ENSURING SAFETY OF HYDRAULIC STRUCTURES AGAINST GROUND VIBRATIONS GENERATED DURING BLASTING OPERATIONS

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ABSTRACT

During strengthening of old hydraulic structures and expansion activities, deep excavations are required to be carried out in the close vicinity of existing hydraulic structures. Blasting is one of the most economical, efficient and time saving method for deep excavation of hard rock materials. In the process of blasting, the energy released due to the detonation of explosives is utilized for fragmentation of rock. However, during explosion ground vibrations are generated which may endanger structural safety of the nearby structures. Therefore, controlled blasting methodology is generally adopted by limiting the quantity of charge for restricting the ground vibration level within the safe limit. The amplitude of the ground vibration can further be kept within the safe limit by optimizing the blast design parameters. The present paper is based on controlled blast studies carried out near two old Dams in Maharashtra i.e. during strengthening of spillway portion of Koyna Dam, a concrete gravity Dam and project expansion activities near to Yedgaon Dam, a composite type of Dam. In both the cases, trial blasting has been conducted at the site and the data collected by monitoring the ground vibrations at different locations near the Dams has been utilized to develop site specific attenuation relationship. Further, the site specific attenuation relationships have been utilized to estimate the safe charge weight per delay for different distances to be used during the actual rock excavation process. In both the cases, the studies carried out by Central water and Power Research Station, Pune helped the Project Authority to complete the rock excavation work safely in time ensuring the safety of the Dams and other nearby important structures by monitoring the blast vibrations during actual rock excavation.

Keywords: *Ground vibration, Explosive, controlled blasting, Dam, Attenuation relationship*

1. INTRODUCTION

Blasting is one of the most economical and efficient method used for rock excavation in construction, quarry and mining projects. However, utilization of explosive is always associated with some undesired effects like ground vibration, air blast, fly rock, fumes, etc. It has been reported that only a fraction of the energy released, is used for breaking and displacing the rock while rest of the energy, is transmitted through the rock and air. However, these unwanted effects can be minimized by using the methodology of controlled blasting and optimising pattern of blasting. When the energy released due to blasting is not sufficient to fragment the rock, it is exhibited in the form of elastic waves. These waves travelling in all directions from the blasting site give rise to ground vibrations, which may cause damage to the nearby structures. Therefore, completion of excavation work without endangering the safety of surrounding structures is of great concern.

Blast-induced ground vibrations are characterized by two important parameters, i.e. the peak particle velocity (PPV) and frequency. The Damage potential of ground vibrations is largely quantified either in terms of only PPV (Duvall and Fogelson, 1962; Langefors and Kihlstrom, 1978) or PPV and its associated frequency (Siskind et al., 1980; Dowding, 1985; BS 7385, 1993). Therefore, estimation of PPV levels at different distances from blasting location and assessment of their impact on surrounding structures plays an important role during rock excavation in construction, quarry and mining projects.

There are a large number of Dams in India which are quite old and required to be strengthened as per prevailing seismic criteria. Strengthening of the Dam is generally carried out by increasing cross section of the Dam by adding buttresses or concrete backing which involves excavation of rock mass in the vicinity of the existing Dam. The Dams are generally founded on sound rock mass having very high strength which are generally very hard in nature and can only be excavated by using blasting operations. Moreover, in order to meet energy demand, existing power generation capacity is being enhanced since last several years through expansion activities near the existing Dams to setup additional hydroelectric projects. To construct such power projects, controlled blasting is required to be carried out for the excavation of hard rock materials near the Dams. Adequate precaution must be taken to safe guard the Dam from the adverse effects of blasting operations. Suitable blast design parameters are to be established by conducting several trial blasts to prevent damage to Dam structures.

2. METHODOLOGY OF BLASTING

Blasting is a process of reducing a solid body, such as rock into small pieces by using suitable quantity of explosives. Conventional blasting operations involve (1) drilling of holes, (2) placing a charge and detonator in each hole, (3) detonating the charge, and (4) removal of the broken material.

