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Performance Evaluation of Controlled Blasting and Prediction of Attenuation Relation for Charnockite Rocks

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Abstract. Blasting is a common method, employed in mines for production and excavation of rock where precision of excavated level is not necessary. However, when important and critical structures are located adjacent to the blasting area and precision is required for the excavated level, controlled blasting technique needs to be adopted for hard rock excavation. Performance of controlled blasting is evaluated using a parameter namely Peak Particle Velocity (PPV) and this needs to be limited to minimize the damage of existing structure and specified by Directorate General of Mines Safety (DGMS) in India. The specific explosive charges were obtained by carrying out site specific trial blast studies. For a charnockite rocky site located along East Coast of India, site specific relation and specific charge per delay was established through trial blast studies. Further, controlled blasting was carried out and the PPV values observed were compared with the predicted one. The empirical relation, established during trail blast studies is found to be non-conservative beyond 200 m and site specific relation is modified with alternate scaling distance formulations. This predicted equation can be used for arriving specific charge per delay and for carrying out controlled blasting in similar geology.

Keywords: Blasting, PPV, scaling distance, attenuation predictor.

1 Introduction

Foundations of nuclear power plant structures, dams and other heavily loaded structures are often rests on competent rock strata which are moderate to slightly weathered rock. To reach this level, excavation in rock strata is required and is often carried out by mechanical chiselling, hydraulic splitting, expansive grouts and blasting. However, the choice of hard rock excavation depends on the quantum of rock to be excavated, strength and type of the rock and safety of adjacent structures. Controlled blasting is an advanced rock excavation technique which is employed for hard rock (like chanockite type) excavation, where in both production and safety of the existing structures are ensured.

Excavation using controlled blasting involves use of explosives and are detonated using non electric detonators. These release shock waves and these shock waves exert pressure on the rock resulting into fragmentation of rock masses. In controlled blasting, the blasting is designed with suitable burden, spacing and depth of blast holes, stemming, and delayed detonation to ensure the required fragmentation and safety of adjacent structures. Performance of controlled blasting is usually evaluated using a parameter Peak Particle Velocity (PPV) and this value is limited to that prescribed by Directorate General of Mines Safety (DGMS) [1] in India to minimize the damage of existing structure. By knowing the required PPV, the charge per delay can be estimated by conducting a site specific trial blast study. The PPV is usually expressed in terms of scaling distance and site specific constants and the expression is given in Equation (1).

$$V = K \times SD^{-B} \qquad \text{------ (1)}$$

Where,
K, B; are site constants
V is the PPV in mm/s
SD is the scaling distance.

Scaling distance (SD) is defined as the ratio of distance at which PPV measured from source to the charge to the quantity of explosive, used per delay in blasting. There are various relations available in the literature for assessment of PPV in terms of SD. Most commonly used relations are that proposed by United States Bureau of Mines (USBM), Langerfors&Kihlstrom, Ambraseys- Hendron and Bureau of Indian Standard and are indicated in Table 1.

Table 1. Predictor relations for attenuation of blast waves

Proposers of attenuation relations	Equations
United States Bureau of Mines (USBM); DGMS (by Duvall and Fogelson) [5]	$v = K\left(\frac{R}{\sqrt{Q}}\right)^{-B}$
Ambraseys- Hendron [6]	$v = K\left(\frac{R}{\sqrt[3]{Q}}\right)^{-B}$
Langerfors- Kihlstrom [7]& [8]	$v = K\left(\frac{R^{1/3}}{\sqrt{Q}}\right)^{-B}$
Indian Standard (IS) predictor [9]	$v = K\left(\frac{R^{2/3}}{Q}\right)^{-B}$

These predictive models are proposed based on size of explosive charges, shot to measurement distance, explosive types, method of initiation, geology of site, type of rock etc.

