

Scientific/Technical Paper

Measurement and Analysis of Air Overpressure from Blasting in Surface Mines

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Abstract

Five microphones along with seismographs of the same make and model were checked for accuracy of measurements of air overpressure from a source at different distances. Four microphones gave identical readings while the fifth one showed some discrepancies. The same five microphones and seismographs were also used to study the influence of mounting height on air overpressure measurements. The microphones were mounted at a height varying from 1 m to 4 m and five quarry blasts were monitored. This experiment established that the mounting height has negligible influence on the measurements. Another experiment was conducted to measure air overpressure levels from detonating cord and to suggest a suitable method to reduce these levels.

The data generated by the authors from different projects were grouped into two categories and analyzed to derive predictor equations for estimating sound pressure levels and associated frequencies from blasting in surface mines and quarries.

1. Introduction

Human response to a blast is a combined effect of both ground vibration and air overpressure. Air overpressure is the air pressure from blasting which rises very rapidly and returns to the ambient atmospheric pressure after a number of oscillations. The maximum amplitude of the pressure is known as peak air overpressure. Air overpressure from blasting consists of a wide range of frequencies, some of which are sensed by the people as noise, while the low frequency component (<20 Hz) causes concussion.

Generally, air overpressure is monitored together with ground vibration using blasting seismographs to assess and control environmental impacts of blasting. Air overpressure is measured with microphones having linear weighting scale. Air overpressure levels, measured in Pascals (Pa) can be converted into sound pressure levels in decibels (dB). Seismographs of different makes and models are supposed to give same readings for the same source at the same distance. Because of the different hardware and software used by different manufacturers, some instrumental errors seem to occur. Instrumental errors are also possible with microphones of same model. Therefore, the accuracy of the microphones needs to be ascertained. Besides the instrumental errors, there could be measurement errors. One such error may crop up on account of the mounting

height of microphones, which varies in practice due to lack of standardization. A study was conducted by Eltschlager and Wheeler (2005) up to a limited microphone height of 0.9 m but further studies are needed in this area.

Though shock tube systems and electronic initiators are commercially available, detonating cord, being inexpensive, is still widely used for blast initiation in surface mines. A major disadvantage in the use of detonating cord is the air overpressure produced on detonation. A better insight into the role of detonating cord on noise generation and its control is essential to mitigate the adverse environmental effects due to blasting.

A large number of investigations were carried out by the authors at surface mines and quarries to exploit the mineral resources profitably with minimal environmental disturbances. There is a need for analysis of the data generated to derive predictor equations which can be used to assess the air overpressure levels from blasting.

This paper presents the details of the experiments and analysis of the air overpressure data from blasting in surface mines and quarries.

2. Accuracy of Measurements

In order to compare the response of microphones, an experiment was conducted by deploying five units of Minimate Plus at the same location and at the same height to record the air overpressure levels. Comparisons are made of Instantel seismographs to eliminate any possible differences among microphones of different manufacturers. All these units were factory calibrated and were within the validity period. These microphones were mounted side by side at a uniform height of 1.2 m in a playground (Figure 1). The microphones are denoted by Mike-1, Mike-2,...Mike-5. To create air overpressure, festive crackers "atom bombs" were exploded one after another at distances ranging from 7 m to 45 m from the microphones. A total of 17 shots, each comprising five events, were recorded on two different days.