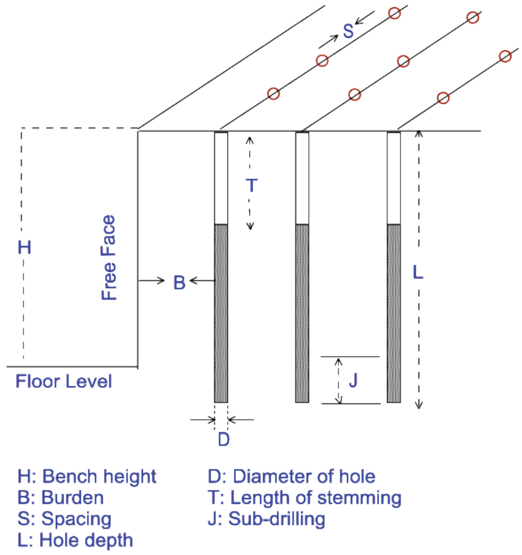

Figure 1 : Schematic diagram showing various blast design parameters

The performance of a blasting operation depends mainly on the rock properties, explosive properties and various blast design parameters. Blast design parameters like burden (B), spacing (S), depth (L) and diameter of blast hole (D), sub-drilling (J), length of stemming column (T), charge per hole, etc. are required to be selected judiciously for a particular application. Fig. 1 illustrates various parameters associated with design of blasting pattern for rock excavation. Faulty blast design produces undesirable effects such as excessive ground vibrations, air blast, flyrock, over-breakage and poor fragmentation. For optimization of various parameters associated with blasting, several trial blasts were monitored by varying the blast design parameters. Based on these observations, blasting patterns were optimized and used for actual rock excavation at site.

3. ATTENUATION OF BLAST VIBRATION

The blast induced ground motion decreases in amplitude and frequency with increase in distance. Vibration observed at a point is dependent on many parameters such as distance, charge weight per delay; type of rock, burden, delay period, sequence of initiation, presence of free face, powder factor, etc. However, out of these charge weight per delay and distance between the observation point and blasting zone are the two most influential parameters of blasting. Due to non-availability of suitable and practical mathematical model, the attenuation characteristics of blast vibration is commonly studied empirically by using the field data collected by detonating a few trial blasts at the actual excavation site. The interrelationship between the charge weight (Q), distance (R) and the observed ground vibration amplitude (V) form the basis of the attenuation relationship. Several empirical relationships have been suggested by different investigators to describe the attenuation of blast vibration. However, the following form of the attenuation equation is used most widely to study the attenuation of blast vibration :

$$V = K\left(\frac{R}{\sqrt{Q}}\right)^{-n} \quad ...(1)$$

Here, V is the PPV (mm/s), R is the distance (m) between the observation and blast points, Q is the quantity of explosive charge used per delay. K and n are site-specific constants, which are estimated by the regression analysis of the observed data obtained from recording several experimental blasts with different charge weights at various distances. The factor $R/\sqrt{Q}$ is the square-root scaled distance.

4. SAFETY CRITERIA

For ensuring the safety of various structures against blast vibrations, safety standards are commonly suggested in terms of the peak particle velocity (PPV). By analyzing a large amount of blast Damage data, the United States Bureau of Mines (USBM) has established that the Damage produced in a structure could be related to the PPV of ground motion (Duvall & Fogelson, 1962). The physical basis for this is the fact that PPV response of a structure is directly related to the strain, ε, produced in a structure as:

$$\varepsilon = \frac{SV_P}{V} \times 10^{-6} \quad \text{....(2)}$$

Here SV_P is the PPV response of the structure in mm/s and V is the wave propagation velocity through the structural material in km/s. As V is fixed for a structure, the strain is directly proportional to SV_P. It has been further observed that the peak response velocity is generally proportional to the PPV of the ground motion (Siskind et al., 1980). Thus, PPV of ground vibration is commonly used to correlate the structural Damage produced due to blast vibrations.

