situ* rockmass only. A large part of explosive energy dissipates as uncontrolled ground vibration, air blast, back-break or over break and fly rock. Among these, back-break or over break is termed as blast induced damage to surrounding rock and is the main concern of this present research.

Damaged rock due to blasting causes a number of problems, viz. (i) drilling to the next blast round becomes critical, (ii) chances of eruption/ejection of explosive energy in uncontrolled manner leading to poor fragmentation during next blasting and also the chances of fly rock, (iii) increase in support cost (for underground opening) and many more. Thus, it is felt to assess the extent of rock damage due to blasting, which is considered as a function of peak particle velocity (PPV). However, rock damage occurs very close to the blast hole and PPV can not be measured at such close distance. In this research work, a mathematical model is developed to assess the near field PPV.

REVIEW OF PREVIOUS WORKS

A rock is considered damaged, if it no longer reacts elastically and the deformation is plastic (Paventi et al., 1996). Dey (2004) classified blast-induced damage to surrounding rocks in underground openings as over break zone (where rock is severely damaged and unable to stand itself), cracked zone (where rock suffers minor damage and the fresh cracks initiated or existing cracks widened which can not be noticed by normal observations) and intact zone (where rock is not damaged significantly) (Figure 1). The line between over break and cracked zone is easy to identify as over break zone dislodged immediately or by roof dressing.

However, the line between cracked and intact zone needs to be established. Rock damage is related to

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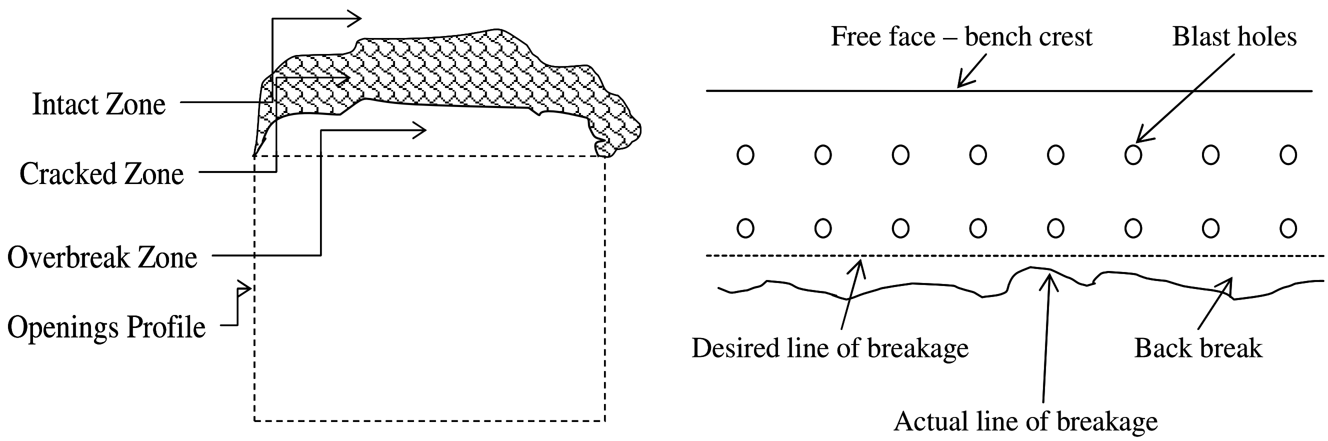

(a) Blasting in uunderground opening. (b) Bench blasting in surface mines.

Figure 1. Zones of blast-induced rock damage.

ground vibration by many researchers. Different researchers have developed the threshold levels of peak particle velocity (PPV) for different degrees of rock damage as shown in Table 1. However, most of the above estimations of PPV are arrived either by extrapolating far-field observations or by using Holmberg-Persson Near-field model (Bogdanhoff, 1995). Direct measurement of near-field PPV using a seismograph is difficult and also bears a risk of damaging the instrument. Thus, use of Holmberg-Persson Near-field model is very popular for estimating near-field PPV levels. A general form of PPV predictor equation used by different researchers like Holmberg and Persson (1979) is given by,

$$v = K \times Q^{\alpha} \times D^{\beta} \tag{1}$$

Where,

v = peak particle velocity,
K, *α*, *β* are empirical site constants to be established through far-field monitoring,
Q = Weight of explosive charge per delay (kg), and
D = distance of point of interest from blast (m).

