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Effects and control of blast vibrations in the vicinity of the limestone quarry

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Abstract: Experimental blast studies were carried out in a limestone quarry to study the effects of blasting on structures. To have an in-depth understanding of the possible relation between parameters like vibrations, frequency and scale distance and ten trial blast were conducted. 29 monitoring stations were located in such a pattern to give a true representation of blast induced vibrations for the entire mining in this area. The vibrations were monitored in the vicinity of structures surrounding the quarry in the direction towards the village, road, railway line, office building, etc. Scale distances were determined to identify the maximum charge permissible to cause damage to structures.

1. Introduction

Ground vibrations are an integral part of the process of rock blasting. Vibrations can be a source of structural damage and is an undesirable feature associated with rock blasting. The purpose of the present study was to study the effects of ground vibrations due to blasting and plan to ensure safety of the surrounding existing structures. The blasting operations were approaching within 300 meters of the surface structures not belonging to the owner of the mine. This included village habitation, railway lines, public road and temples.

Various researchers all over the world have extensively studied the blast induced ground movement, velocity, acceleration and frequency with respect to structural damage. Important contributions in this field have been made by Duvall-Fogelson(1962) Langefors-Kihlstrom (1973), Siskind et al (1980) and Pal Roy (1991). Upon reviewing the literature it is found that site specific constants are to be developed to predict the level of vibrations generated from blasting. In India, Central Mining Research Institute (CMRI) has contributed to a great extent in evolving threshold limit of ground vibrations for structural stability of different structures. In a recent study by A. K. Raina et al (2003) of CMRI it was found that there is a marked increase in response from the people around mines to blasting with increased level of education. Fear of damage to property is a major concern in contrast to the physiological damage. The damage to property is related to ground excitation wave produced by the blast and the natural frequencies of the structures. The vibrations have considerable effect on the stresses and strains produced in the structures if the natural frequency of the structure is in the vicinity of blast induced vibration frequency, the magnitude of vibration in the structure is likely to be much greater than the ground vibration. Amplification of such type of ground vibration in the structures (even at low peak particle velocities) is dependent on the amount of energy in the ground vibration spectrum that is in the vicinity of the structures resonant frequencies together with the damping ratio of the structure at these particular frequencies. The vibrations of walls and floor in the structure can lead to secondary vibrations due to movement of furniture, wall hangings, etc. The subjective estimate of these secondary vibrations by the residents can be much higher. Also the human perception of ground vibrations begins at levels much below that are likely cause any damage to most of the structures. In most of the opencast mining areas complaints from local residents due to blasting are due such human perception or annoyance rather than material damage. It is in this context study of ground vibrations in the vicinity mines has gained much importance.

2. Site Description

The mine is located at distance of 95 kms from Tiruchirappalli in the Perambalur district of Tamil Nadu. The location has latitude of 11°17′ and longitude of 79° 11′. The lease of the mine has an area of 0.565 sq km, with 6.27 Million tons of reserves. The mine surrounded by villages in the east, north and south at distance of 400m, 700m and 300m. There is a railway line within 50m of mine boundary on the western side. In between the mine boundary (on the north side and eastern side) and the villages there are state highways, some of structures like – offices, building and workshop are located within the mine lease. There are also a number of small temples within 300 m of the mine boundary in the north and eastern direction. The mine workings are approaching the ultimate pit limit. The daily average production of the mine is 450 tons of limestone. The limestone deposit is of sedimentary formation and has a soft overburden of 3 to 5m thickness and two limestone bands each of 6 m thickness separated by a sand stone partition of 5m thickness. The limestone band strikes NNE-SSW with an easterly dip of about 10° to 14° towards east. As the limestone dips towards the eastern side, the depth of the over burden increases in the eastern side. The limestone is soft, medium to coarse grained, light yellowish in colour with an average purity of 76 to78% total carbonate and 12% to 15% of silica.

The mine is a semi-mechanized mine. Blast holes are drilled by, 115mm diameter down-the-hole drills. The burden to spacing is 2.5 x 2.5m in a square pattern with a depth of 6.0m. The explosives used were slurry with ANFO. The decking varied from1.0 to 1.5 m and the stemming varied from 2.6 to 2.8 m. The average explosive consumption on a daily basis is around 250 kg.