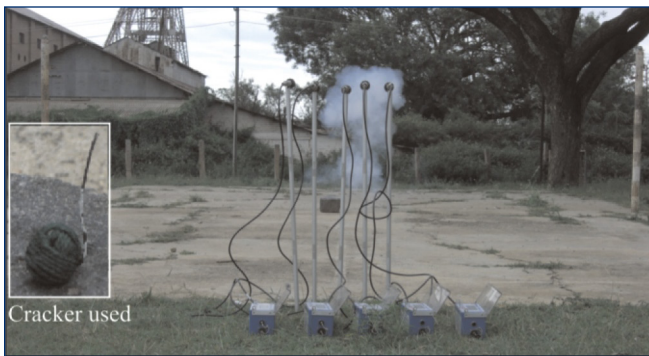


Figure 1: Experimental set-up for ascertaining the accuracy of microphones

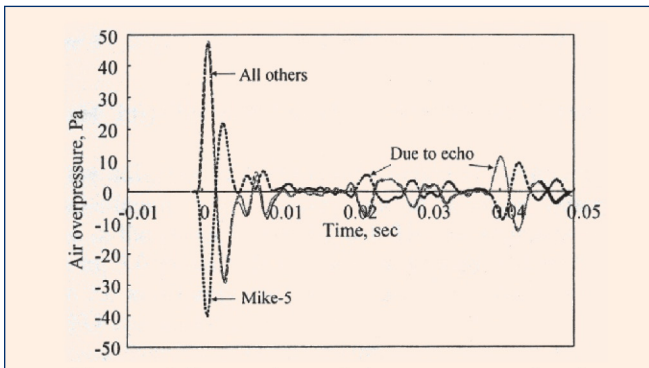


Figure 2: Comparison of air overpressure levels monitored by five microphones at 40 m distance

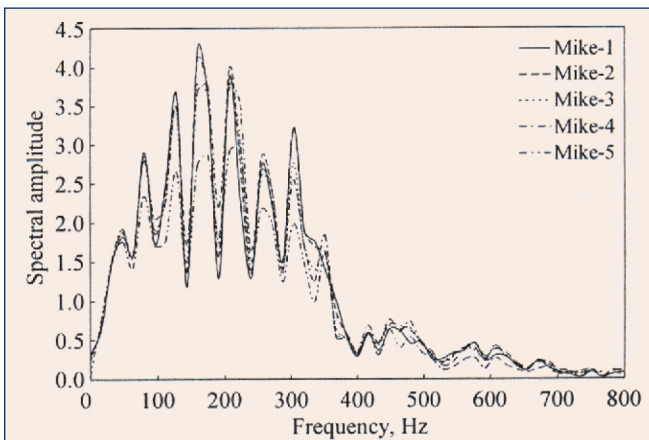


Figure 3: Comparison of frequency spectra monitored by five microphones at 40 m distance

Figure 2 shows air overpressure waveforms recorded by five microphones at a distance of 40 m. The superimposed waveforms are virtually identical except for Mike-5 whose waveform is the mirror image of other waveforms. This disparity, which might be due to the change in the polarity within Mike-5 in relation to others, does not make any difference in the measurements. The relatively high amplitudes in the later part of the waveforms are due to echo from the nearby structures. The superimposed frequency spectra of these waveforms shown in Figure 3 have slight variations. The dominant frequencies are inconsistent due to the presence of two or more frequencies having nearly equal spectral amplitudes. The waveforms from all the shots for five microphones were also compared and the observed discrepancies were similar to that at 40 m. For all the shots, the dominant frequency ranged from 144 to 224 Hz.

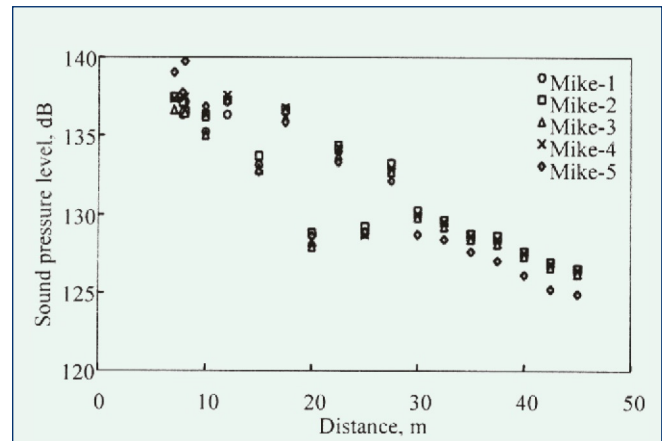


Figure 4: Sound pressure levels from crackers at different distances.

Figure 4 shows the sound pressure levels against the distance. As expected, the sound pressure level decreases with increasing distance. The variations in the sound pressure levels at distances between 12.5 and 27.5 m is due to the change in the velocity and direction of wind as the experiments were conducted on two different days. However, it can be observed that all the microphones have recorded almost the same sound pressure levels indicating that the microphones are functioning within the tolerable limits.

