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Environmental Impacts of Rock Blasting and Their Mitigation

Dhekne P. Y.

Abstract---Blasting is the most accepted and practiced technique for the breakage of rock. During blasting, the energy transformation takes place in the explosive. Rock breakage during blasting process is accompanied by the generation of ground vibrations, noise, dust, fumes and flyrock. The environmental impacts of ground vibrations, noise and flyrock pose a great challenge to the safety of the nearby structures and the people. This paper deals with a case study of a Limestone quarry wherein mitigation of environmental impacts of ground vibration, noise and flyrock was carried out. To lessen the environmental impacts, initially three blasts with the prevailing practice were monitored. It was noticed that these blasts resulted into an unacceptable level of ground vibration, noise and fly rock. The results indicated that there was a necessity to modify the blast design. The modification was done by changing the delay interval and ground vibrations, noise and flyrock were once again monitored with the modified design and the levels were found to be drastically low. It can therefore be concluded that an appropriate blast design can help in reducing the environmental impacts of blasting.

Key words--- Fly Rock, Ground Vibrations, Noise, Rock blasting

I. INTRODUCTION

ROCK blasting is a day-to-day operation in an opencast mine. During rock blasting, a chemical reaction takes place which converts the chemical energy of the explosive into the shock energy and gas energy. It is established that nearly 20 % of the energy goes to the breakage of the rock whereas the remaining manifests itself in the form of waste energy. The waste energy appears in the form of seismic energy, noise heat and light. Rock blasting is further accompanied by the generation of the dust and the fumes and flyrock. In India, the opencast mines are being operated in the vicinity of cities, villages and dwellings. This calls for the mitigation of the environmental impacts of the rock blasting.

A review of the environmental impacts of rock blasting in opencast mines indicates that the fumes and the dust do not pose a significant danger to the people who are in the vicinity of the mine. The fumes generated during the course of blasting get instantly diluted whereas the dust suppression measures ensure that the airborne dust due to blasting is within the permissible limits.

The effect of ground vibrations and noise on the human beings is well documented but they sometimes also cause damage to the property. The flyrock not only pose a major danger to the properties but at the same time can lead to the fatalities also. Fig. 1 depicts the areas of concern during blasting.

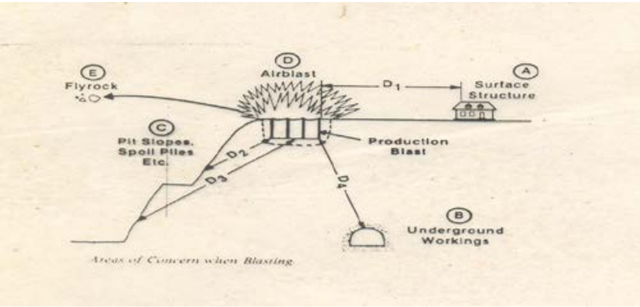


Fig. 1 Areas of concern when blasting

This paper discusses a case study of identification of mitigative measures in respect of ground vibrations, noise and flyrock. The study refers to a Limestone quarry which is being operated within a short distance of dwellings and public road.

II. GENERATION OF GROUND VIBRATIONS, NOISE AND FLYROCK

When an explosive charge detonates, intense dynamic waves are set around the blast hole, due to sudden acceleration of the rock mass. The energy liberated by the explosive is transmitted to the rock mass as strain energy. The transmission of the energy takes place in the form of the waves. The energy carried by these waves crushes the rock, which is the immediate vicinity of the hole, to a fine powder. The region in which this takes place is called shock zone. The radius of this zone is nearly two times the radius of the hole. Beyond the shock zone, the energy of the waves gets attenuated to some degree which causes the radial cracking of the rock mass. The gas generated as a result of detonation enters into these cracks and displaces the rock further apart causing its fragmentation. The region in which this phenomenon takes place is called transition zone. The radius of this zone is twenty to fifty times the radius of the hole. As a result of further attenuation taking place in the transition zone, the waves although cause generation of the cracks to a lesser extent but they are not in a position to cause the permanent deformation in the rock mass located outside the transition zone. If these attenuated waves are not reflected from a free face, then they may cause vibrations in the rock. However if a free face is available, the waves get reflected from a free face cause further breakage in

Dhekne P.Y. is with the National Institute of Technology, Raipur Chattisgarh Province, India Technology, 492010 (corresponding author's phone: +919669400678 ; fax: +917712254600 ; e-mail: pyd_05@yahoo.co.in).

the rock mass under the influence of the dynamic tensile stress. Fig. 2 is a pictorial representation of the various zones described above and explains the phenomenon of reflection of waves.