3. Blast induced vibration study

An explosive or a blasting agent when initiated by heat, impact, friction or shock is capable of undergoing a rapid decomposition, releasing tremendous amount of energy following a blast. Vibration is an undesirable feature associated with any blasting practice. Experience has shown that only 20 to 30% of the energy of an explosive is utilized for fragmenting the rock, the rest of the energy is lost in throw, vibrations, noise and other detrimental features. The ground vibration generating from a blast is a seismic wave motion, spreading outward from a blast like ripples spreading outwards due to the impact of a stone dropped in a pond of water. The ground motions due to blast has three mutually perpendicular components (X, Y, Z, directions) labelled L (longitudinal), T (transverse), and V (vertical). The L and T directions are oriented in the horizontal plane with L directed along the line between the blast and recording transducer. Peak Particle Velocity (PPV) is a term for the greatest speed in which the earth vibrates while it travelled back and forth during the passage of the disturbance. Reviewing all the research and available data, it has been found that PPV and frequency of the wave is the best criterion for evaluating blast vibrations in terms of its potential cause to damage. Hence, any instrument should be capable of measuring these parameters. The instrument used for the present study provides tri-axial transducers for recording the blast vibrations in the three directions it also consists of microphone for recording the air pressure levels. It is PC compatible computer based system with an in-built memory. The software with instrument combines the ease-of-use with Windows Operating System.

The effects of blasting on the buildings and structures in the vicinity of the mine were studied for 5 days. In all 10 blasts (2 blasts per day) were observed. The vibrations were monitored at different locations simultaneously for every blast.

4. Vibration standards and criteria to prevent damage:

The damage from blasting can be either due to vibrations or air over pressure (air blast). Various countries have their own statutory restrictions imposed limiting the same. The Director General of Mines Safety (DGMS) in India has issued guidelines for Indian mines as shown in Table 1.

Table 1. Permissible Peak Particle Velocity (PPV) at the foundation level of structures in Mining Areas in mm/s.

Type of Structure	Dominant excitation Frequency, Hz		
	< 8Hz	8-25 Hz	> 25 Hz
(A) Buildings / Structures not belong to the owner			
(i) Domestic house / structures (Kuchha, Brick & Cement)	5	10	15
(ii) Industrial Buildings (RCC & Framed structures)	10	20	25
(iii) Objects of historical importance & sensitive structures	2	5	10
(B) Buildings belonging to owner with limited span of life			
(i) Domestic houses / structures (Kuchha, Brick & Cement)	10	15	25
(ii) Industrial buildings (RCC & framed structures)	15	25	50

However, there are no guidelines for restricting air over pressure level produced due to blasting. This is due to the fact the standard for limiting the air blast is much higher than for limiting ground vibrations. In a normal blast where ground vibrations are limited to a safe value than over pressure created due to air blast is automatically restricted within the safe limits. Also as can be seen from the table PPV based on frequency govern the damage potential. To predict the extent of damage and to take preventive measures, it is necessary to measure the ground vibrations due to blasting. Studies should be made at site to develop site specific constants and develop a predictor equation. In order to arrive at the safer limits of vibration for the different structures the permissible peak particle velocity at the foundation level of structures as per DGMS guidelines was used. The most delicate (houses) and important (temple) structures liable for damage were made of brick and concrete. The natural frequencies of which generally lie in the range of 8 – 16 Hz.

5. Field study and data analysis:

The blast design was arrived based on the site conditions, keeping in view the production requirements, blast performance in terms of powder factor, fragmentation, muck profile, and safety. The first consideration was to place the charge well down the blast holes, depth of stemming never less than the burden (20 times diameter of the blast hole), at the same it also reduces fly rock, air blast and vibrations. Inclined hole improve the breakage at the bottom. The vibration monitoring stations were selected in a manner to be indicative of giving a true assessment of the likely effect of damage to structures. There were in all 29 monitoring stations, for each blast frequency, PPV in 3 modes along with air pressure were recorded (Table–2). The maximum charge per delay was restricted to 33.36kg for all the blasts, except in blast-2 where it was 36.14kg. The explosive mass charge varied between 200 to 300 kg. The observations indicate that the maximum PPV recorded was 2.54 mm/s at a frequency of 11 Hz at distance of 191.0m for the fifth blast.

The PPV is related to scaled distance, which is the distance between the blast location and the monitoring station divided by square root of the charge per delay. This relation involves important factors namely PPV, distance from measuring site and maximum charge per delay. Using regression analysis a mathematical relation can be obtained between these parameters. This allows mine operators to develop a site specific form of the scaled distance equation. Experience has shown that the relation can be of the form $V = H\ (S)^{-\beta}$, where V is the peak particle velocity in mm/sec, S is the scaled distance, H and β are field constants. The values of H and β are highly site specific and are to be established based on extensive observations at the site. Figure I shows the plot of PPV against scaled distance.

