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Prediction of Ground Vibrations due to Construction Blasts in Different Types of Rock

By

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1. Introduction

A knowledge of the level of peak ground motion expected at a site from detonation of a known charge weight per delay at a specified distance is necessary for planning a safe blasting operation. The seismic wave energy associated with the blast induced ground vibration decreases with distances due to decay of both the amplitude and the frequency of vibration. The attenuation of ground motion depends mainly on the charge weight, frequency content of wave motion, and the elastic properties of the transmitting medium. The interrelationship between the charge weight, distance and the amplitude of the ground motion forms the basis of describing an attenuation law.

With a view to study the attenuation law for blast vibration in different geological formations, the blast vibration data acquired from site specific studies at 14 different project sites has been used. The data base used cover very wide ranges of charge and recording the resulted ground motions at widely varying distances. The data set collected from each site has been used to obtain the mean attenuation relationship by least squares regression method. Standard deviations of the regression coefficients and coefficient of correlation for each data set have been also evaluated. The empirical constants obtained are found to differ significantly for site to site, emphasizing the need for a separate attenuation equation for each site. However, to get generalized attenuation relations which could be useful in the absence of a site specific attenuation relation, the blast data collected from similar rock type has been combined and the attenuation equations applicable for basalt, granite, quartzite and sandstone types of rock have been developed.

The ground vibration levels observed from identical blasts are, in general, seen to be associated with very large scattering. Such uncertainties need to be quantified by appropriate probability distributions for having better confidence in the predicted peak particle velocity levels. Therefore, to take into account the scattering in the observed data, attenuation equations with higher confidence level (95%) are also established. Further, by combining all the data together, a mean zone of attenuation has been also defined for the construction blasting.

2. Attenuation Relationship

To study the attenuation characteristics of blast waves, the most general form of the attenuation relation is as follows:

$$V_p = KQ^m R^{-n} e^{-\alpha R}, \tag{1}$$

where Q (kg) is the charge weight, R (m) is the distance between the source and the observation point, and V_p (mm/s) is the peak particle velocity of ground vibration. In the above equation, R^{-n} and $e^{-\alpha R}$ are introduced to take into account the effects of the attenuation due to geometrical spreading and the internal friction, respectively. The term Q^m accounts for the scaling of ground motion with variation in charge weight. The effect of α is significant only at long distances. Parameters K, m, n and α are greatly influenced by the physical properties of the transmitting medium and these parameters are thus evaluated by multiple regression analysis of the field data.

The attenuation relation of the form of Eq. (1) can be classified into two main categories, viz., the fixed and the flexible scaling laws. In the former, the power of Q is fixed beforehand (Ambraseys and Hendron, 1968; Langefors and Kihlstrom, 1963; Siskind et al., 1980 etc.) and in the later it is evaluated by the analysis of field data (Duvall et al., 1963; Attewell et al., 1965; Ghosh and Daemen, 1983 etc.). The flexible scaling law, without the factor $e^{-\alpha R}$, could be written with a little algebraic manipulation of the power of Q as:

$$V_p = K(R/Q^s)^{-n}; \quad s = m/n. \tag{2}$$

This equation represents a straight line on log-log coordinate system with R/Q^s, known as scaled distance on x-axis and V_p, the peak particle velocity, on y-axis.

$$\log V_p = \log K - n \log(R/Q^s). \tag{3}$$

In fixed scaling laws, the most commonly used powers of Q in Eq. (2) are 0.5, 0.33 and 0.66. These are respectively known as square-root, cube-root and two-thirds scaling laws and are illustrated in Fig. 1. The value of 0.66 has been recommended by Indian standards (IS: 6922–1973). However, the field data suggests that the two-thirds scaling is not suitable for predicting the ground vibrations at long as well as at short distances. The cube-root scaling is based on the assumption that the radiation source is of spherical nature (Ambraseys and Hendron, 1968). The safe charges estimated for small distances (≤ 10 m) by using cube-root scaling are found to be very small, which will not be able to produce any effective blasting. Also, beyond 20 to 25 m, the cube-root scaling of data gives non-conservative estimation of charge. The square-root scaling of data is based on the assumption