The basic assumption in this equation is that the explosive column is considered as a point charge considering the distance is much more as compared to explosive column length. However, this is not true in case of near-field PPV and Holmberg and Persson (1979) developed their model taking into account the appreciable length of explosive column as compared to the distance in near-field conditions. Figure 2 show Near-field PPV approximation as proposed by Holmberg and Persson (1979). For an extended charge of linear charge concentration q (kg/m) charge length as shown in Figure 2, Holmberg and Persson has obtained a first approximation of the resulting PPV (*v)* by integrating the generalized equation for the total charge length as given by:

$$v = K q^{\alpha} \left[\int_0^h \frac{dx}{\left\{ R_0^2 + (Z - x)^2 \right\}^{\frac{\beta}{2\alpha}}} \right]^{\alpha} \tag{2}$$

Where,

v =peak particle velocity,
K, *α*, *β* are empirical site constants to be established through far-field monitoring,
q=linear charge concentration (kg/m),
h= total charge length in hole (m) and
x=position of the elemental charge from bottom of the hole (m). R_0 and *Z* are the distances as shown Figure 2.

The above mathematical equation can be solved for *β* = 2*α*, and the resultant PPV can be obtained as given by

$$v = K \left(\frac{q}{R_0} \right)^{\alpha} \left[\tan^{-1} \frac{Z}{R_0} - \tan^{-1} \frac{Z\text{-}h}{R_0} \right]^{\alpha} \tag{3}$$

MATHEMATICAL MODELS

It has been felt that the resulting peak particle velocity at a close distance from explosive column can also be obtained by mathematically summing up of the PPVs caused by the elemental explosive charges (‘dx’) of the

Table 1. Suggested damage threshold levels for rock damage.

Langefors et al. (1973), Edwards and Northwood (1960), Nicholls et al. (1971)	Langefors et al. (1973), Edwards and Northwood (1960), USBM (1971) and several others proposed particle velocity as blast damage criteria. There was a common agreement that a PPV of less than 50 mm/s would have low probability of structural damage to residential buildings.
Langefors and Kihlstrom (1973)	Langefors and Kihlstrom (1973) have proposed the following criteria for tunnels. - PPV's of 305 mm/s and 610 mm/s results in fall of rock in unlined tunnels and formation of new cracks respectively.
Bauer and Calder (1970)	They observed that no fracturing of intact rock will occur for a PPV of 254 mm/s, PPV of 254 - 635 mm/s results in minor tensile slabbing and PPV of 635 - 2540 mm/s would cause strong tensile and some radial cracking. Break up of rockmass will occur at a PPV of 2540 mm/s.
Oriard (1982)	Oriard proposed that most rock mass suffer from damage at PPV above 635 mm/s.
Holmberg and Persson (1979)	Proposed a model for near-field PPV estimation by integrating the generalized PPV predictor equation for the total charge length. They found that PPV level for rock damage varies from 700 – 1000 mm/s.
Rustan (1985)	Rustan (1985) measured vibrations from contour blasts with low void pipe charge. The PPV at lowest measured range was 300 - 900 mm/s for explosives commonly used for smooth blasting. An extrapolation for 0.5 m range gives PPV s around 1000-3000 mm/s. This is considerably higher than the often referred range of damages, 700-1000 mm/s. The calculation with 700 mm/s extends to 0.1 m. range. The observed damage range by direct methods is 0.5 m. This work suggests that PPV for damages can be higher than 700–1000 mm/ s.
Yang et al. (1993)	Yang (1993) used the Holmberg model for estimating PPV in the damage zone at Queen's University blast test - site. It was shown that the actual data from the field related closely with theoretically estimated values.
Meyer and Dunn (1995)	Meyer (1995) studied blast vibrations at Perseverance nickel mine in Australia. A PPV damage threshold of 600-mm/ s has been determined for the Perseverance Mine rock mass with minor damage occurring above 300 mm/s.
Bogdanhoff (1996)	Bogdanhoff (1995) monitored near field blast acceleration of an access tunnel in Stockholm. Vibration measurements were done at distances between 0.25 and 1.0 m. outside tunnel perimeter holes with accelerometers. Altogether eight blasts were monitored and the vibrations were filtered in the low pass filtered. The PPV in the assumed damage range was found to be between 2000 and 2500 mm/s.
Blair et al (1996)	Blair et al. (1996) proposed that Holmberg model warrants further investigation. The Holmberg model assumes that for blast-hole of length, L the vibrations peaks (such as V_1 and V_2) may be numerically added at point P to yield the total peak vibration (V_T). Blair argued that as this model does not incorporate any time lag for the vibration peaks at point P the model is not capable of providing the correct near field analysis. They developed a Dynamic finite element model to assess the damage zone.
Murthy and Dey (2002)	Murthy and Dey (2002) proposed that the threshold level of PPV for over break in compact basalt rock is 2050 mm/s.
Dey (2004)	Modeled near-field ground vibration and found PPV threshold levels for over break varies between 700 – 1300 mm/s in five horizontal drifts of metaliferrous mines.