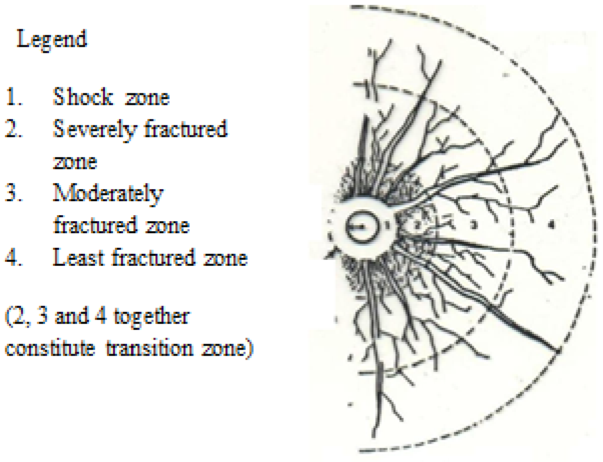


Fig. 2 Rock breakage process

A. *Effect of Ground Vibrations on the Structures*

The ground vibrations cause the ground to vibrate in transverse, longitudinal and the vertical direction leading to its damage. Fig. 3 shows the vibration of the structures on account of ground vibrations.

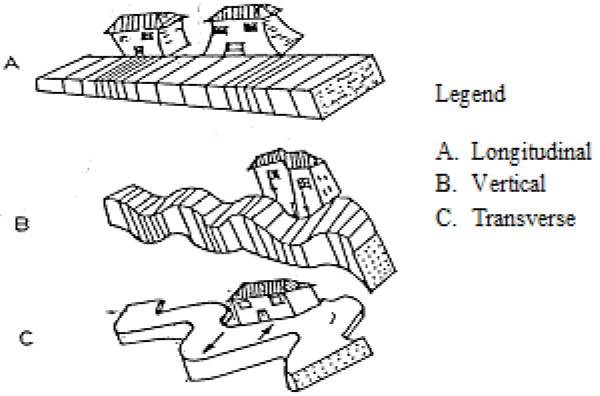


Fig. 3 Structural response to ground vibrations

Although the differences in the accelerations, amplitudes, particle velocities and the frequencies in three directions result into the damage to the structures but the peak particle velocity and the frequency are normally taken into consideration for evaluating the structural response. The damage criteria due to ground vibrations are therefore often specified with the peak particle velocity and the associated dominant frequencies. Table I gives the permissible levels of the ground vibrations under different conditions as specified by DGMS, India

TABLE I

PERMISSIBLE PEAK PARTICLE VELOCITY AT THE FOUNDATION LEVELS OF THE STRUCTURES IN MINING AREAS

Type of Structure	Dominant Excitation Frequency, Hz		
	< 8	8-25	>25
Buildings/Structures not belonging to the owner			
Domestic houses/Structures	5	10	15
Industrial buildings (Framed/concrete structures	10	20	25
Objects of historical importance and sensitive structures	2	5	10
Buildings/Structures belonging to the owner			
Domestic houses/Structures	10	15	25
Industrial buildings (Framed/concrete structures	15	25	50

(After Directorate General of Mines Safety, Govt. of India, Circular No.7 of 1997)

It is observed from the table that as the dominant excitation frequency increases, the permissible peak particle velocity also increases. The frequencies below 8 Hz are the most serious for potential damage from structure cracking. They produce large ground displacements and high level of strain. They also couple very efficiently into structures on account of resonance. The ground vibration levels beyond those specified in the approved standards may lead to the damage to the structures. Plate 1 shows the cracks generated in the walls of a building due to ground vibrations.

B. *Mitigation of the Ground Vibrations*

It is not possible to completely prevent the generation of ground vibrations nevertheless the blasts can be designed in order to minimize their effects at the point of contention. Table II presents an overview of the effect of the different blast parameters on the control of ground vibrations.

Plate 1: Cracks in a structure due to blast induced ground vibrations (Source: Google Images)

TABLE II

AN OVERVIEW OF THE EFFECT OF THE DIFFERENT BLAST PARAMETERS ON THE CONTROL OF GROUND VIBRATIONS

Variables within the control of a blaster	Effect on ground vibrations		
	Significant	Moderately Significant	Insignificant
Charge/delay, kg	×		
Delay interval, ms	×		
Spacing and burden, m		×	
Stemming (type and amount), m			×
Charge length and diameter, m			×
Angle of borehole,°			×
Direction of initiation		×	
Total charge, kg			
Bare versus open detonating cord			×

It is therefore obvious that the ground vibrations can be controlled either by controlling the charge per delay or by controlling delay interval, if spacing and burden are within acceptable ranges.