3. Influence of the Mounting Height of Microphones

In order to study the influence of the mounting height of the microphone on air overpressure measurements, experiments were carried out at a stone quarry using the same five seismographs used in the previous experiment. The microphones were placed at a height of 1.0 m, 1.5 m, 2.0 m, 3.0 m, and 4.0 m from the ground (Figure 5). In practice, a mounting height greater than 2.0 m is rarely used. Five blasts were conducted using jack hammer holes, charged with ANFO and initiated with instantaneous electric detonators. The details of the blasts and the distance from the blasts to the monitoring station are given in Table 1.

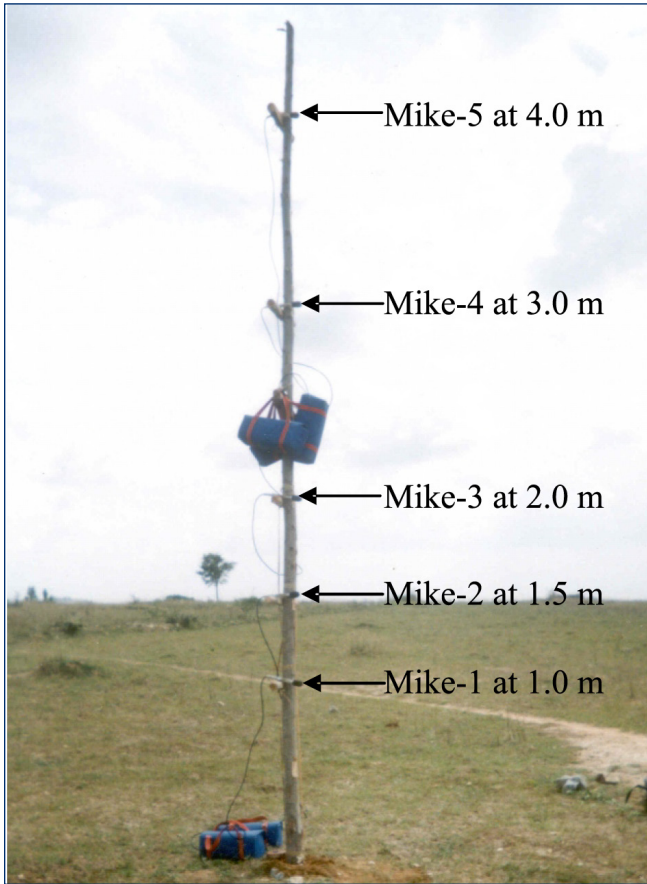


Figure 5: Experimental set up to study the influence of the mounting height of microphones

Table 1 - Summary of the blasts and distance from the blasts to the monitoring station

Blast Number	Total Charge (kg)	Number of Holes	Depth of Holes (m)	Distance from the blast (m)
1	35	40	1.5	290
2	10	25	0.9	275
3	45	55	1.5	305
4	40	60	1.2	195
5	13	25	0.9	334

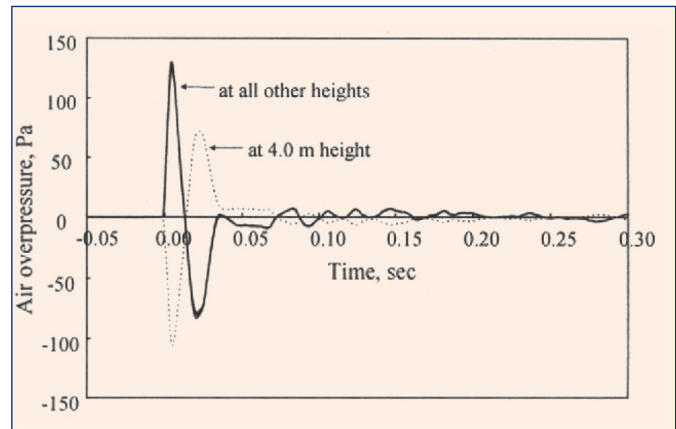


Figure 6: Air overpressure waveforms at different mounting heights for Blast No. 1

Figure 6 shows air overpressure waveforms at different heights for Blast No. 1. The superimposed waveforms are virtually identical except for 4 m height (Mike-5) whose waveform is the mirror image of the waveforms at other heights. No echo like in the previous experiment was observed as the monitoring station was in a large open field just outside the quarry. The superimposed frequency spectra of the waveforms for the same blast are given in Figure 7. These spectra in general are identical for all microphones except Mike-5 at 4 m height.