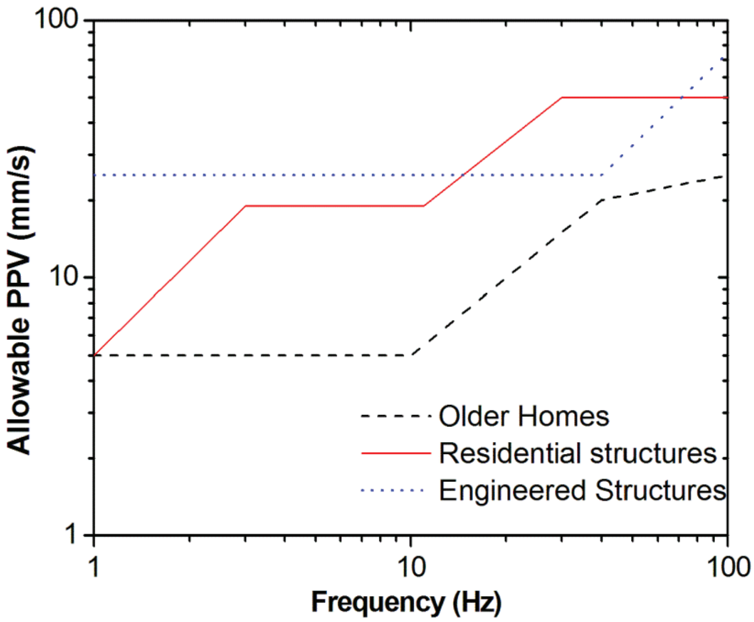

Figure 2 : Frequency dependent safety criteria as per IS 14881:2001

By taking into account the wide variations in different parameters such as amplitudes, frequencies and duration associated with ground motion; type, importance, condition and dynamic properties of structures; and characteristic properties of the transmitting media, various investigators and agencies (Langefors and Kihlstrom, 1978; Edwards and Northwood, 1960; Duval and Fogelson, 1962; Esteves, 1978; Siskind et al 1980, IS-code 14881, 2001, B.S.:7385, 1993, etc.) have put forward safety criteria which vary over a wide range. The Bureau of Indian Standards (IS – 14881, 2001) recommends frequency dependent safety criteria to ensure safety of different structures against blast vibrations. The methodology used for conducting rock excavation work during strengthening of Koyna Dam and expansion of Yedgaon Dam has been discussed in brief as example studies.

5. EXAMPLE 1 : CONTROLLED BLAST STUDIES FOR EXCAVATION OF ROCK DURING STRENGTHENING OF KOYNA DAM, MAHARASHTRA

Koyna Dam is one of the largest Dams in Maharashtra, India. It is a rubble concrete gravity type of Dam with a length of about 807.2 m and maximum height above deepest foundation level as 103.2 m. The Dam suffered considerable Damage due to earthquake of 6.5 magnitude in December 1967 following which, as a measure towards improvement of safety of the Dam, Non-Overflow section of the Dam has been strengthened by providing concrete buttresses during 1973. Post Killari earthquake, for further safety improvement measures, it has been decided by the Project Authority to strengthen Overflow portion of the Dam extending from half of monolith No. 18 to half of monolith No. 24 by providing full concrete backing. For this purpose, rock mass just downstream of spillway in close proximity of the Dam and the Koyna Dam Power House (KDPH), has been excavated to the extent of about 50,000 m^3 of hard rock and 21,000 m^3 of the overlying R.C. concrete by traditional method of drilling and blasting. The excavation area and various structures located nearby are shown schematically in Fig.3.

