Prediction of Ground Vibration from Construction Blasts

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ABSTRACT

Prediction of ground vibration from blasting with a known charge per delay at a specified distance is necessary for planning a safe blasting operation. In this paper, ground vibrations from 13 construction projects are analysed for peak particle velocity (PPV) and frequency. PPV can be estimated from the derived vibration attenuation relations. The dominant frequency of ground vibration varied over a wide range but it was always greater than 10 Hz. The frequency was the same whether blasts were conducted with or without delays and there was no significant relation between the frequency of blast vibration with the maximum charge per delay or the distance.

Keywords: Blasting, Vibration analysis, Vibration control, Construction

1. INTRODUCTION

A large number of construction projects involving drilling and blasting are being executed in India for various purposes. Unlike mining blasts, the size of blasts in construction projects is small. Construction blasts usually employ small diameter holes (32-36 mm and rarely up to 100 mm) and use relatively small quantities of explosives. The ground vibration produced from these blasts may not affect surface structures at far off distances, but as these blasts are often conducted close to structures, ground vibrations need to be assessed and controlled.

The National Institute of Rock Mechanics (NIRM) carried out trial blasts at a number of construction projects in India and monitored ground vibration so as to establish maximum charge per delay for each specific site. A large number of data base has been generated and analysed to develop guidelines for prediction of ground vibration and to calculate charge per delay to control vibration within safe limits.

2. GENERATION OF DATA

Field investigations were conducted at 13 construction projects, small to large hydroelectric projects, with an exception of a chemical and fertiliser plant (Table 1). For surface excavation, the structures to be protected from blast vibration were irrigation dams, residential and commercial buildings, temples etc. For underground excavation, the structures to be protected were walls and roofs of the cavities and the partings between the cavities. These surface or underground structures were located close to blasts as given in Table 1. A wide range of rock types (soft to hard) were encountered at the sites.

A summary of blast design and the vibration data are given in Table 2. They were compiled from various unpublished internal reports of NIRM. Blasts were conducted using small diameter holes drilled up to a depth of 6 m. The holes were charged with explosives (nitroglycerine based, ANFO, slurry and emulsion) and initiated with various types of initiation systems including ordinary electric detonators, short delay electric detonators, long delay electric detonators, detonating cord down lines and shock tube system. Ground vibrations were monitored with two or more seismographs for each blast and the range of the measured data are given in Table 2.

3. ANALYSIS OF THE DATA

3.1 Attenuation Relations

The intensity of ground vibration decays with distance and depends on the maximum charge per delay. The most common vibration attenuation model is given by [ISEE, 1998]:

$$V = K (D/\sqrt{Q})^b \quad (1)$$

where V is the peak particle velocity (mm/s), D is the radial distance from blast to monitoring station (m), Q is the maximum charge weight per delay (kg) and K and b are site constants. These site constants are determined by regression analysis. $D/\sqrt{Q}$ is called scaled distance. Peak particle velocity is plotted against scaled distance on a log-log graph. The straight line representing the data has a negative slope, b and an intercept, K at $D/\sqrt{Q} = 1.0$.

Prediction of ground vibration based on site-specific attenuation relation is the most common method at the excavation stage of the project. The site constants of Eq. 1 were derived for each site by regression analysis of the data (Table 2). The wide range of K-values is due to variations in rock mass and blasting practices. Since the rock mass properties for different sites were not available, detailed analyses could be carried out.

At the planning stage, however, it is often not possible to conduct trial blasts and monitor ground vibrations. In such cases, generalised attenuation relations, derived from the