C. Air Over Pressure (Noise)

Air overpressure is a transient impulse that travels through the atmosphere. Much of the air overpressure produced by blasting has a frequency below the audible limit of 20 Hz. Air overpressure, both audible and inaudible, can cause a structure to vibrate in much the same way as ground vibrations It is a frequent cause of the complaints as a person senses air overpressure more than vibrations. The causes of generation are the energy released from unconfined explosives such as uncovered detonating cord trunk lines or mud caps used for secondary blasting, the release of explosive energy from inadequately confined borehole charges (inadequate stemming, inadequate burden, or mud seams) and the movement of the burden and the ground surface.

The causes of the noise are summarized in Table III.

TABLE III
CAUSES OF THE NOISE LEVELS

1. Too small a burden	4. Detonating cord trunk lines	Inaccurate drilling
2. Adverse geology	5. Improper delay configurations, inaccurate detonators	8. Incorrect explosive selection
3. Insufficient stemming length	6. Overbreak from previous shot	Excessive powder factors

A perusal of the causes indicates that the control of the noise is well within the scope of the blasters. The control techniques of noise are summarized in Table IV.

TABLE IV
CONTROL TECHNIQUES OF NOISE

Variables within the control of a blaster	Effect on ground vibrations		
	Significant	Moderately Significant	Insignificant
Charge/delay, kg	×		
Delay interval, ms	×		
Spacing and burden, m	×		
Stemming amount, m	×		
Stemming type		×	
Charge length and diameter, m			×
Angle of borehole,°			×
Direction of initiation	×		
Total charge, kg			×
Bare versus open detonating cord	×		

Control measures for noise can be planned accordingly.

D. Flyrock

Excessive flyrock is rock that is projected beyond the normal blast-affected area. It is generated when there is too much explosive energy for the amount of burden, when stemming in insufficient, or when the explosive energy is rapidly vented through a plane of weakness. The flyrock may take place from the bench face or bench top (Fig. 4). Excessive flyrock is responsible for 40-60% of the accidents due to blasting in opencast mines. Table V presents the causes of the flyrock.

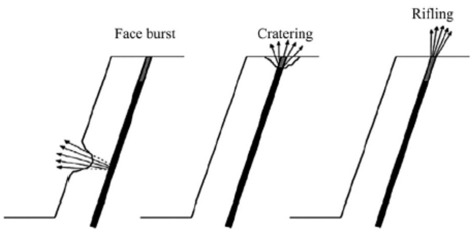


Fig. 3. Mechanisms of blast-induced flyrock in opencast mines.

Fig. 4 Mechanism of blast-induced flyrocks in opencast mines

TABLE V
CAUSES OF THE FLYROCK

Geology and Rock conditions	Blast design
Mud seams, natural joint or bedding planes, fractures, or cavities	a. Improper blast design b. Insufficient explosive confinement or the rapid venting of the explosive gases Blast design errors such as too high a powder factor c. An inadequate burden d. Too short a stemming region e. Ineffective stemming material f. Improper delays between rows g. The wrong blasthole delay sequence

The control techniques of flyrock are summarized in Table VI

TABLE VI
CONTROL OF FLYROCK

Bench face flyrock	Bench top flyrock
a. Burdens must be sufficient to contain the explosive energy. b. This means that effective or instantaneous burdens are at least 25 times the blast hole diameters. c. Explosive weights should be monitored to avoid overloading into void spaces. d. Fissures, mud seams and weaknesses should be stemmed through rather than loaded with explosive. Additional burden may be needed if the face is broken up or irregular. e. The explosive column may have to be shortened to avoid the lightly-burdened collar region. f. In general, burden to diameter ratio of 14.2 or more should limit flyrock to a manageable initial velocity of 100 ft/sec and range of 300 ft	a. Optimum blast design parameters should be selected as the top flyrock results due to excessive explosive and/or not enough relief and ineffective stemming and/or cratering and too less burden. b. Sufficient delay time must be provided to allow relief of later-firing rows of blast holes. c. This means that delay timing should be at least 2 ms/ft of burden to avoid both flyrock and back break. Far worse than delays which are too short are delays which are out of sequence. d. A stemming length of about 0.7 times the burden and coarse angular material which will interlock and hold against explosive gas pressure. e. No condition should be provided to allow misfires as the misfires are serious flyrock generators. f. Adopting Nonel initiation system (Bottom hole initiation) g. Applying muffling arrangements like sand bags, conveyor belts and wire-meshes

III. CASE STUDY

As discussed above, the ground vibrations, noise and the flyrock constitute the important environmental impacts of blasting. A study was recently conducted in Limestone quarry

‘X’ to reduce the impacts of these.