charge column. Thus, a mathematical model is developed based on the assumption that PPVs due to all the elemental charges ($q \times dx$) of the explosive column are arrived at point of interest simultaneously and can be algebraically added to obtain the resultant PPV (Figure 2). Thus, the PPV obtained from elemental charge ($q \times dx$) becomes,

$$\delta v = Kq^{\alpha} \frac{dx^{\alpha}}{\left\{\sqrt{R_0^{2} + (Z - x)^{2}}\right\}^{\beta}} \quad (4)$$

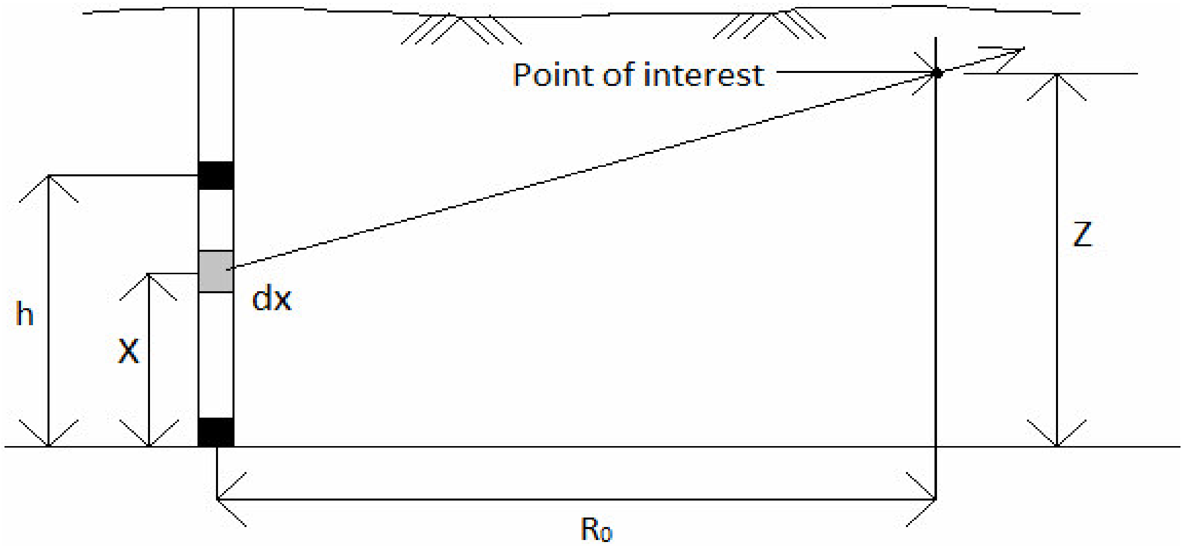

Figure 2. Near-field PPV approximation as proposed by Holmberg and Persson (1979). For an extended charge of linear charge concentration q (kg/m) charge length.