2 Geology of the Site & Trial Blast Studies

The study area is located along East Cost of India, and the site consists of 8 to 10 m of course to medium grained loose to dense sand. This layer is followed by 4 to 5 m of greenish Clayey/sandy layer. Subsequent to this clay layer, highly weathered, decomposed & disintegrated rock is observed and the foundation strata of Weathering grade III rock is available at a depth of 15 to 20m, which is charckoite in nature. However the slightly weathered to fresh and strong to very strong fractured rock is encountered at various places which required to be excavated through controlled blasting. The view of the excavated pit is shown in Fig 1. In-situ compressive strength of exposed rock was determined by Schmidt rebound hammer (Figure-2) and the rebound test report shows, in-situ compressive strength range 38-63 MPa.

Fig. 1. View of the excavated pit

Fig. 2. Assessment of insitu strength of rock

Subsequently, trial blast studies were conducted and Peak Particle velocity was monitored at four locations. From the observed data, a site specific relation was established between PPV and charge per delay and the relation is given in Fig 3.

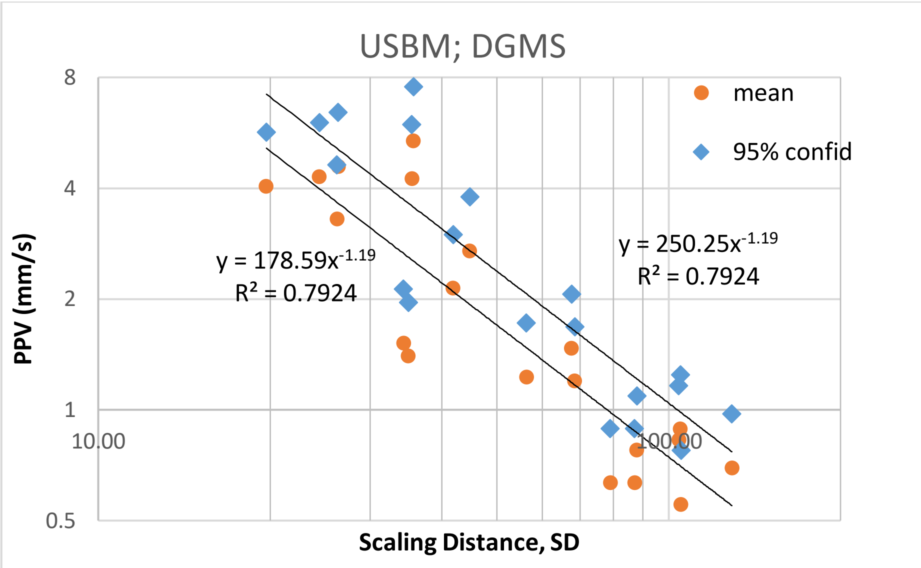

Fig .3. Relation between PPV and Scaled Distance from trial blast studies

The V_{max} (PPV) for 50% confidence is given in Equation (2).

$V_{max} = 178.6\ (D/\sqrt{Q})^{-1.19}$ $R^2 = 0.79$ ---- (2)

Statistical analysis of the trial blast data was carried out to determine the mean, standard deviation and margin of error of all the data points and shown in Table 2.

Table. 2. Results of statistical analysis

Property	Value
Mean	0.208
SD, Standard Deviation	0.334
SE, Standard error	0.075
Z (confidence coeff) for 95 % confidence level	1.96
95% Confidence band upper level, ME= SE x Z	1.401

Using these values, PPV for 95 % confidence was predicted and shown below in Equation 3. The upper bound value for 95% confidence level is indicated in Figure 3.

$V_{max} = 250.24\ (D/\sqrt{Q})^{-1.19}$ mm/s. $R^2 = 0.79$ ---- (3).

The dominant ground vibration frequencies in all the trial blast cases were more than 8 to 40 Hz. The permissible Vmax (Peak particle velocity) as per [2] for sensitive and critical structures is 5 mm/s for the frequency range of 8-25Hz. The permissible peak particle velocity for various dominant frequency as per [2] is given in table 3. As a conservative approach towards safety of sensitive structures located at farther distances, where the occurrence of low frequency waves cannot be negated, the frequency is considered lesser than 8 Hz, conservatively. Accordingly, the safe permissible limit of ground vibration has been considered as 2 mm/s for analysis and safe permissible maximum charge per delay was estimated.

