STUDY OF GROUND VIBRATION DUE TO ROCK BLASTING OF METAL QUARRY: A CASE STUDY

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Abstract: This study was carried out to compare vertical and horizontal bench blast(s) at a granitic gneiss rock quarry located in Colombo, Sri Lanka and predict the resulting peak particle velocities of ground vibration levels. To achieve these objectives, particle velocities and frequencies of 38 and 35 blasts respectively were measured in three perpendicular directions for horizontal and vertical bench blasts respectively with the use of Instantel Blastmate II seismographs. In the blasts, Ammonium Nitrate (ANFO)(blasting agent) primed by a Gelatine Dynamite primer were electrically initiated. Scaled distance parameters (Maximum charge weight per delay and distance between blasting points to monitoring location) were also recorded. The extensively used equation for seismic low of propagation proposed by Devine (1962) and Devine and Duvall (1963) was used for the prediction of peak particle velocities. Points were plotted with Peak Particle Velocity (PPV) in Y- axis against Scaled Distance ($D/Q^{0.5}$) in X- axis. Regression analysis was performed to define the line of best fit. At the end of statistical analysis, an empirical relationship with good correlation was established for prediction of peak particle velocity. Frequency analysis was also done for dominant frequency and Zero crossing frequency to identify the effect of frequency of ground vibration to structural damages and defining the most suitable type of frequency analysis to define the single frequency value for ground vibration. The established relationship, frequency analysis and result obtained are presented.

Key words: Ground vibration attenuation equations; Rock blasting, Peak Particle Velocity, Scaled Distance, Dominant frequency

1. Introduction

Ground vibration, air blast and fly-rock are unavoidable environmental impacts of rock blasting. Despite these, blasting is the widely accepted method of rock breaking in mining and quarrying industries because of cost effectiveness, higher efficiency, convenience and ability to break hardest rock. Among the environmental impacts, ground vibration is the most critical since it can cause damage to nearby structures. Therefore, prediction of ground vibration before blasting through the statistically reliable formula is vital.

2. Test site description

This study was carried out at Hesei Construction company quarry site at Kaduwela Divisional Secretariat division in Colombo District (GPS co-ordinates 06° 54′ 17″ N, 80° 00′ 43″ E) in Sri Lanka, in order to establish a reliable formula to predict the ground vibration and compare vertical and horizontal bench blasts. ANFO was initiated with a gelatin dynamite primer with electric initiation. Vertical and horizontal bench blast geometries applied are shown in figure 1 and 2 respectively. Blasting parameters are also shown in table 1 and 2 for vertical and horizontal bench blasts respectively.