and the resultant PPV (*v*) becomes,

$$v = Kq^{\alpha}\left[\sum_{x=0}^{h}\left\{\frac{dx}{\{R_0^{\ 2}+(Z-x)^2\}^{\frac{\beta}{2\alpha}}}\right\}\right]^{\alpha} \tag{5}$$

Where,

δ*v* = the elemental peak particle velocity,
v= total peak particle velocity,
K, α, β are the empirical site constants to be established through far-field monitoring,
R_0=horizontal distance between blast hole axis and point of interest (m),
Z=vertical distance between the blast hole bottom and the point of interest (m),
q=linear charge concentration (kg/m),
h= total charge length in hole (m), and
x=position of the elemental charge from bottom of the hole (m).

The developed model is further extended. In the extended model, instead of algebraic sum of the elemental PPVs, vector sum is considered as shown in Figure 3. Thus, elemental PPV at 'X' direction obtained from elemental charge (q ×dy) becomes:

$$\delta vx = Kq^{\alpha}\frac{dy^{\alpha}}{\left\{\sqrt{R_0^{\ 2}+(Z-y)^2}\right\}^{\beta}}\cos\theta \tag{6}$$

and elemental PPV at 'Y' direction obtained from elemental charge (q ×dy) becomes

$$\delta v\,y = Kq^{\alpha}\frac{dy^{\alpha}}{\left\{\sqrt{R_0^{\ 2}+(Z-y)^2}\right\}^{\beta}}\sin\theta \tag{7}$$

and the resultant PPV at 'X' and 'Y' direction becomes

$$ppvx = Kq^{\alpha}\left[\sum_{y=0}^{h}\left\{\frac{dy}{\{R_0^{\ 2}+(Z-y)^2\}^{\frac{\beta}{2\alpha}}}\right\}\cos\theta\right]^{\alpha} \tag{8}$$

$$ppvy = Kq^{\alpha}\left[\sum_{y=0}^{h}\left\{\frac{dy}{\{R_0^{\ 2}+(Z-y)^2\}^{\frac{\beta}{2\alpha}}}\right\}\sin\theta\right]^{\alpha} \tag{9}$$

and the vector sum of resultant PPV becomes

$$ppv = [(ppvx)^2 + (ppvy)^2]^{0} \tag{10}$$

Where,

δ*vx*, δ*vy* = the elemental peak particle velocity along 'X' and 'Y' co-ordinate axes,
ppvx, ppvy = component of peak particle velocity along 'X' and 'Y' co-ordinate axes,
ppv = Resultant PPV or vector sum of *ppvx* and *ppvy*, *K, α, β* are the empirical site constants,
R_0 = horizontal distance between blast hole axis and point