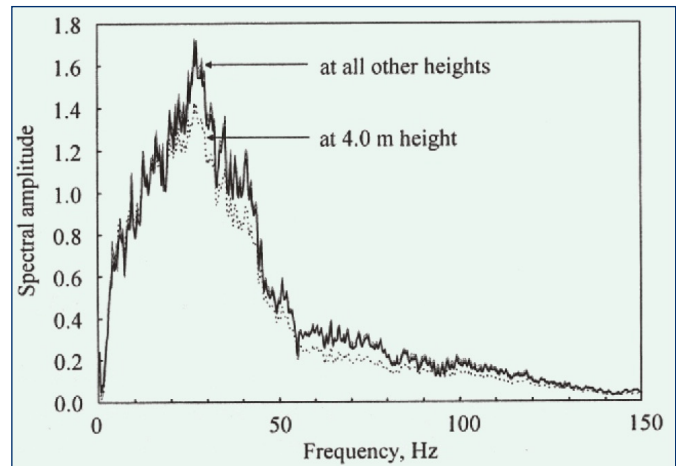


Figure 7: Frequency spectra for waveforms given in Figure 6

Figure 8 shows the plot of dominant frequency of air overpressure for all microphones and for all the blasts. With the exception of Mike-5 at 4 m height for Blast 2, the dominant frequencies at all other heights are very close to one another. Even for Blast 2, the frequency which contained most of the energy for all the microphones ranged from 14 to 30 Hz.

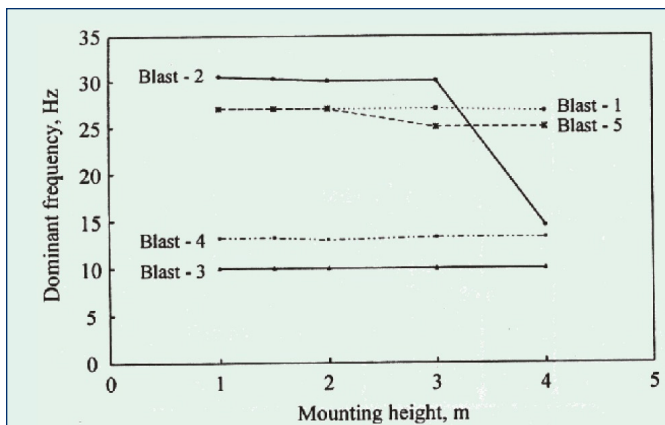


Figure 8: Dominant frequencies of air overpressure at different mounting heights

Figure 9 shows that all microphones recorded almost the same sound pressure except Mike-5 at 4 m height. The lower levels recorded by Mike-5 for all the five blasts are attributed to the instrumental errors with Mike-5 whose values deviated slightly in the previous experiments also. Hence, it is concluded that the microphone height has negligible influence on air overpressure measurements, while Mike-5 needs recalibration.