Table 1 - Brief description of the construction projects used in this study

Site No.	Name of the project	Sponsor and location of the project	Purpose of the project	Principal rock type	Critical structures	Minimum distance (m)
1	Boothathenkettu Small Hydroelectric Project	Silcal Metallurgic Ltd. Ernakulam district, Kerala	16 MW Power generation	Granitic gneiss	Barrage, Guest house, Forest office	200
2	Thirumoorthy Mini Hydroelectric Project	TNEB Coimbatore district, Tamilnadu	1300 kW Power generation	-	Dam Residential buildings	25
3	Kuthungal Small Hydroelectric Project	Indsil Electrosmelts Ltd. Idukki district, Kerala	21 MW Power generation	Granitic gneiss	Residential houses	100
4	Maniyar Hydroelectric Project	Corborundam Universal Ltd. Pathanamthitta district, Kerala	12 MW Power generation	Granitic gneiss	Residential houses Barrage	150
5	Chambal Fertilisers and Chemicals Ltd.	CFCL Kota, Rajasthan	Expansion of the existing project	Sandstone Limestone	Facilities of the existing plant	50
6	Manihamsa Mini Hydro-electric Project	Manihamsa Power Projects Ltd. Nellore district, Andhra Pradesh	3000 kW Power generation	-	Dam	20
7	Malankara Power Project	KSEB Idukki district, Kerala	10.5MW Power generation	Charnokite gneiss	Dam and hutments	100
8	Upper Tunga Project (Gajanur)	Mysore Const. Co. Ltd. Shimoga district, Karnataka	Irrigation and power Generation	Granitic schist	Dam, residential buildings and Inspection Bungalow	50
9	Somasila Power Project	Balaji Energy Pvt. Ltd. Nellore district, Andhra Pradesh	10 MW Power generation	Quartzite	Dam, temple, colony, school building etc.	50
10	Subhas Kabini Power Project	SKPC Mysore district, Karnataka	20 MW Power generation	Granite	Dam, Masonry training wall	88 12
11	PUSHEP	TNEB, Ootty district, Tamilnadu	150 MW Power generation	Charnokite	Underground structures (walls, roofs and partings)	-
12	Srisailam Project	APSEB, Srisailam, Andhra Pradesh	900 MW Power generation	Quartzite	Underground structures (walls, roofs and partings)	-
13	Nathpa Jhakri Hydroelectric Project	NJPC, Jhakri, H.P.	1500 MW Power generation	Augen gneiss	Underground structures (walls, roofs and partings)	-

Table 2 - Summary of blast design parameters and vibration data from different construction sites

Site No.	Blast design parameters						Range of the measured data				Results of regression analysis				Frequency (Hz)	NIRM Report No.
	Dia. (mm)	Depth (m)	Burden (m)	Spacing (m)	Explosive used	Initiation system	No. of blasts	D (m)	Q (kg)	PPV (mm/s)	No. of data	K-value	b-value	r-value		
1	40 100	3.0 5.0	1.0 2.0	1.0 2.5	SG ANFO	ED	11	17-304	8.0-50.5	0.4-48.8	39	1347.5	1.80	-0.77	11-53	RB9802
2	32	1.2 -1.8	1.0-1.2	1.0-1.5	SG	SDD	13	23-107	2.5-18.0	0.4-10.4	38	342.7	1.62	-0.70	11-53	RB9708
3	32	1.5-2.4	0.6	0.6	Telgex ANFO	LDD	10	24-500	2.7-29.4	0.2-20.3	20	49.5	0.89	-0.54	13-243	RB9804
4	32	1.5 -3.0	0.5-0.8	0.7-0.9	SG ANFO	LDD	10	60-300	13.3-38.5	0.9-21.6	16	41.9	0.96	-0.62	40-213	RB9201
5	32	1.2	1.0	1.0	SG	SDD	4	50-80	0.7-1.0	1.0-4.8	9	2273.8	1.78	-0.72	41-88	RB9704
6	32	1.5	0.75	0.7	Nobelgel	SDD	7	37-40	0.1-1.0	3.0-13.1	7	1445.0	1.36	-0.79	>100	RB9910
7	32	1.5-2.4	1.0	1.0	SG	SDD	11	10-130	0.2-1.1	0.8-17.2	32	541.8	1.19	-0.80	.40-85	RB9707
8	115	5.5	2.5	2.8	ANFO	EXEL	11	29-283	11.8-48.6	1.0-55.8	37	350.7	1.45	-0.88	25-64	RB9919
9	38 115	1.0 6.0	0.9 3.0	0.9 3.5	Dynex-E Powergel ANFO	EXEL SDD	11	40-115	1.5-25.0	0.9-32.3	44	561.2	1.42	-0.79	20-70	RB0204
10	32	1.0-1.2	0.8	1.0	Telgex	SDD D-cord	52	12-130	0.6-2.5	0.2-10.4	17	204.8	1.37	-0.90	20-80	RB0005
11	32 45	varying	varying	varying	SG	LDD	7	100-950	12.0-30.4	1.0-90.4	21	1665.7	1.22	-0.76	-	RB9601
12	32 65	varying	varying	varying	SG ANFO	SDD LDD	15	26-250	4.0-30.0	0.9-28.5	40	55.4	0.71	-0.52	-	RB9402
13	45	varying	varying	varying	Powergel	SDD LDD	14	15-230	11.7-18.0	1.0-39.8	34	334.4	1.32	-0.91	28-213	RB0101