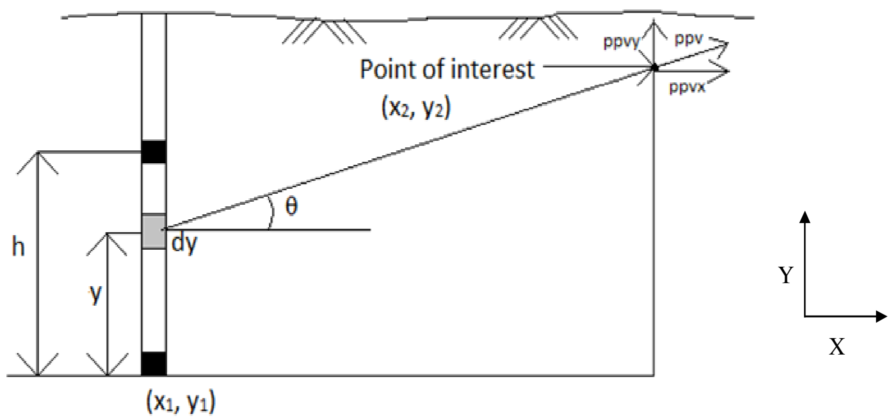

Figure 3. Near-field PPV estimation from the vector sum of the elemental PPVs.

Table 2. Estimation of near-field PPV levels.

Parameters	Values
β	1.44
$\alpha = \beta/2$	0.72
k	1065
Linear charge concentration (kg/m)	0.625
Total explosive (kg)	0.25
Damage distance (m) R_0	1.69
Length of explosive column (m)	0.4
Depth of hole (m)	1.0
Near-field PPV value using Equation 3 (mm/s)	159.42
Near-field PPV value using Equation 5 (mm/s)	159.28
Near-field PPV value using Equation 10 (mm/s)	171.18

of interest (m) = (x_2-x_1),
Z = vertical distance between the blast hole bottom and the point of interest (m) = (y_2-y_1),
q = linear charge concentration (kg/m),
h = total charge length in hole (m),
y = position of the elemental charge from bottom of the hole (m), and
θ = angle with the 'X'-axis so that

$$\cos\theta = \frac{R_0}{\sqrt{R_0^{\,2} + (Z-y)^2}}$$

$$\sin\theta = \frac{(Z - y)}{\sqrt{R_0^{\,2} + (Z-y)^2}}$$

MODEL VALIDATION

The above models are validated using a case study conducted in a surface mines (Dey, 2004). The values of required parameters are shown in Table 2. The Equation 10 shows better accuracy over the Equations 5 and 3 as it incorporates the direction of the wave. Theoretically, two waves at opposite direction should neutralise their effect however, in Equations 5 and 3 it is not considered. Thus, Equation 10 is theoretically more acceptable model for near-field peak particle velocity estimation. The Equations 5 and 10 are solved using MATLAB. The programme code written allows user to enter values of R_0, Z, K, α, β, q, h and finally the number of finite iterations 'n'. Number of iterations are chosen in such a way that $dx \to 0$. This helps in obtaining the desired level of accuracy. The final value of PPV is stored in a variable 'ppv'. The flow sheet of the programme is shown in Figure 4.

CONCLUSION

The suggested mathematical model has greater accuracy over its predecessor in calculating near-field PPV. The accuracy further increases with the increase in the