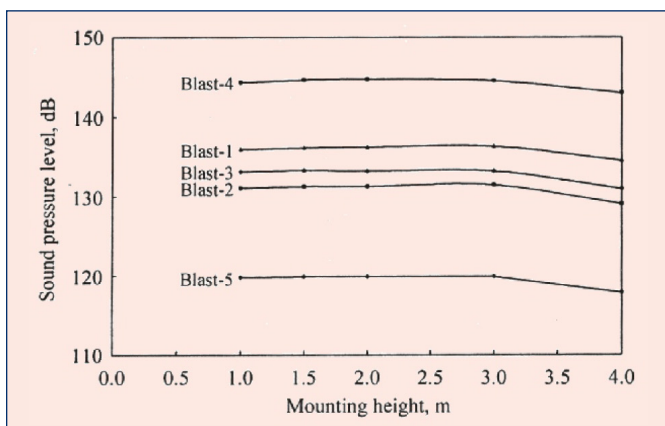


Figure 9: Sound pressure levels from blasting at different mounting heights

4. Air Overpressure From Detonating Cord

Detonating cord having a core of 10 g/m of PETN was cut to desired lengths (1 m to 50 m) and each of the cut pieces was laid on the ground and fired individually with an electric detonator. Air overpressure levels were monitored with two seismographs at 50 and 100 m distances across the cord (Figure 10). A series of tests were performed to determine air overpressure levels produced by: a) uncovered detonating cord, b) detonating cord covered with soil, c) detonating cord covered with sand and, d) detonating cord covered with slush. The thickness of the cover was about 100 mm, which was maintained uniformly throughout the length (Adhikari et al, 1992).

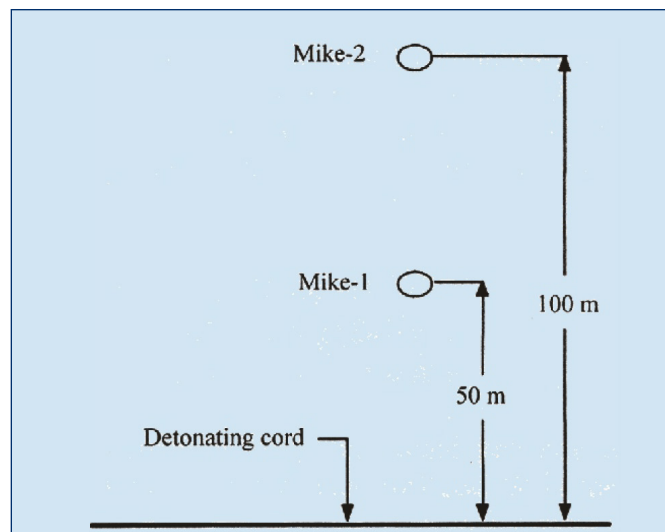


Figure 10: Experimental set up for monitoring air overpressure from detonating cord

The sound pressure levels with and without cover against the length of the cord are shown in Figure 11. Obviously, the sound pressure levels at 50 m distance are higher than those at 100 m distance. The sound pressure level increases gradually with cord length and the intensity can be reduced by 15 to 16 dB by covering it with soil.