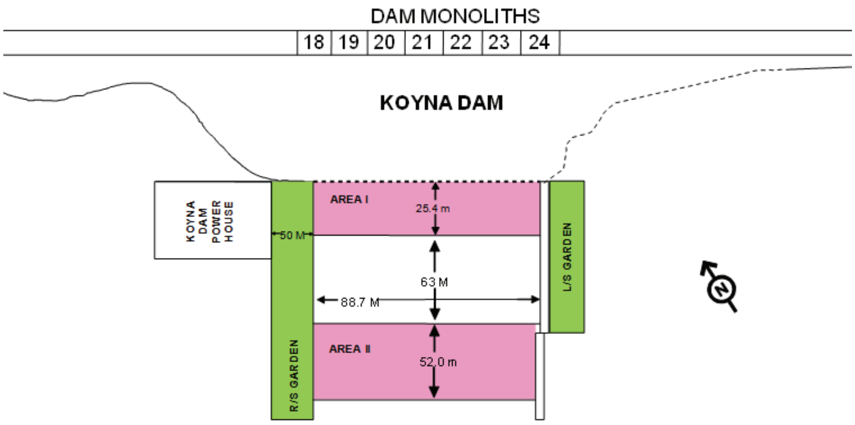

Figure 3 : Schematic diagram showing the location of Koyna Dam and Power House

A total of sixteen trial blasts have been carried out for Koyna Dam site. The vibrations generated from the trial blasts were measured on the bedrock at several different distances varying from 1.35 m to 79.3 m. The ground vibrations resulted from these blasts were recorded at different distances using three component engineering seismographs (DS-077 from M/s Instantel Inc., Canada and Mini Supergraph from M/s NOMIS Seismographs, USA). These data have been used for developing the site specific attenuation relation. Keeping in view of the importance of the Koyna Dam, a PPV level of 70 mm/s was adopted for the safety of Koyna Dam. However, the same cannot be applied to the power house structure installed with several sophisticated instruments. A much more stringent criterion of 10 mm/s was suggested for the Koyna Dam Power House (KDPH) structure. The excavation work at the Koyna Dam site has been carried out in two separate areas, marked in Fig. 3 as Area-I and Area-II, respectively. The depths of excavation in Areas-I & II are about 20 m and 6 m, respectively. Area-I is overlain by a thickness of about 6 m of RC concrete above the rock, whereas the thickness of R.C. concrete at Area-II is about 1.65 m only. The rock type at the Koyna Dam site is the Deccan Traps basalt. Trial blast for koyna Dam site has been conducted using 32 mm diameter holes in foundation rock mass with depth varying from 0.75 to 2.5 m. The charge weights used per blast/delay was varied between 0.04 kg to 2.44 kg. 20 mm diameter gelatine sticks of 0.125 kg each with electrical detonators have been used for initiating the blasts. The blasting and removal of the rock carried out at site is shown in Fig. 4.

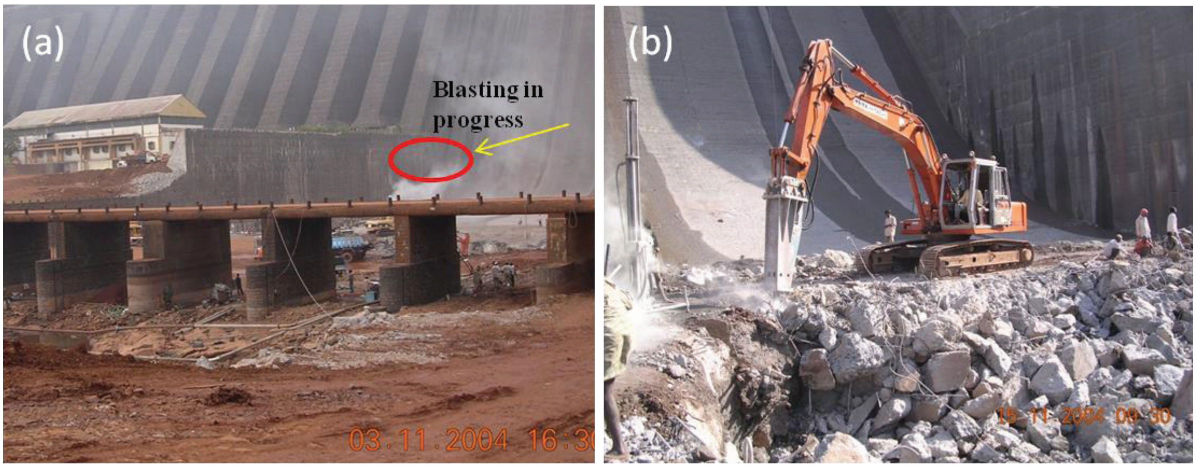

Figure 4 : Photographs showing (a) blasting and (b) excavation work in progress at Koyna Dam site