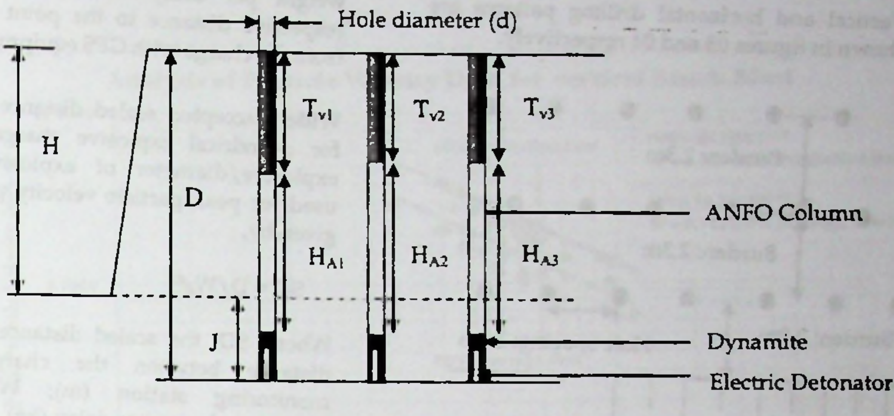

Fig. 01- Blasting geometry of the vertical bench blast

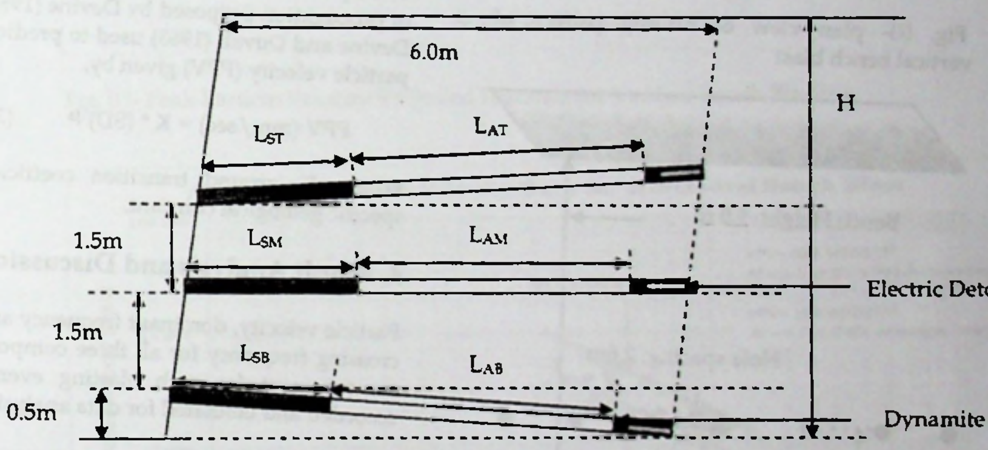

Fig. 02- Blasting geometry of a horizontal bench blast

Table 01- Blasting parameters of vertical bench blast

Parameter		Value
Drill hole diameter		64mm
Bench height(H)		5.25m
Hole depth (D)		6.00m
Sub drilling (J)		0.75m
Weight of Dynamite	First column	1.00kg
	Second column	1.00kg
	Third column	1.00kg
Height of ANFO column	First column (H_{A1})	2.85m
	Second column (H_{A2})	3.35m
	Third column (H_{A3})	3.60m
Stemming height	First column (T_{v1})	2.75m
	Second column (T_{v2})	2.25m
	Third column (T_{v3})	2.00m

Table 02- Blasting parameters of horizontal bench blast

Parameter		Value
Drill hole diameter		64mm
Bench height(H)		9.00m
Hole length		6.00m
Weight of Dynamite	Bottom row	1.00kg
	Intermediate row	1.00kg
	Top row	1.00kg
Length of ANFO	Bottom row(L_{AB})	3.60m
	Intermediate row(T_{AM})	3.30m
	Top row(T_{AT})	3.30m
Length of Stemming	Bottom row(L_{SB})	2.00m
	Intermediate row(T_{SM})	2.30m
	Top row(T_{ST})	2.30m

Vertical and horizontal drilling patterns are shown in figures 03 and 04 respectively.

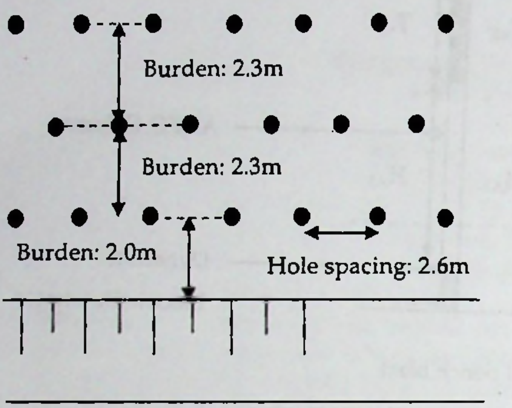

Fig. 03- plan view of drilling pattern of vertical bench blast

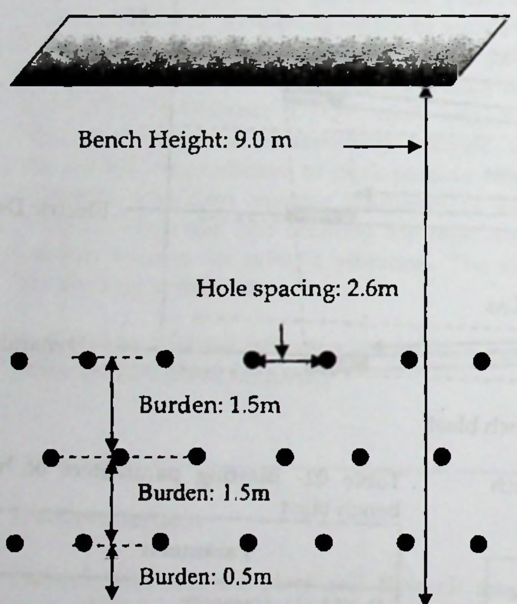

Fig. 04- Cross sectional view of drilling pattern of horizontal bench blast

3. Procedure

Ground vibration and frequency components were measured for the 38 and 35 horizontal and vertical blasts respectively with Instantel Blast Mate II seismographs over a period of 7 months. Maximum instantaneous charge weight per delay was recorded with the respective distance to the point of reference from the charge with GPS equipment.