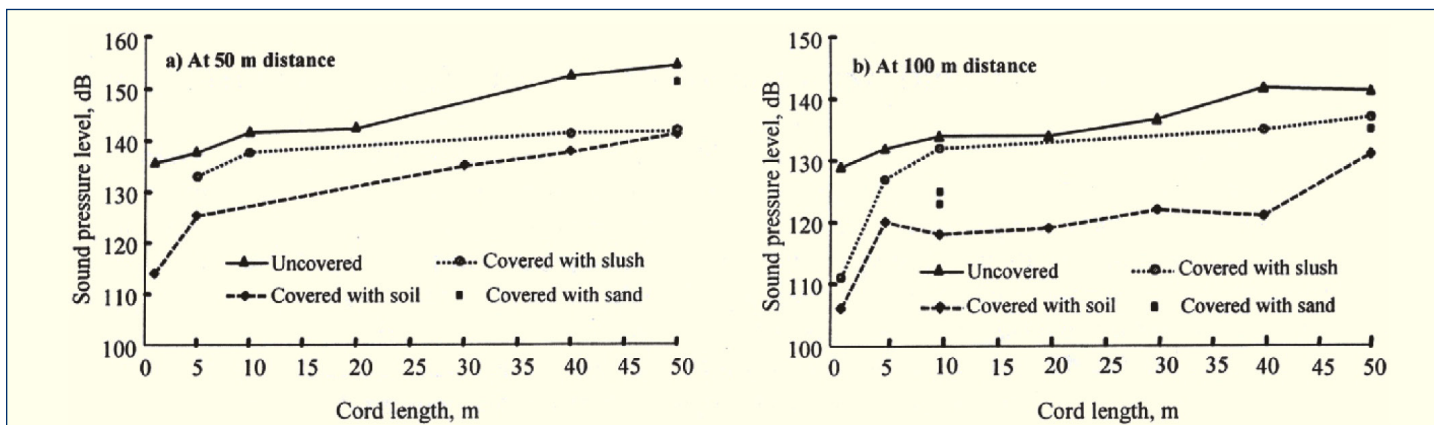


Figure 11: Sound pressure levels from detonating cord with and without cover

For equal cord lengths, the sound pressure level is the highest for the uncovered detonating cord and the least with the soil cover. The frequency analysis of recorded air overpressure was within 20 - 300 Hz and there was no appreciable change in this frequency with and without cover. Therefore soil, which is better covering material than sand, can be used as a covering material for trunklines of the detonating cord. A thick cover will obviously give better confinement but it is a tedious and cumbersome operation in the mining environment. Alternatively, better initiation systems such as shock tube system may be used in place of detonating cord.

Considering the detonating cord as an explosive and expressing its length in terms of the mass of the explosive, the maximum charge per delay, which happens to be same as the total explosives, was calculated. The sound pressure level plotted against cube root scaled distance is shown in Figure 12. The cube root scaled distance is divided by the cube root of the maximum charge per delay. The best-fit equations were derived for different test conditions and the correlation coefficient was -0.92, -0.94 and -0.96 respectively for uncovered, covered with slush and covered with soil. If detonating cord with various core loads were tested, the experimental data would apparently follow a similar trend. The derived equations are as follows:

Uncovered	$P = 200 - 28 \log(D/\sqrt[3]{W})$	(1)
Covered with Slush	$P = 201 - 32 \log(D/\sqrt[3]{W})$	(2)
Covered with Soil	$P = 207 - 38 \log(D/\sqrt[3]{W})$	(3)

In these and subsequent equations, P is the sound pressure level (dB), D is the distance between monitoring station and the blast (m) and W is the maximum charge per delay (kg).

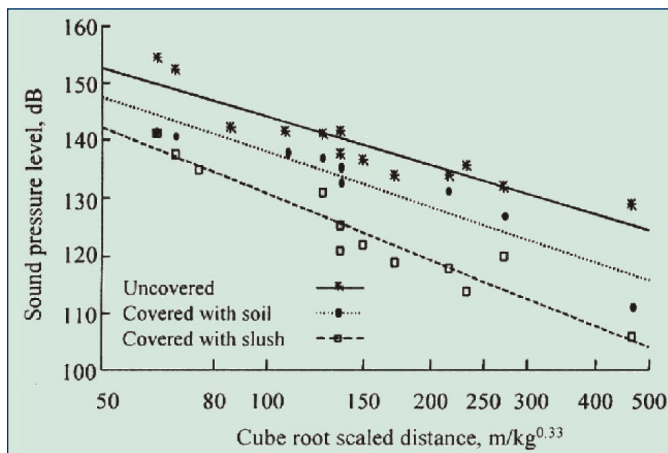


Figure 12: Sound pressure levels from detonating cord against cube root scaled distance

5. Air Overpressure From Routine Blasting Operations

Surface mines and quarries carry out routine blasting operations. Because of the basic differences in the scale of operation and the level of mechanization, blasting techniques in surface mines are significantly different from those of quarries. Large diameter, deep hole blasting using large quantities of explosives is common in quarries. A variety of initiation systems and a complex delay pattern are used in surface mines whereas instantaneous electric detonators are commonly used in quarries. Therefore, the air overpressure data for mines and quarries were grouped separately for analysis.

Using 125 sets of air overpressure data for surface mines, sound pressure level was plotted against the cube root scaled distance as shown in Figure 13 (Adhikari et al, 1995). The best-fit equation to these data is given by Equation 4. A similar plot for quarry blasting is shown in Figure 14. The best-fit equation for quarry data is given by Equation 5.