Table. 3. PPV limits in mm/s as per DGMS Guidelines

Sl no	Type of structure	Dominant frequency		
		< 8Hz	8-25 Hz	>25Hz
1	Domestic houses	5	10	15
2	Industrial buildings	10	20	25
3	Buildings of historical importance	2	5	10
	Building belonging to the owner			
1	Domestic House	10	15	25
2	Industrial Buildings	15	25	50

3 Analysis of Actual Blast

The actual blasts were monitored at different locations and PPV were observed for different specific charge. The observed PPV value was compared with the PPV value predicted from the site specific attenuation relation Equation (3) established from trial blast studies and indicated in Figure 4. The comparison indicates that, the PPV values observed are around 40% higher than those predicted from the Equation 3. The best fit line of PPV value for 50 % confidence level is indicated in Equation (4). The best fit line has a better correlation coefficient compared to that obtained from trial blast studies.

$$V_{max} = 356.96\ (D/\sqrt{Q})^{-1.203}\ \text{mm/s}\ R^2 = 0.905 \text{----(4)}$$

Further, statistical analysis was carried out and 95% confidence level was estimated for PPV value and the relation is shown in Equation (5) and Fig 5.

$$V_{max} = 414.37\ (D/\sqrt{Q})^{-1.203}\ \text{mm/s}\ R^2 = 0.905 \text{----(5)}$$