The mean and the 95% confidence level attenuation relations for the Koyna Dam site are found to be as follows:

$$V_P(0.50) = 1020\left(\frac{R}{Q^{0.5}}\right)^{-1.44} \qquad ...(3a)$$

$$V_P(0.50) = 2444\left(\frac{R}{Q^{0.5}}\right)^{-1.44} \qquad ...(3b)$$

These attenuation equations are plotted in Fig. 5 along with the observed data. 95% confidence level relation has been used for estimating the safe charge weight per delay. The safe charges thus obtained for excavation in different zones of Area - I located in front of the various monoliths of Koyna Dam are given in Table 1.

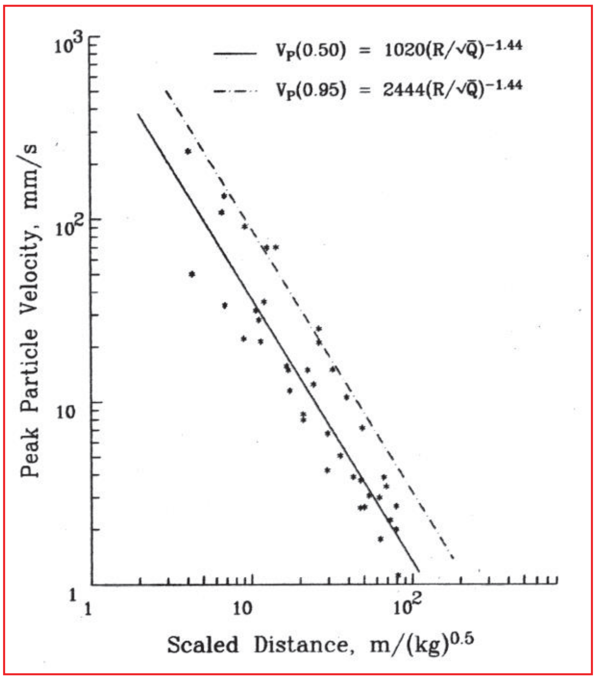

Figure 5 : Site specific attenuation relations with mean and 95% confi-dence levels developed for Koyna Dam Site

Table 1 : Safe charge weight per delay for excavation of rock in Area –I of Koyna Dam

Monolith No.	Zone - I		Zone - II		Zone - III		Zone - IV		Zone - V	
	No. of Holes	Charge weight (kg)	No. of Holes	Charge weight (kg)	No. of Holes	Charge weight (kg)	No. of Holes/ delay	Charge weight (kg)	No. of Holes	Charge weight (kg)
18	1	0.75	1	0.75	1	0.75	1	0.75	1	0.75
19	1	0.75	2	1.5	2	1.50	2	1.50	2	1.50
20	1	0.75	2	1.5	3	2.25	3	2.25	3	2.25
21	1	0.75	2	1.5	3	2.25	4	3.00	5	3.75
22	1	0.75	2	1.5	3	2.25	5	3.75	6	4.50
23	1	0.75	2	1.5	3	2.25	5	3.75	8	6.00
24	1	0.75	2	1.5	3	2.25	5	3.75	8	6.00

Similarly, for excavation in Area-II, safe charge weights per delay have been estimated and are given in Table 2. It may be noted that the above safe charges are recommended for the excavation of rock and the same can be used for excavation of the overlying concrete which would ensure additional safety.

Table 2 : Safe charge weight per delay for excavation of rock in Area –II of Koyna Dam

Minimum Distance (m) From		Recommended Safe charge wt. per delay (kg)
Power House	Dam	
80	98	3.0
100	98	5.0
115	124	6.0
130	124	8.0

6. EXAMPLE 2 : CONTROLLED BLAST STUDIES FOR EXCAVATION OF ROCK FOR YEDGAON HEP, MAHARSHTRA

Yedgaon Dam is located in Krishna basin across river Kukadi in the Pune district of Maharashtra, is a part of Kukadi Irrigation Project. It is a 4470 m long composite Dam (earthen and masonry) and was completed in the year 1977. Project Authority had proposed for the construction of two units of Captive Power Plants (2× 1.5 MW) to generate 3 MW of power by utilizing the water released from the Dam. The proposed project involved construction of an approach channel, intake well, water conveyor system comprising about 165 m long tunnel and about 60 m long open excavation, a power house and tail race channel joining the Kukadi Left Bank canal. Fig. 6 shows a schematic diagram of various components of the proposed Yedgaon H.E. project.