Notation: Dia. = blasthole diameter; SG = special Gelatine; D = distance between blast and the monitoring station; Q = maximum charge per delay; PPV = peak particle velocity; r = coefficient of correlation, Ed = electric detonator (ordinary); SDD = short delay detonator; LDD = long delay detonators; EXEL = shock tube initiation; D-cord = detonating chord analysis of a large number of data generated from multiple several sites, can be used to predict ground vibration.

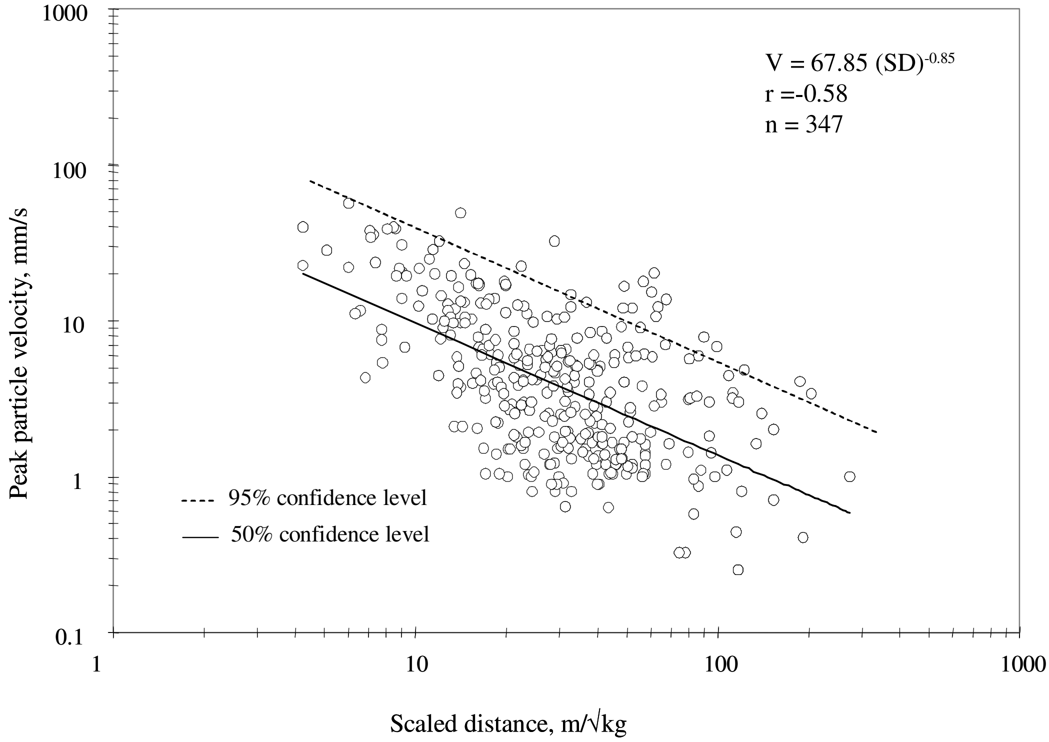

Fig. 1 - Generalised attenuation relation for construction blasts

Using 347 sets of data from 13 sites, the attenuation relation defined by Eq. 1 has been fitted by least squares regression analysis. The generalised relations, as shown in Fig. 1, are:

$$V = 67.85\ (D/\sqrt{Q})^{-0.85} \quad \text{at 50\% confidence level} \qquad (2)$$

$$V = 285.52\ (D/\sqrt{Q})^{-0.85} \quad \text{at 95\% confidence level} \qquad (3)$$

Equation 2 gives the mean value, whereas Eq. 3 gives the upper bound value. Equation 3 ensures that actual vibration levels do not exceed the prescribed limit. These relations are valid for scaled distances between 4 and 300 m/√kg, which is in fact is the range of practical interest. Results and conclusions should not be extrapolated beyond this range. The estimated PPV may be lower or higher depending on other factors like delay interval, initiation sequence, burden, rock and explosive properties.