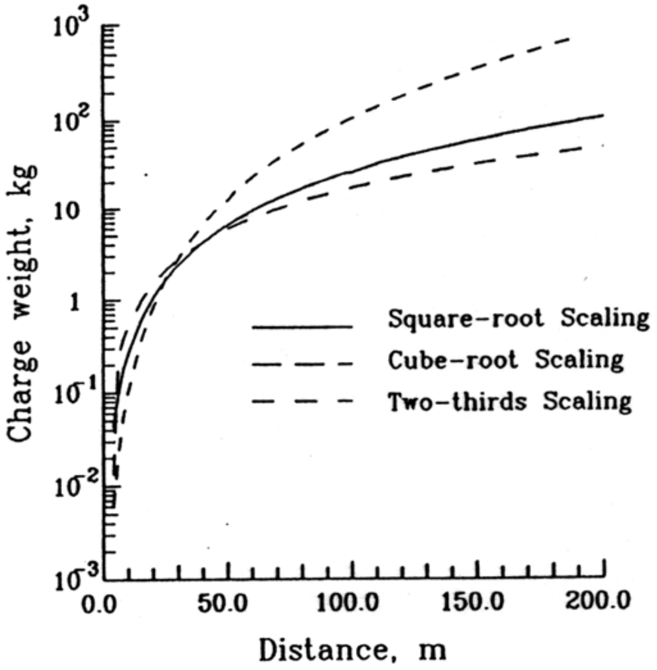

Fig. 1. Variation of safe charge weight with distance for different scaling laws

that the explosive charge is distributed in a cylindrical hole (Siskind et al., 1980). If the charge weight per unit length of the hole is constant, the diameter of the hole would be proportional to the square root of the charge weight. Thus the ratio $R/Q^{0.5}$ is more or less proportional to the ratio between the two lengths, the distance between the blasting and the observation point and the radius of the blast hole. Use of square-root scaling of data to predict the blast vibrations has been recommended by several investigators (Siskind et al., 1980; Tripathy et al., 1995). As the charge weight for construction blasting is mostly distributed in cylindrical holes, the square-root scaling law can be considered more appropriate. Therefore, in the present study, square-root scaling of data has been used for developing the generalized attenuation relations for various rock types.

3. Data Base Used

To develop the attenuation relations in the present study, blast vibration data sets from fourteen different project sites located in different parts of the country (Fig. 2) have been used. The details of the data sets are given in Table 1. The ground vibration data are recorded in three mutually perpendicular directions, viz., transverse, vertical and longitudinal. The peak amplitudes corresponding to these three orthogonal directions, in general, occurred at different times and none of the single component is always predominant. Hence, the peak particle velocity (PPV) values used are the pseudo vector sum of the three components, which are found to be, on average, about 16% higher than the values obtained by true vector sum. These data sets represent varied type of geologic condition, which could broadly be grouped into four types, viz., basalt, granite, quartzite and sandstone.