Table 2. Details of blast induced vibration data collected.

Sl. No.	Blast No.	Dist (m)	Peak Particle (mm/s)	Dominant peak frequency mm/s	Air over pressure (dB)	Total charge (Kgs)	Monitoring Station
1.	1	130	0.127	100	112	300.00	South of mine
2.	1	193	0.318	111	114		South of mine
3.	2	213	0.254	120	100	200.00	Towards village north
4.	2	320	No blast vibration recorded				Towards north east
5.	2	303	0.381	114	114		House north west
6.	3	364	No blast vibration recorded			222:22	Near ANFO station
7.	3	210	1.65	115	100		Towards fuel station
8.	3	266	0.572	118	100		Mine Office
9.	4	401	0.953	9.0	110	277.78	Tiled house west
10.	4	301	1.14	20	122		Towards road east
11.	4	391	0.826	98	117		House with thatched roof north-west
12.	5	191	2.54	11	116	255.56	South-east of mine
13.	5	388	0.635	48	114		ANFO shed
14.	5	383	0.127	17	116		Railway line
15.	6	276	0.508	39	114	277.78	Fuel station
16.	6	383	0.508	17	114		House with thatched roof north
17.	6	326	0.254	21	106		Railway line
18.	7	326	0.508	15	112	266.88	Office
19.	7	291	0.826	19	110		South Road
20.	7	231	0.381	41	112		South West side road
21.	8	155	1.02	13	117	255.56	Temple north
22.	8	239	1.97	13	120		Magazine
23.	8	229	1.65	11	120		North side houses
24.	9	285	0.826	33	110	244.46	East side houses
25.	9	250	1.08	100	112		East side houses
26.	9	352	0.254	111	116		Railway line
27.	10	477	0.127	38	110	266.88	Tiled house
28.	10	290	0.889	41	114		Temple east
29.	10	299	0.572	23	123		Railway gate

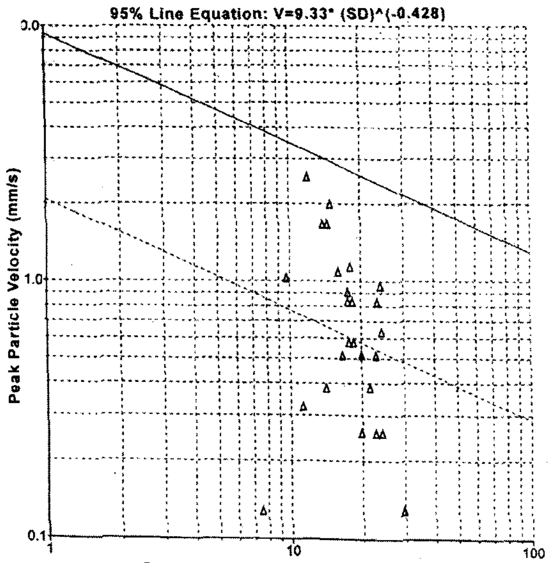

Fig. 1.Regression line for measured data

The following predictor equation was derived based for 10 blasts with 29 observations. With a standard deviation of 0.327,

$V = 9.3\ (S)^{-0.428}$ .... 95% confidence level

This relation can be used for estimating the peak particles velocities likely to be generated at various locations and charges are to be determined accordingly. In order to determine the safe limit of charge for the mine the maximum PPV can be restricted to 5.0 mm/sec. This is based on the type of structures existing as said earlier.

6. Conclusions

In order to assess and control blast vibrations, site specific relations between Peak Particle Velocity and scaled distance are to be developed. Regression analysis methodology offers a simple means to achieve the same. In the present study 29 stations were identified for blast vibrations study and were located based on the site conditions. The blast design was based on production requirements. The maximum PPV was recorded as 2.54mm/s, at 11Hz frequency indicating the existing blast design was adequate and the vibration levels were well within the statutory limits to cause any concern in the neighbourhood. The vibration frequencies are also to be considered, some of the structures would be experiencing amplification of vibrations if the vibration frequency is in the range of natural frequency of the structures. Further, the wide variation in PPV suggest that other features also influence PPV requiring a more detailed investigation.

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