3.2 Correlation between the Site Constants

There are two site constants in Eq. (1), the K-value indicates the magnitude of vibration generated near the source whereas the b-value indicates the rate of its attenuation. Using 13 pairs of site constants from (Table 2), the slope constant, b, was plotted as a function of logK (Fig. 2). There is some correlation between the site constants, confirming that they are interrelated (Tripathy and Gupta, 2002). By virtue of this relation, high vibration amplitudes attenuate very fast with distance, thus providing natural a safety mechanism at distances of practical interest.

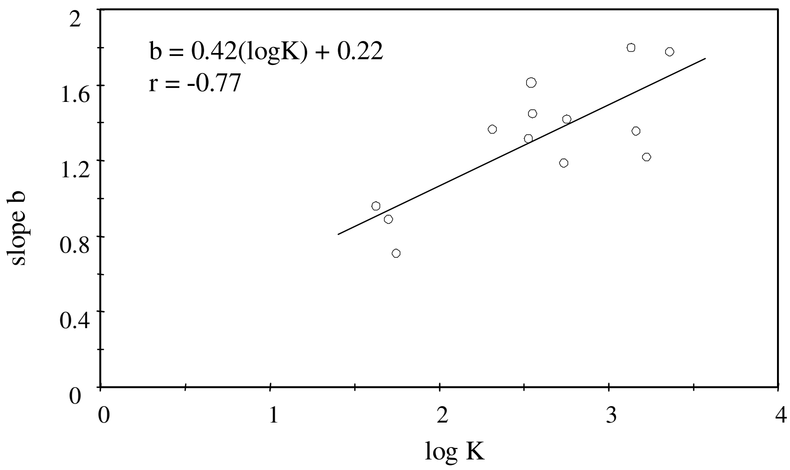

Fig. 2 - Correlation between the site constants of the attenuation relations

3.3 Frequency of Ground Vibration

Blasts produce a range of frequencies containing varying degrees of the vibration energy. Low frequency waves in the range of natural frequencies of structures will cause resonance and increase the damage potential. Frequency in the range of 4-20 Hz falls within the natural frequency range of residential buildings (Siskind et al. 1980). As the frequency produced by construction blasts ranges from 11 to 243 Hz (Table 2), the lower frequency portion is likely to cause resonance in the buildings.

Figure 3 shows the energy contents for different frequency bands for 15 events from Site-1 and Fig. 4 for 12 events from Site-2. Ignoring the bands containing energy less than 10 %, the dominant frequency ranges were found to vary from 11 to 53 Hz. This range is the same for blasts conducted without delays (Site-1) and with delays (Site-2). Furthermore, there was no significant correlation between the frequency of ground vibration and the maximum charge per delay or with distance. Unlike frequencies contained in earthquake records, which gradually become lower with increasing distance due to preferential attenuation of high frequencies (Agrawal 1991), frequencies of blast vibration for both the sites remained more or less the same with distance. Though possibilities for frequency control using delays have been presented (Anderson et al, 1982), it is still difficult to control the frequency of the ground vibration.

3.4 Control of Ground Vibration

Permissible level of ground vibration for a construction site can be decided as per the DGMS circular (DGMS, 1997), which specifies peak particle velocity depending on the frequency and the type of structure. For structures not mentioned in the circular, permissible level can be decided in consultation with blasting specialists. Undue