Widely accepted scaled distance relationship for cylindrical explosive charge (height of explosive/diameter of explosive> 6) was used for peak particle velocity prediction, as given by,

$$SD = D/W_d^{0.5} \qquad (1)$$

Where, SD, the scaled distance; D, absolute distance between the charge and the monitoring station (m); W_d maximum explosive charge per delay (kg).

The equation extensively used for seismic low of propagation proposed by Devine (1962) and Devine and Duvall (1963) used to predict peak particle velocity (PPV) given by,

$$PPV\ (mm/sec) = K * (SD)^{-\beta} \qquad (2)$$

Where, K, ground transition coefficient; β, specific geological constant.

4. Result Analysis and Discussion

Particle velocity, dominant frequency and zero crossing frequency for all three component of measurement for each blasting event were recorded and tabulated for data analysis.

4.1 Analysis of the particle velocity data

Peak Particle Velocity (PPV), which is the maximum particle velocity among the radial/longitudinal, vertical, and transverse components recorded from the same blast event is considered to be a reliable measure for ground vibration caused by blasting.

Statistically reliable equations for ground vibration attenuation were obtained for the vertical and horizontal blasts by plotting the data pairs of peak particle velocity and scaled distance in log scale and simple regression analysis as shown in figure 5 and 6 respectively. Summary of regression analysis is shown in table 3.