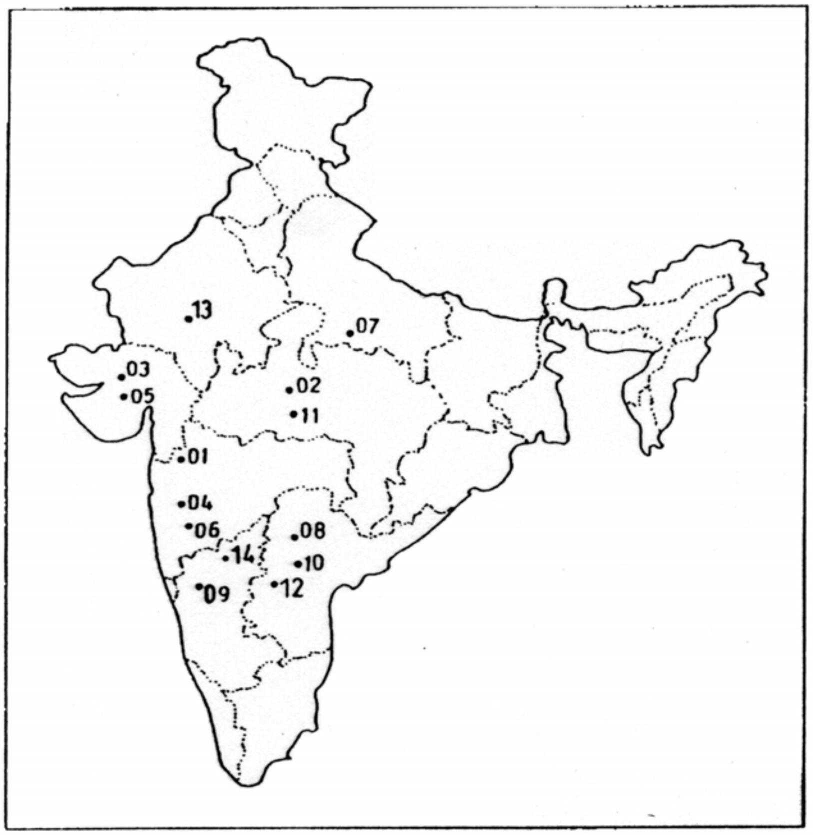

Fig. 2. Location of fourteen project sites (column 2 of Table 1) in India from which the blast data are acquired

4. Development of Attenuation Relationships

The attenuation relationship defined by Eq. (2) with square-root scaling ($s = 0.5$) has been fitted by least squares regression method to the 14 data sets described above. The regression constants K and n alongwith their standard deviations and the coefficient of correlation obtained for all the data sets are listed in Table 2. From the results in Table 2 it is seen that the regression coefficients K and n differ widely even for the same type of geological condition. This perhaps is due to the difference in local rock characteristics such as joint pattern, extent of weathering etc.. Thus, the attenuation coefficients are very much site specific.

The intercept $\log K$ of the attenuation equation is equal to the logarithm of the peak particle velocity, V_p, expected to occur at a scaled distance of unity. Thus, $\log K$ can physically be considered to represent the strength of the blast vibration at the source, which attenuates with distance as per the slope n of the attenuation curve. Figure 3 shows the interrelationship between the slope n and the intercept $\log K$, wherein the data of Marwadi et al., (1993) and Tripathy et al., (1995) have been also included to have a larger data base. It is observed that for larger $\log K$ values, the attenuation is faster as indicated by higher n values. It is found that compact and massive rocks with higher seismic wave velocity are characterized by smaller $\log K$ compared to the fractured and jointed rock mass. This is because, in a weak rock, comparatively less amount of explosive energy is used for break-

Table 1. Details of blast data collected from various project sites

Data set #	Name of project	Rock type	Range of parameters		
			Charge (kg)	Distance (m)	PPV (mm/s)
01	TAPP Maharashtra	basalt	1.00–10.00	13.5–135.0	0.9–38.8
02	Maheshwar project Madhya Pradesh	basalt	1.30–15.00	10.0–145.0	1.0–63.0
03	KAPP Gujarat	weathered basalt	0.30–22.00	5.0–98.0	1.9–54.9
04	Surya project Maharashtra	basalt	0.10–1.00	2.0–37.0	1.1–95.8
05	Champaner project Gujarat	basalt	0.20–5.80	5.8–484.0	0.1–36.5
06	Bembla project Maharashtra	basalt	8.00–37.00	30.0–550.0	0.3–55.4
07	Rajghat project Uttar Pradesh	granite	0.70–13.50	10.0–85.0	1.0–24.0
08	PJP Gadwal Andhra Pradesh	granite	0.70–3.55	11.0–64.0	0.5–11.00
09	Kaiga project Karnataka	weathered granite	0.03–17.00	2.1–92.0	1.7–44.8
10	Singur project Andhra Pradesh	granite	0.43–1.43	5.0–32.0	1.8–41.8
11	Omkareshwar project Madhya Pradesh	quartzite	1.00–25.00	30.0–630.0	0.1–4.5
12	Srisailam project Andhra Pradesh	quartzite	2.00–10.28	4.5–245.0	1.2–300.0
13	RAPP Rajasthan	sandstone	0.28–2.86	10.0–131.0	0.3–168.0
14	Hidkal project Karnataka	sandstone	3.14–31.00	25.0–200.0	0.7–38.0