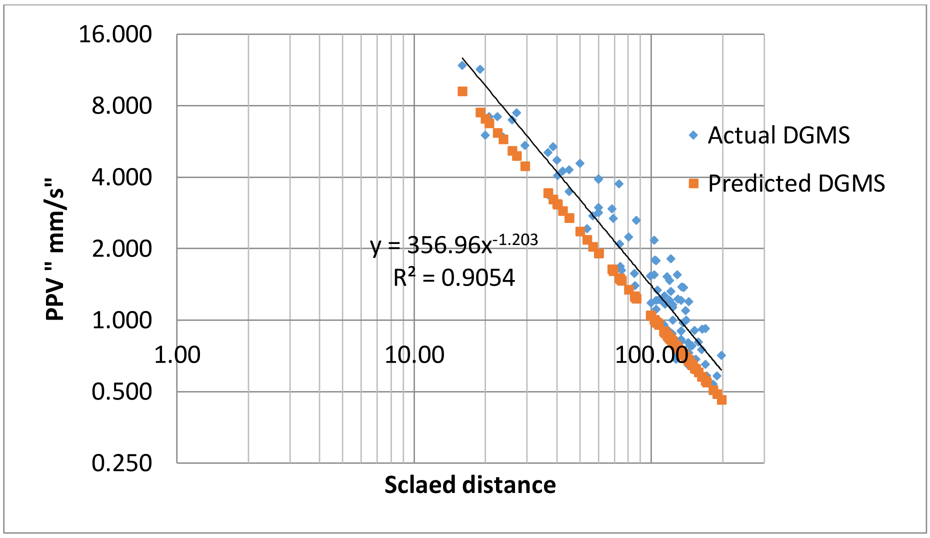

Fig. 4. Comparison of PPV monitored and predicted from site specific relation

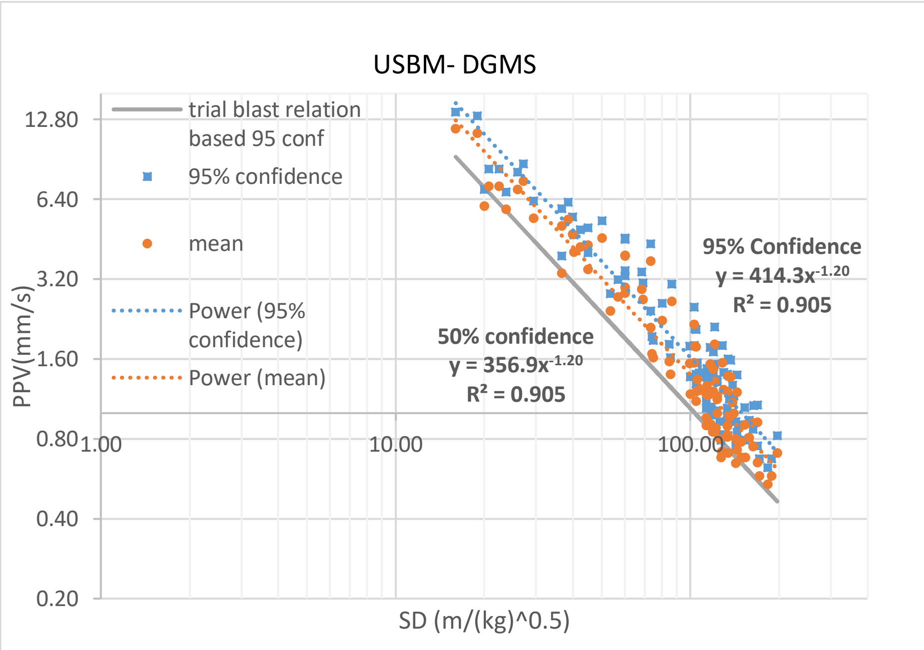

Fig. 5. Site specific relation for PPV with 95% confidence

The empirical relations proposed by other researchers as indicated in Table 1 was used for prediction of PPV value and the predicted values were compared with the actual field data. The relations are indicated in Fig 6 & 7. Statistical site specific parameters obtained for these relations are shown in Table 4.

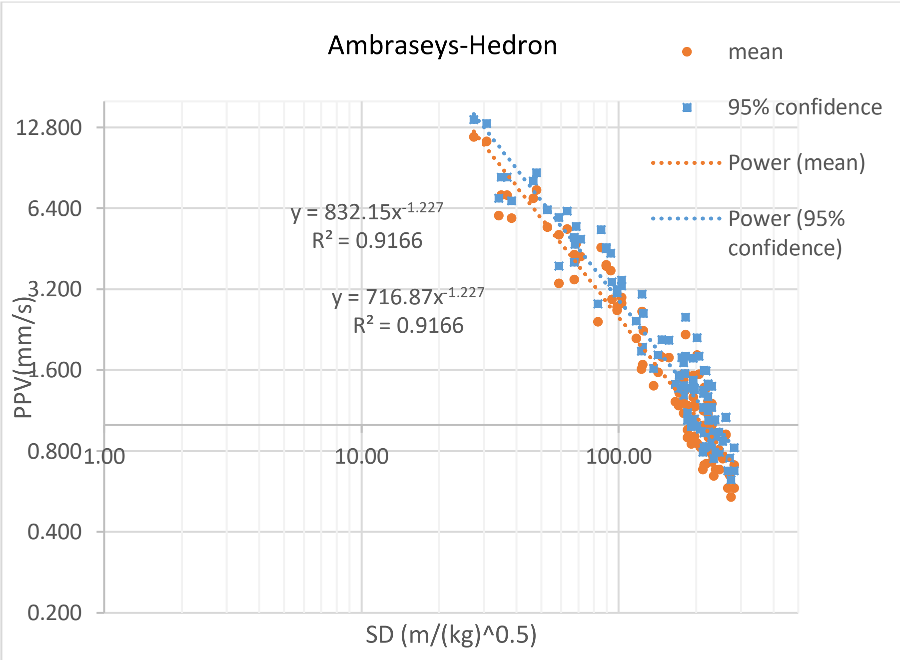

Fig. 6. Relationship between PPV and scaling distance for actual blast study based on Am braseys- Hedron

Table 4. Comparison of site specific parameters for various empirical relations

	site constants			site constants	
Predictor relation name	K	B	R^2	K95%	B95%
USBM (adopted by DGMS)	356.96	1.203	0.9054	414.37	1.203
Ambraseys- Hedron	716.87	1.227	0.9166	832.15	1.227
Langerfors- Kihlstom	5.475	2.313	0.6042	6.3553	2.313
Trial Blast	178.67	1.19	0.7922	250.38	1.19