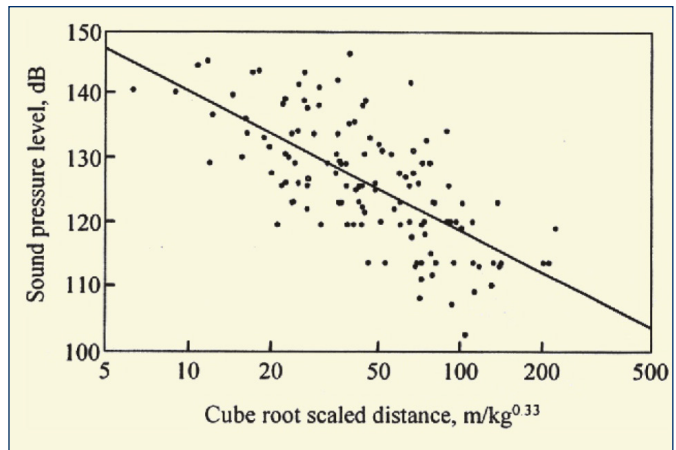


Figure 13: Sound pressure levels versus cube root scaled distance for surface mine blasting

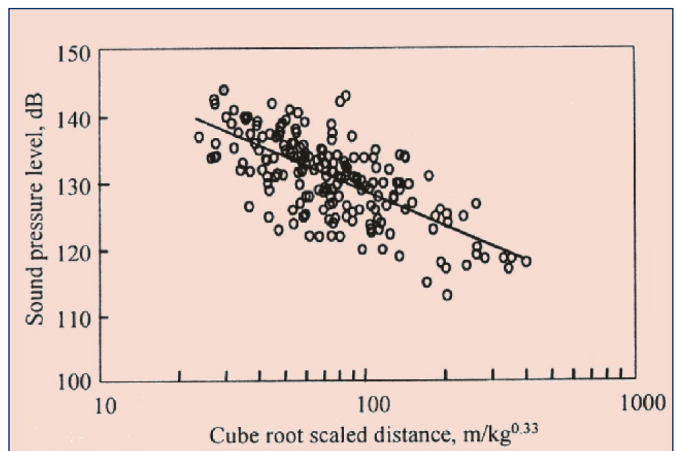


Figure 14: Sound pressure levels versus cube root scaled distance for quarry blasting

The correlation coefficient was -0.69 for both the equations.

Surface Mines $P=162-22 \log (D/\sqrt{W})$ (4)

Quarries $P=163-16 \log (D/\sqrt{W})$ (5)

These generalized equations can be used to estimate the sound pressure level from blasting for known maximum charge per delay and the distance in the corresponding equation. The calculated value needs to be checked with the permissible level (Siskind et al, 1980) and controlled, if necessary. The measured data are expected to lie within the range of data scattering as shown in Figure 13 and 14. Besides maximum charge per delay, some of the factors that influence sound pressure levels are delay interval, burden, spacing, stemming, charge depth, initiation system, and the direction and velocity of wind (Dowding, 1985).

The dominant frequencies of air overpressure from blasting in surface mines and quarries varied mostly from 4 to 60 Hz. These frequencies are different from those of the 'crackers' which varied from 144 to 244 Hz.

During blasting, some boulders are inevitably produced and require secondary blasting. Secondary blasting produces sound pressure levels higher than the primary blasting often leading to complaints (Adhikari et al, 1995). These complaints can be minimized by controlling boulders through proper blast design and eliminated by using hydraulic rock breakers.

6. Conclusions

Though all the five microphones were within the validity period of calibration, the experiments ascertained that four microphones were accurate while the accuracy of the fifth one was doubtful. When these microphones were mounted at different heights to monitor five quarry blasts, four of them gave fairly consistent readings but the fifth one showed slightly lower levels. Ignoring the readings of Mike-5 which needs recalibration, it was found that the mounting height had negligible influence on air overpressure measurements.

Studies with regard to detonating cord showed that sound pressure levels from detonating cord were significantly high which could be reduced by 15-16 db with a minimum soil cover of 100 mm. While blasting close to built-up areas, it is better to replace the detonating cord trunklines with a suitable initiation system.

Sound pressure levels from blasting in opencast mines and quarries can be predicted from the generalized equations for known maximum charge per delay and distance from the blast to the monitoring station. The sound pressure levels from secondary blasting, which are higher than those of primary blasting, underline the importance of blast design to eliminate or reduce the need for secondary blasting.

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