Table 2. Least squares fitting of the attenuation equation $\log V_p = \log K - n \log\left(\frac{R}{\sqrt{Q}}\right)$ to the 14 data sets used in the present study

Data set #	No. of observations	Regression constants		Correction coefficient	Geology
		$\log K \pm$ SD	$n \pm$ SD		
01	61	2.84 ± .140	1.36 ± .095	0.98	basalt
02	48	2.74 ± .156	1.17 ± .113	0.98	basalt
03	42	2.61 ± .205	1.20 ± .156	0.98	weathered basalt
04	9	2.86 ± .147	1.47 ± .097	0.99	basalt
05	11	2.52 ± .124	1.28 ± .075	0.99	basalt
06	18	2.51 ± .182	1.27 ± .106	0.96	basalt
07	42	2.59 ± .260	1.41 ± .193	0.95	granite
08	37	2.21 ± .181	1.23 ± .123	0.95	granite
09	20	2.40 ± .183	1.08 ± .139	0.98	weathered granite
10	11	2.97 ± .144	1.58 ± .112	0.99	granite
11	24	2.70 ± .275	1.53 ± .156	0.90	quartzite
12	45	2.72 ± .103	1.44 ± .091	0.98	quartzite
13	61	3.49 ± .098	1.68 ± .060	0.96	sandstone
14	62	2.88 ± .190	1.57 ± .120	0.93	sandstone

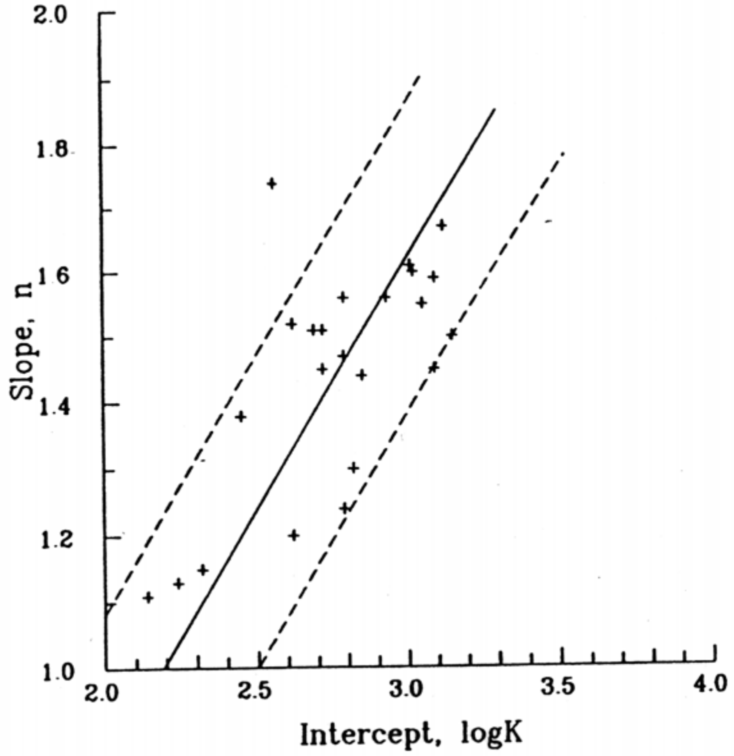

Fig. 3. Inter dependence of regression constants log *K* and *n*

ing the rock and hence higher levels of ground vibrations are produced close to the source. However, at distances of practical interest these are moderated by the faster rate of attenuation in a weaker rock mass, thus providing a natural safety mechanism.

In addition to the rock type, the attenuation constants (log *K* and *n*) also depend on the various blast design parameters. It has been found that, at the same excavation site (same geology), the values of attenuation constants are higher for smaller values of charge weight per delay and recording distance. This may possibly be due to the fact that near the source, the high frequency ground motion decays at a faster rate (high log *K* and *n* values) than the low frequency ground motion observed away from the source. In Fig. 3, there is slight convergence in the scattering of *n* values with increase in log *K* values. This convergence indicates stronger influence of blast design parameters on attenuation constants than that of the transmitting media at near distances.