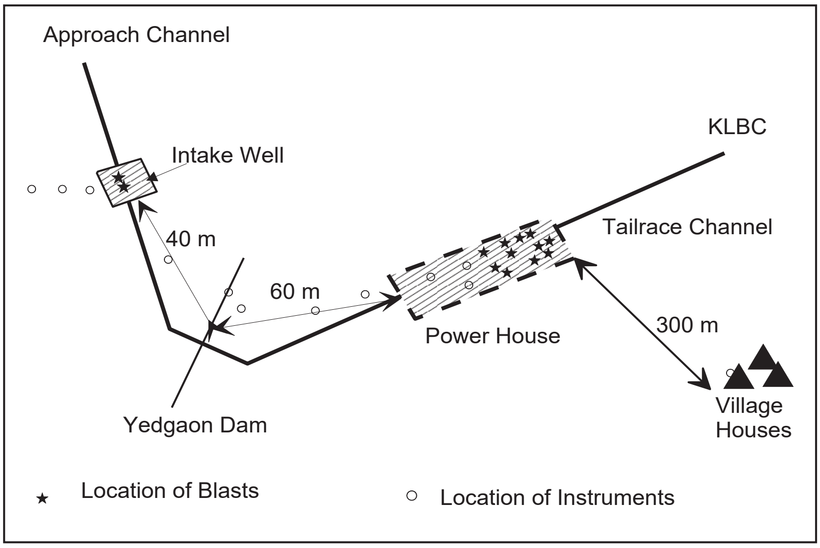

Figure 6 : Schematic diagram showing the location of Yedgaon Dam and village houses w.r.t. the blasting areas

In this connection, based on request from the respective Project Authority controlled blast studies have been carried out for both the Dams by CWPRS, Pune. The rock formation at the Yedgaon Dam site is the Deccan Traps Basalt and two major rock types, namely compact basalt and amygdaloidal basalt are mainly found in the project areas. With a view to develop a site-specific attenuation relation for the site, a total of thirteen blasts were conducted. For all the thirteen blasts, holes were drilled using 33 mm diameter jack hammer. For trial blasts, the depths of hole varied from 1 m to 2.4 m. The holes were charged with 20 mm diameter cartridge explosive each weighing 0.125 kg. The charge weights used per delay was varied from 0.125 kg to 2.75 kg. The vibrations generated from the blasts were measured on the exposed rock at several different distances and also on the Dam top and near residential buildings. The blasting zone was about 20 m to 125 m distances from the Yedgaon Dam. The residential structures located in the nearby "Neharkarwadi"village, were about 300 m away from the proposed blasting site. The residential structures located in the village were of different types. Also, blasts carried out at longer distances are expected to produce lower frequency ground motion which is more harmful to structure than their counterpart with higher frequencies. Hence, a more conservative safety criterion was necessary to ensure safety of village houses. Based on foregoing discussions, PPV level of 25 mm/s and 10 mm/s in all frequency ranges was considered safe for ensuring safety of Yedgaon Dam and village houses, respectively. The drilling of holes and rock removal occurred after blasting operation is shown in Fig.7.