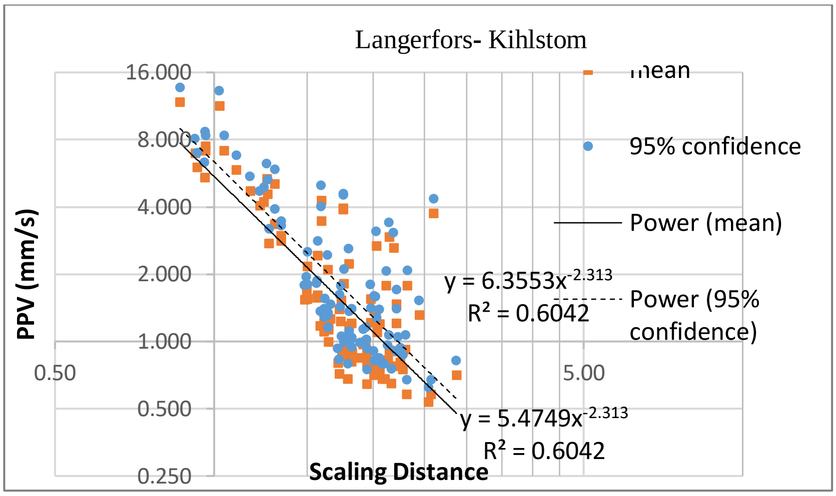

Fig. 7. Relationship between PPV and scaling distance for actual blast study based on Langerfors-Kihlstom

The PPV vales predicted by Ambrasey's shows a better correlation compared to that predicted from Langerfors-Kihlstom and comparable to the actual PPV values. The analysis has indicated that, the DGMS criteria provides lesser PPV values in comparison of with actual field monitored value, and hence the specific charges can be higher and hence not conservative. Considering this, charge per delay to limit the PPV to 2mm/s is calculated for various empirical relations shown in Table1 and the results are presented in Fig 8.

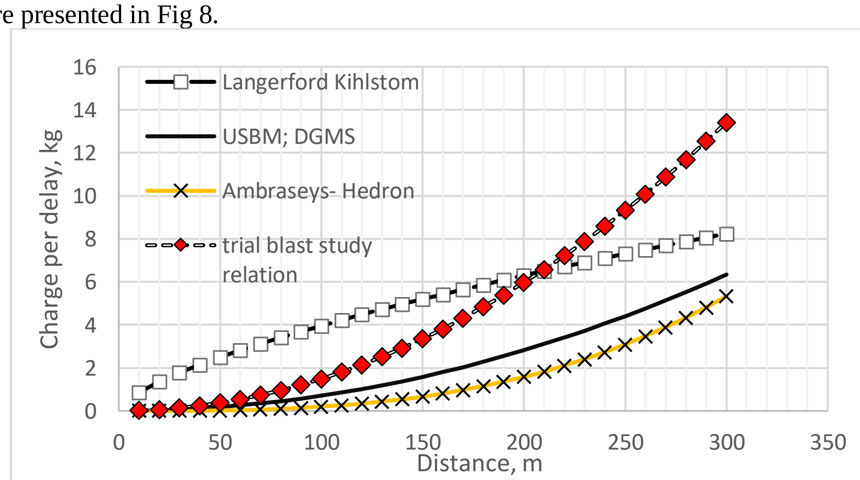

Fig. 8. Charge per delay for limiting PPV to 2mm/s[2] for various empirical relation

It is evident from Fig (8) that, Ambraseys-Herdon empirical formulation is conservative as the charge per delay required to limit the PPV is least among all the relations. Also this formulation shows better correlation coefficient compared to other relations. The site specific relation obtained from trial blast studies is not conservative for distances beyond 200m is also evident from the Fig 8. This can be attributable to the limited number of PPV observations beyond 200m during trial blast studies. The site specific relation developed using Ambraseys-Herdon relation can be used for assessment of charge per delay required for controlled blasting in sites of similar geology.

4 Conclusions

The major conclusions, drawn from the study are

1. The PPV values observed during actual blast are higher than predicted using the site specific relation established during trial blast employing DGMS relations.

2. Site specific relation established from trial blast studies using DGMS correlations are not conservative for distance beyond 200 m and provides higher specific charge per delay in comparison with other relations.

3. Ambraseys-Hendron relation shows a better correlation and the predicted PPV values are comparable with the actual field values.

4. The site specific relation established using Ambraseys-Hendron formulation provides least specific charge per delay and hence recommended for carrying out controlled blasting in the sites having similar geology of charnockite rocks.

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