Though the regression coefficients (log *K* and *n*) of the attenuation relationship are different for different sets of data, an attempt has been made to establish generalized attenuation equations for different types of rock formation. The data collected from similar type of rock have been combined to form a larger data base. As such, four different groups of data have been formed for basalt, granite, quartzite and sandstone types of rock. The mean regression relations and their 95% confidence limits are found for each type of rock formations, which are as follows:

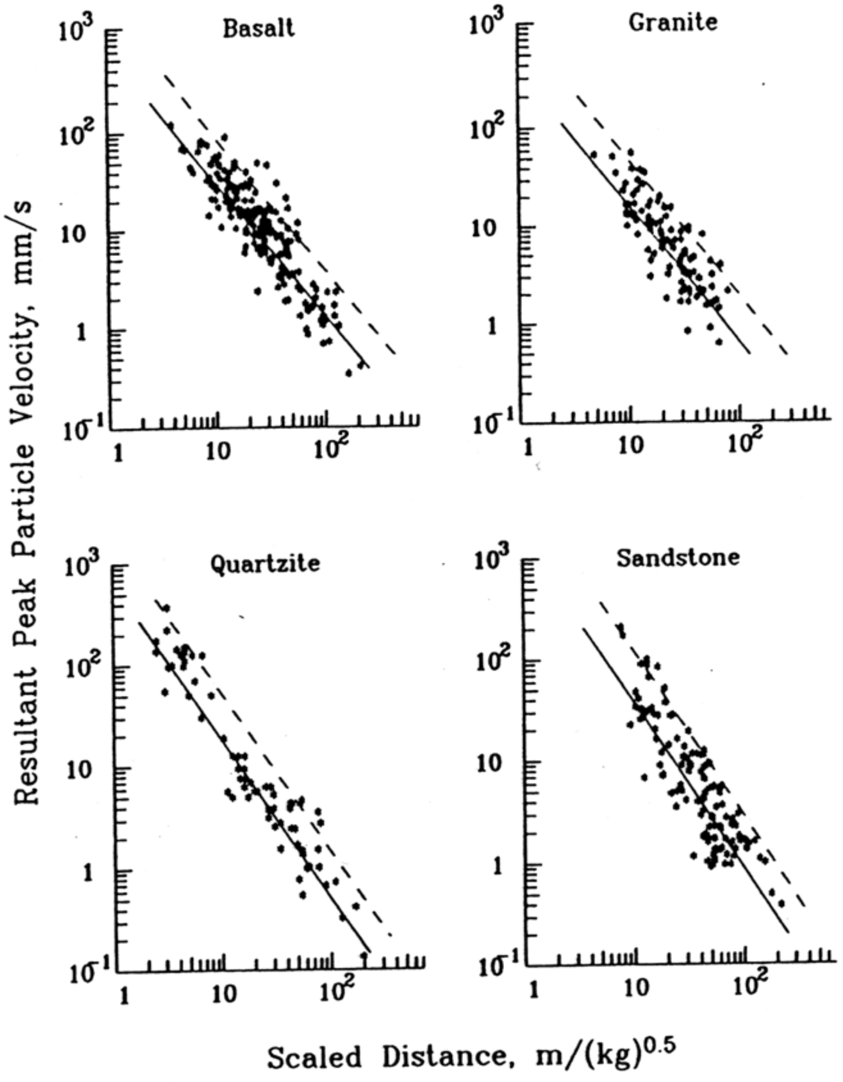

Fig. 4. Fitting of the mean and 95% confidence attenuation relationships to the available data for four different rock types

$$\log V_p = \begin{cases} 2.839 - 1.36\log(R/\sqrt{Q}) \pm 0.457; & \text{Basalt} \\ 2.602 - 1.40\log(R/\sqrt{Q}) \pm 0.464; & \text{Granite} \\ 2.814 - 1.55\log(R/\sqrt{Q}) \pm 0.457; & \text{Quartzite} \\ 3.196 - 1.68\log(R/\sqrt{Q}) \pm 0.513; & \text{Sandstone} \end{cases}$$

The fitting of the mean attenuation equations to the observed data and their 95% confidence levels are shown in Fig. 4. The relations with 95% may be used to ensure adequate safety of the structures.