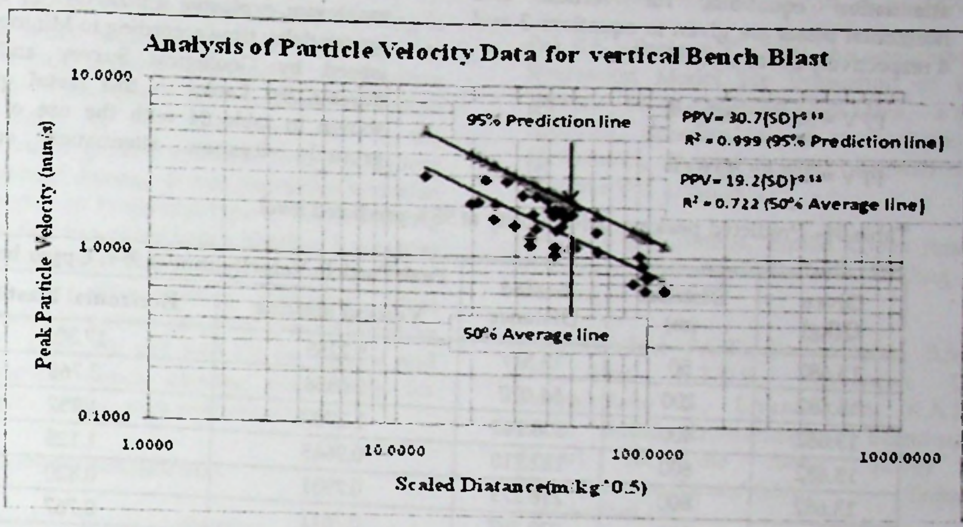

Fig. 05- Peak Particle Velocity Vs Scaled Distance for Vertical Bench Blasting

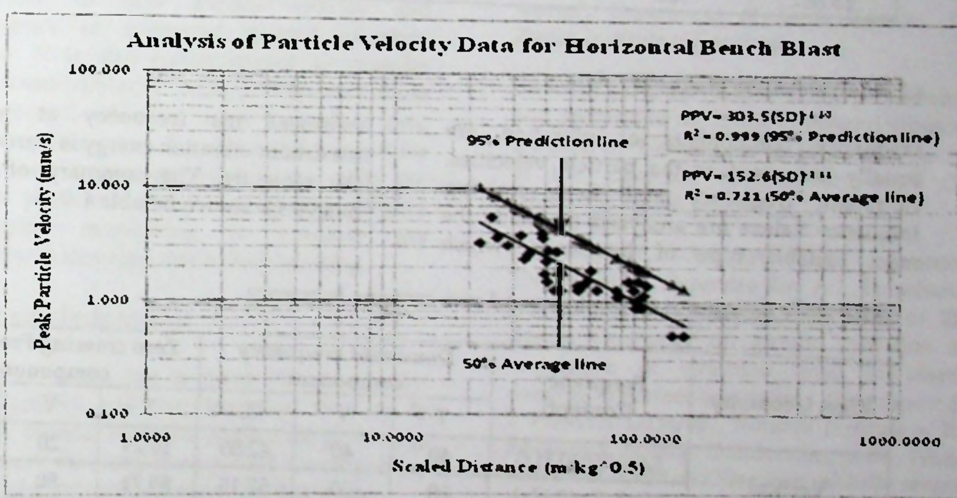

Fig. 06- Peak Particle Velocity Vs Scaled Distance for Horizontal Blasting

Table 03- Summary of regression analysis

Parameter	Vertical bench blast		Horizontal bench blast	
	50% Average line	95% Predicted level (upper bound)	50% Average line	95% Predicted level (upper bound)
Ground transmission coefficient - k	19.2	30.7	152.6	303.5
Geological constant - β	-0.68	-0.68	-1.11	1.10
R^2,(%)	72.2	99.9	72.1	99.9

The upper bound ground vibration attenuation equations, for vertical and horizontal blasts are given in equations 3 and 4 respectively as follows.

$$PPV = 30.70 * (SD)^{-0.68} \quad (3)$$

$$PPV = 303.5 * (SD)^{-1.10} \quad (4)$$

Predicted peak particle velocity for vertical and horizontal blasting based on the maximum explosive utilization (Q) of 13.682 kg per delay time according to Mining License issued by Geological Survey and Mines Bureau, Sri Lanka to this metal quarry is shown in table 04 with the use of derived ground vibration attenuation equations.

Table 04-. Predicted peak particle velocity at 95% predicted level.

Given Q(kg)	Distance (m)	Scaled Distance	Peak Particle Velocity(mm/s)-95% Upper bound	
			Vertical blasting	Horizontal blasting
13.682	50	13.517	5.2255	17.305
13.682	200	54.070	2.0358	3.766
13.682	400	108.140	1.2707	1.757
13.682	600	162.210	0.9645	1.125
13.682	800	216.279	0.7931	0.820
13.682	850	229.797	0.7611	0.767
13.682	875	236.556	0.7462	0.743
13.682	900	243.314	0.7321	0.720

4.2 Analysis of the frequency data

Frequency components of vibration are equally important as the particle velocities. Dominant frequency and Zero crossing frequency values are analyzed to decide the most suitable type of frequency, which represent the frequency at which the maximum vibration energy is transferred into the structure. The summary of frequency analysis is shown in table 4.

Table 05-. Comparison of dominant and zero crossing frequency

Blast Geometry	Frequency Content	Dominant Frequency component			Zero crossing Frequency component		
		T	V	L	T	V	L
Vertical	Low(F<40 Hz)	40	40	42.85	14.29	20	5.72
	High F>40 Hz)	60	60	57.15	85.71	80	94.28
Horizontal	Low(F<40 Hz)	52.89	52.6	68.46	31.58	42.1	44.73
	High F>40 Hz)	47.11	47.4	31.54	68.42	57.9	55.27

It is clearly shown that percentage of low frequencies (F<40 Hz) of dominant frequency are higher for horizontal and vertical bench blasting than zero crossing for all three frequency component. As dominant frequency is more critical than zero crossing frequency, histograms of dominant frequency were plotted to define the most common frequency range of ground vibration for granitic gneiss rock as shown in table 06.

Table 06- Frequency range of dominant frequency

Blast Geometry	Dominant frequency range(Hz)	% of Occurrences		
		T	V	L
Vertical	11-80	74.29	91.43	74.29
Horizontal	0-60	73.89	92.03	78.98

5.0 Conclusion

It is concluded that vertical bench blasting is the most suitable type of blasting, for quarrying activities conducted in sensitive areas (Structures are located in close proximity to the blast site) due to the generated ground vibration and consequent structural damage. It was found that vibration is higher in horizontal type of bench blasting than that in vertical bench blasting. It was also identified that dominant frequency is critical than the zero crossing frequency. Most common frequency ranges of ground vibration are 11-80 Hz and 0-60 Hz for vertical and horizontal bench blasting respectively for granitic gneiss rock environment.

6. Recommendations

Vertical bench blasting is strongly recommended when quarry activities are conducted in sensitive areas giving due attention to peak particle velocity and frequency of generated ground vibration wave. It is also recommended to consider dominant frequency as single frequency value for ground vibration wave instead of zero crossing frequency. It is essential to consider dominant frequency value along with the peak particle velocity during the ground vibration monitoring to evaluate the structural damages due to rock blasting.

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