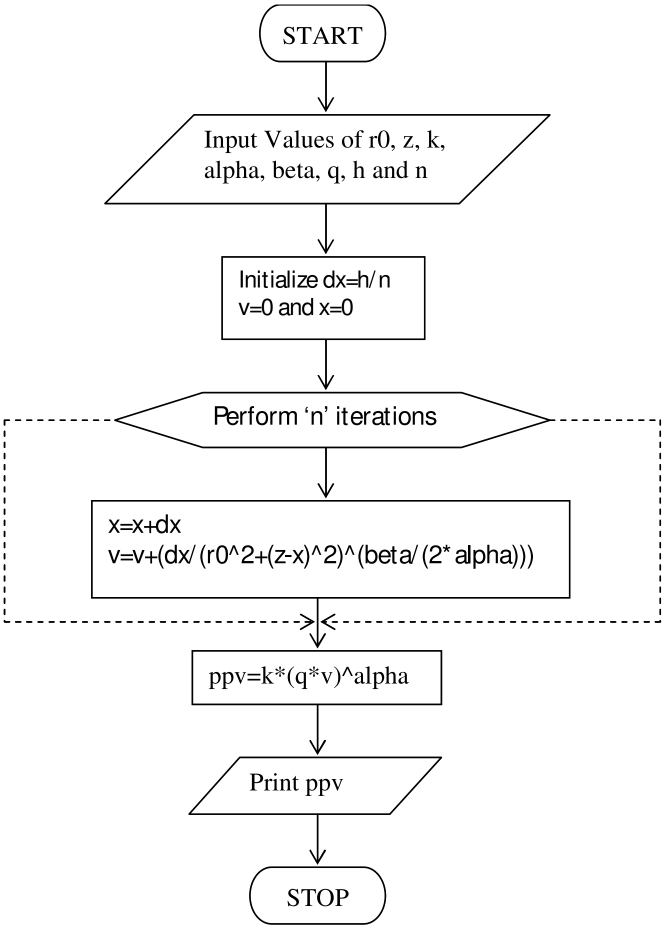

Figure 4. Flow sheet for the MATLAB programme.

iteration. However, it may converge after achieving desired accuracy. Further, this model does not need the condition of $\alpha = \beta /2$ and can be applied for the generalised PPV model also. This model can also be extended for the vector sum of the elemental waves coming from multiple blast holes in a 3-D space.

REFERENCES

Bauer A, Calder PN (1970). Open Pit and Blasting, Seminar Mining Engg. Dept. publication, Queen's University, Kingston, Ontario, p. 3.

Blair D, Minchinton A (1996). On the damage zone surrounding a single blasthole, Proceedings of Rock fragmentation by blasting, FRAGBLAST-5, (Ed) Mohanty, Montreal, Quebec, Canada, 23-24 August, pp. 121-130.

Bogdanhoff I (1996). Vibration measurements in damage zone in tunnel blasting, Proceedings of Rock fragmentation by blasting, FRAGBLAST-5, (Ed) Mohanty, Montreal, Quebec, Canada, 23-24 August, pp. 177-185.

Dey K (2004). Investigation of blast-induced rock damage and development of predictive models in horizontal drivages, Unpublished Ph. D. thesis, ISM, Dhanbad, p. 235.

Edwards AT, Northwood TD (1960). Experimental studies of effects of blasting on structures, The Engineer, p. 211.

Holmberg R, Persson PA (1979). Swedish approach to contour blasting, Proceedings of Fourth Conference on explosive and blasting techniques, pp. 113-127.

Langefors U, Kihlström B (1973). The Modern Techniques of rock blasting, John Wiley and Sons, New York, p. 473.

Meyer T, Dunn PG (1995). Fragmentation and rockmass damage assessment Sunburst excavator and drill and blast, Proceedings North American Rock Mechanics Symposium, pp. 609-616.

Murthy VMSR, Dey K (2002). Prediction of Overbreak in Underground Tunnel Blasting – A Case Study, North American Rock Mechanics Symposium2002, July 7 to July 10, Toronto, Canada, pp. 1499-1506.

Nicholls HR, Johnson CF, Duvall WI (1971). Blasting vibrations and their effects on structures, USBM bulletin, 656: 105.

Oriard LL (1982). Blasting effects and their control, SME Handbook, Littleton, Colorado, pp. 1590-1603.

Paventi M, Lizotte Y, Scoble M, Mohanty B (1996). Measuring Rockmass Damage in Drifting, Proceedings of Fifth International Symposium on Rock Fragmentation by Blasting, FRAGBLAST-5, (Ed) Mohanty, Montreal, Quebec, Canada, August 23-24, pp. 131-138.

Rustan LN (1985). Controlled blasting in hard intense jointed rock in tunnels, CIM Bulletin, Dec. 78(884): 63-68.

Yang RL, Rocque P, Katsabanis P, Bawden WF (1993). Blast damage study by measurement of blast vibration and damage in the area adjacent to blast hole, Proceedings of Fourth International seminar on Rock Fragmentation by Blasting, FRAGBLAST – 4, (Ed) Rossmanith, Vienna, Austria 5-8 July, pp. 137-144.