In addition to the four generalized attenuation equations for different rock types, a mean zone of attenuation for construction blasts has been also defined by considering the mean attenuation equations for all the 14 sites considered in the present study. The individual attenuation relations which do not obey the general

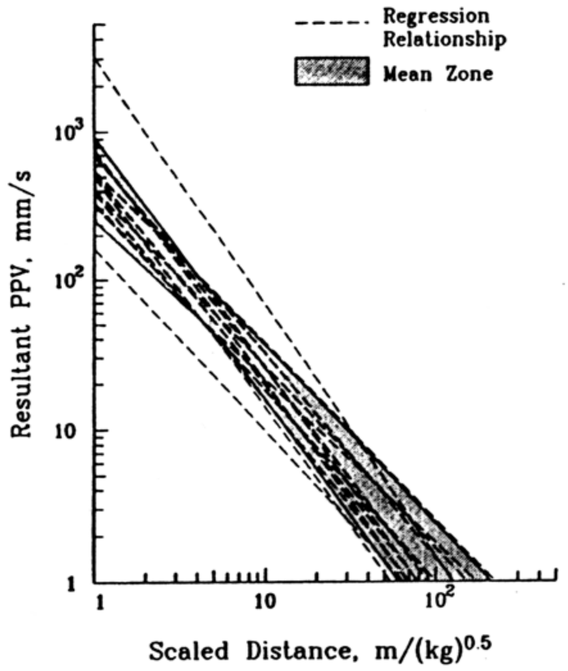

Fig. 5. Mean attenuation curves corresponding to different project sites listed in Table 1 alongwith the expected zone of attenuation for construction blasts (shaded area)

trend of the most of the sites are not given much weightage in defining the mean zone, as shown by shaded area in Fig. 5.

5. Discussion

Development of generalized attenuation relations and mean zone of attenuation for construction blasts are aimed at computing safe charges for construction blasts. Rock excavation by blasting is normally associated with unwanted effects like ground vibration, airblast and flyrock. When blasting is undertaken in an urban environment, the complaints about excessive ground vibration or noise resulted from blasting may be sufficient to jeoparadize the progress of blasting work, as human beings are quite responsive to them. Therefore, the adoption of safe vibration level for blasting work in an urban environment is highly influenced by the response of human beings. According to a study by Foster (1981), velocity levels of 5 mm/s and 10 mm/s are considered unpleasant for human beings with airblast and without airblast effects, respectively. As seen from Fig. 5, these vibration levels, viz., 5 mm/s and 10 mm/s correspond to scaled distances of 60 $m/\sqrt{kg}$ and 30 $m/\sqrt{kg}$, respectively. In the absence of site specific attenuation relation and safe vibration level, these generalized relations with the help of Fig. 5 could be useful for the initial planning stage evaluation of safe charges. In such cases, it may be useful to monitor the blast vibrations during actual excavation of rock, so that the attenuation relation may be modified to suit the actual site conditions.

6. Conclusions

Generalized attenuation relationships are developed for common rock types such as basalt, granite, quartzite and sandstone. These will find useful application in the absence of a site specific relationship. To take into account the random scattering of observed data, prediction equations with higher confidence level (95%) are obtained and are suggested to be used for having better confidence in the prediction.

The ground vibration due to blasting is a vector quantity and is normally recorded in three orthogonal directions. The structural damage may occur if the ground motion in any direction exceeds the prescribed safe limit. Thus the attenuation relationships are developed for the resultant peak particle velocity found by the pseudo vector sum method, which incorporates slight additional safety in the predictions.

Blast data collected from different geological set up have been analyzed and it is found that the regression constants $\log K$ and n are interdependent. An increase in $\log K$ is commonly associated with an increase in n. In solid and massive rock formations, values of $\log K$ and n are small compared to those in weathered and fractured rock.

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