Figure 7 : Photographs showing drilling and blasting operations at Yedgaon Dam site

The mean and the 95% confidence level attenuation relations for the Yedgaon H.E. Project site are found to be as follows:

$$V_P(0.50) = 275\left(\frac{R}{Q^{0.5}}\right)^{-1.10} \quad ...(4a)$$

$$V_P(0.95) = 1095\left(\frac{R}{Q^{0.5}}\right)^{-1.10} \quad ...(4b)$$

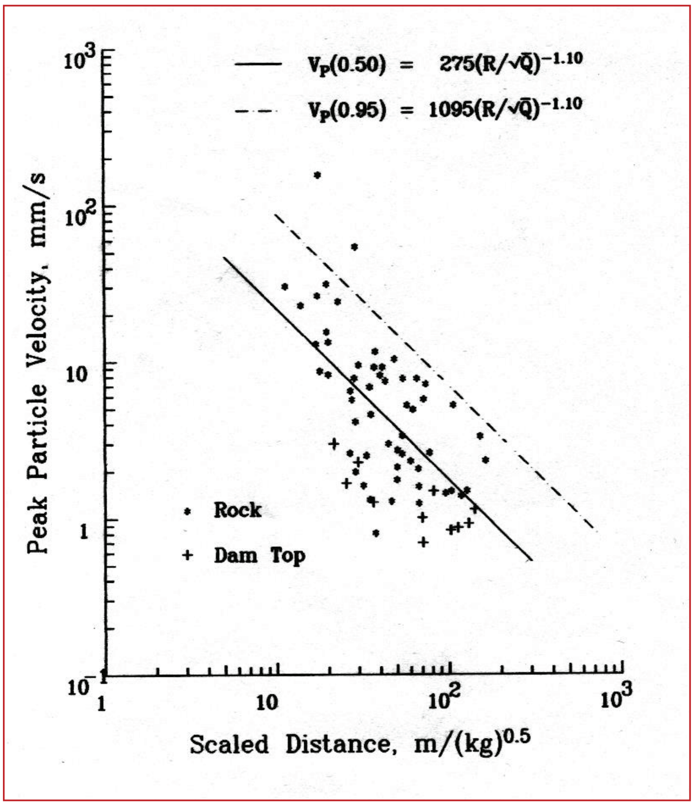

Figure 8 : The site specific attenuation relations with mean and 95% confidence levels developed for Yedgaon Dam site

These attenuation equations are plotted in Fig. 8 along with the observed data. The safe vibration level (25 mm/s) recommended for Yedgaon Dam has been used in the site-specific attenuation relation with 95% confidence level (eqn. 3b) to estimate the safe charges per delay for different distances from the Dam site. The safe charges thus obtained for distances varying from 20 m to 100 m at an interval of 20 m are given in Table-3. The nearest house of the village is located about 300 m away from the blasting site. The maximum charge recommended in Table - 3 (10.36 kg) will produce PPV level of 7.46 mm/s which is about 25% less than the adopted safe vibration level (10 mm/s). Thus, use of safe charge weight recommended in Table -3 will ensure safety of both the Yedgaon dam as well as residential structures in the nearby village.

Table 3 : Safe charge weight per delay recommended for Yedgaon Dam site for different distances

Distance (m)	Safe Charge Weight/ Delay (kg)	Safe PPV level (mm/s)
20	0.41	25
40	1.66	
60	3.73	
80	6.60	
100	10.36	

7. CONCLUSIONS

Based on the studies discussed in this paper following conclusions are drawn:

(i) Excavation of rock near important structures like Dams, Historical monuments, Residential structures are generally carried out by using controlled blasting.

(ii) Prior to blasting operations, a detail site inspection is carried out for assessing the quality of rock formations at the site, quantity of excavation required to be carried out and the condition of important structures located surrounding the blasting zone.

(iii) Based on the site conditions, a safe vibration level for different structures is adopted for carrying out the trial blasting operations.

(iv) During trial blasting operations, various blast design parameters such as quantity of charge, burden, spacing, stemming length and the depth of holes are varied to understand the attenuation characteristics of the ground vibrations.

(v) The ground vibrations are monitored at different distances from the blasting zone and the same is used for developing the site specific attenuation equations.

(vi) The developed site specific attenuation equations are used for estimating the safe quantity of charge to be used while designing the blasting pattern during actual rock excavation process in order to restrict the vibration level within the acceptable limit to safeguard existing structures.

(vii) In the present study, with the help of controlled blasting methodology, rock excavation has been successfully carried out near two old Dams of Maharashtra.

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