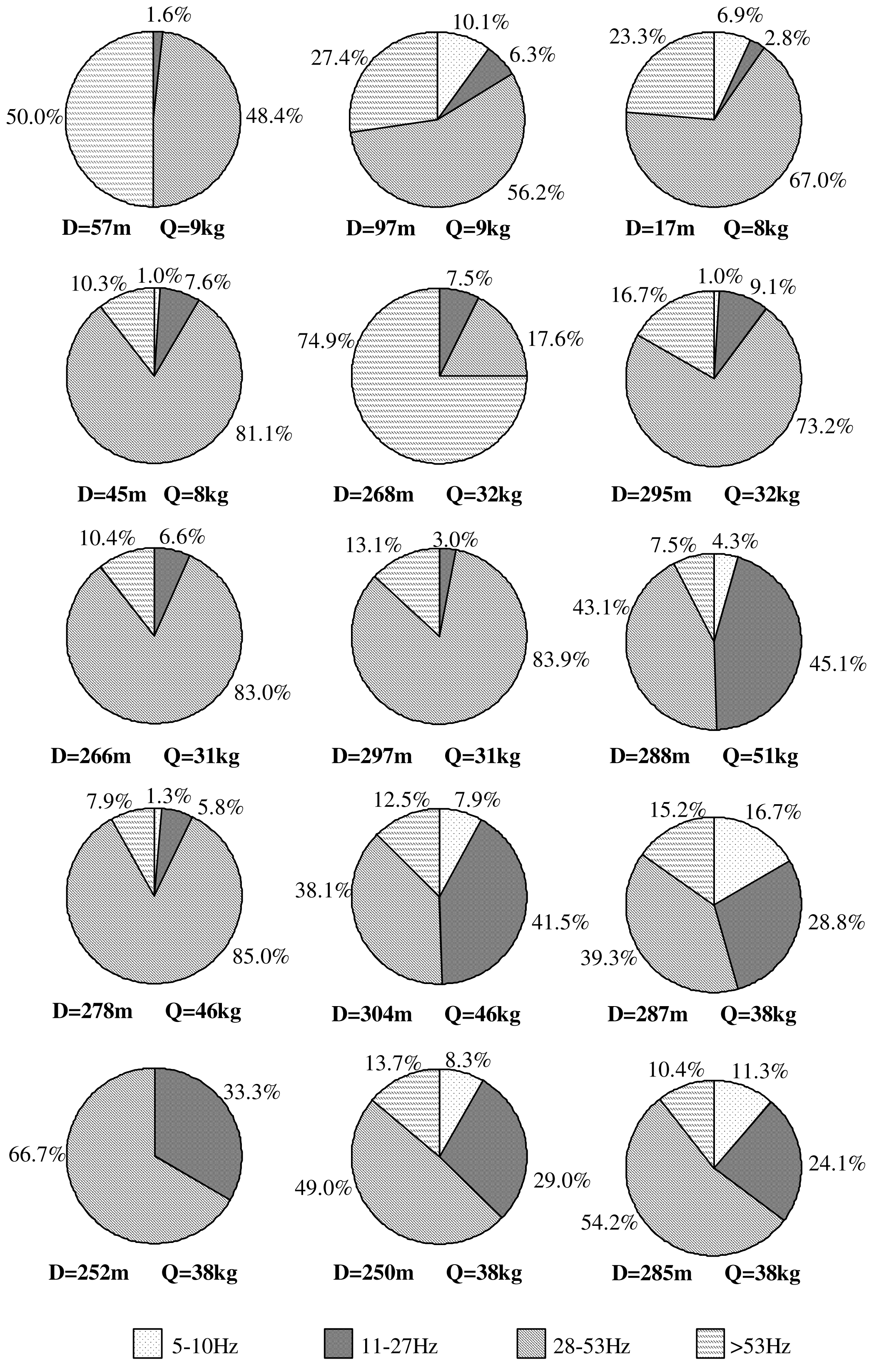

Fig. 3 - Frequency distribution for instantaneous blasts at Site-1

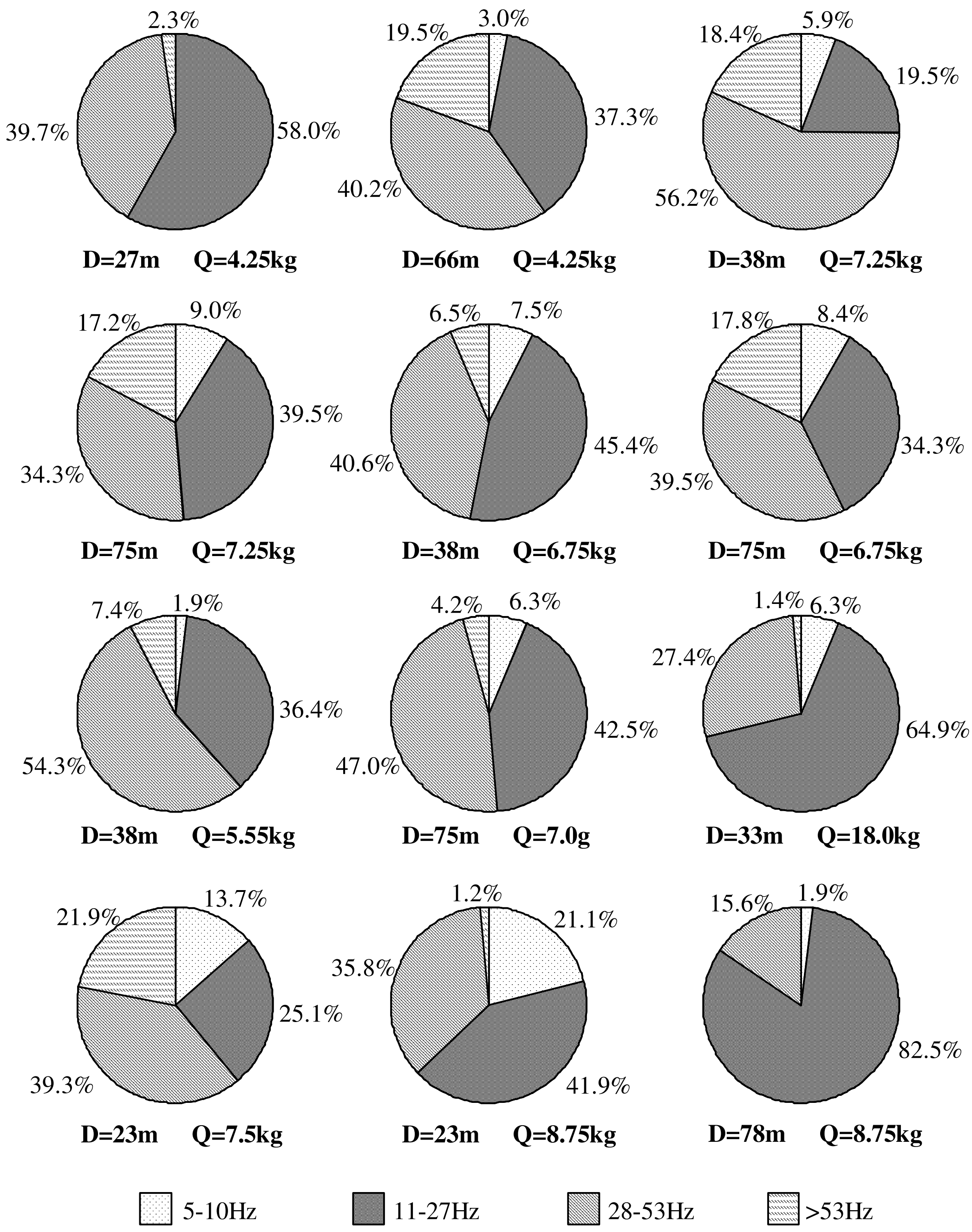

Fig. 4 - Frequency distribution for blasts using delays at Site-2

restriction on the vibration such as those imposed for excavation of Kabini dam (Theresraj et al., 2002) poses severe constraints to blast design and increases the cost.

For each site it is necessary to analyse PPV and frequency from construction blasts to check the vibration compliance with the existing regulations. If the measured vibration levels are high, vibration has to be controlled. Peak particle velocities can be controlled by establishing suitable blast design parameters for a given site condition. It is still difficult to control frequency as it is mostly controlled by the rock rather than by the blast design parameters.

4. GUIDELINES FOR PREDICTION OF GROUND VIBRATION

Based on the above analysis and discussion, the following guidelines are proposed for prediction of ground vibration:

- When no site-specific equation is available, ground vibration can be predicted by Eq. 2 (at 95% confidence level). The actual vibration levels would be lower than the predicted ones. This equation can also be used when it is not possible to monitor ground vibration.
- When blasts are monitored, it is recommended to derive site-specific equations. Again, the derived equation based on 95% confidence level can be used to ensure vibration levels within permissible limits.
- Frequency of ground vibration is expected to be always greater than 10 Hz and greater than 20 Hz in most cases.

5. CONCLUSIONS

Data generated from 13 construction sites have been compiled and analysed to determine generalised attenuation relations. Although these relations can be used to predict peak particle velocity (PPV), it is recommended to monitor the blasts during actual excavation of rock. The dominant frequency varied over a wide range but it was always greater than 10 Hz. The frequency was the same whether blasts were conducted with or without delays and there was no significant relation between the frequency of blast vibration with the maximum charge per delay or the distance. Permissible PPV depends on the type of structures and the frequency For structures not mentioned in the DGMS circular, permissible vibration level can be decided in consultation with a specialist.

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