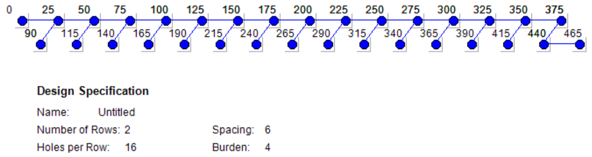
The geotechnical properties of the deposit are given below.

a. Uniaxial Compressive Strength,
b. M Pa:40-45
c. Density,
d. g/cc: 2.40-2.52
e. Young’s Modulus, G Pa: 44-49
f. Porosity, %: 5-7
g. Joint Spacing (Vertical), m: 2-3
h. Joint Spacing (Horizontal), m: Around 1.0 m

The deposits are having three sets of nearly vertical joints in addition to horizontal bedding planes. The quarry is a captive mine of a Cement Plant. The quarry produces the cement grade Limestone which is fed to the Plant. The quarry has the limestone deposits which belong to the sediments of Chhattisgarh basin, which are horizontal, thick bedded and classified as stromatolitic Limestone of Raipur Group. Patches of argillaceous Limestone and shale are other associated rocks. The overburden consists of hard Laterite and clay with an average thickness of 6.0 m. underlying this, the Limestone is structurally disturbed by the vertical and horizontal fissures and joints. This results into difficulties in drilling and poor fragmentation.

The deposit is being worked in two pits. There are four benches in the pit. The average height of the benches is 8.0 m. At present; the mining is being done in 1st, 2nd and 3rd bench. Conventional drilling and blasting method is used for the excavation. The blasted muck is removed by using L & T Poclain hydraulic shovel 4.0 m^3 and TELCON make 60 te dumpers. Rock breaker is used for breaking the oversize boulders.

At mentioned above, the excavation is carried out by conventional drilling and 'blasting method. The holes are drilled by pneumatically operated drills. The blast-holes have a diameter of 115 and 152 mm. Since the blocks are criss-crossed by fissures, drill holes are normally drilled on a staggered pattern. The boulders, which cannot be handled by the excavator, are further fragmented by secondary blasting. The average spacing and burden is nearly 5.0 m and 3.0 m for 115 mm holes and 7.0 and 4.0 m for 152 mm holes. Site mixed emulsion explosives is used for blasting. Charged holes are primed by Cast booster. Initiation system used is Shock tube. The firing sequence is such that there is hole to hole initiation. The typical blasting pattern is shown in Fig. 5.



Design Specification

Name: Untitled
Number of Rows: 2
Holes per Row: 16
Spacing: 6
Burden: 4

Fig. 5 Blasting Pattern

A. Investigations

The mine has a public road within 250 m of the blasting. The road has a sizable traffic density and was required to be closed down at the time of blasting. The mine site is surrounded by a lot of shrubs and the cattle belonging to the villagers graze thereon. There are few temporary structures within 300 m of blast site and they do not belong to the owner of the mine. It is therefore evident that the ground vibrations and noise were of paramount importance to the residents of dwellings. The flyrock was of significance towards the safety of passers-by on the road, residents and cattle.

The objective of the study was to design a blast to limit the ground vibrations and noise within the statutory limits prescribed by Indian regulations and the fly rock was to be totally eliminated.

In order to achieve the objective of the study, four blasts using the normal practice were monitored. The details of the blast are presented in TableVII. The ground vibrations and the noise were measured using the Instantel make Seismograph and the flyrock was visually observed and its distance from the blast site was measured. The results of the blast are presented in Table VIII. It is evident that the ground vibrations were very much on higher side and the maximum distance of flyrock was also high. This could lead to grievances from the residents of dwellings due to vibrations and noise and chances of fatalities on account of the flyrock.

TABLE VII
DETAILS OF THE MONITORED BLASTS

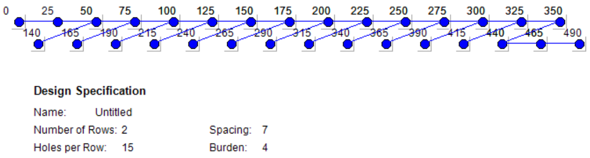
Parameters	Unit	Value
No. of blasts	No.	3
Holes	No.	25-32
No. of Rows	No.	2
Spacing	m	6-7
Burden	m	3.5-4.5
Diameter	mm	152
Height	m	8.5-9
Hole to hole delay	ms	25
Row to row delay	ms	65
Charge per delay	kg	125-130
Cast booster	g	250
Stemming	m	3.5
Type of the explosive		Site Mixed Emulsion

TABLE VIII
RESULTS OF THE MONITORED BLASTS

Results	Blast No.1	Blast No.2	Blast No.3
Peak particle velocity, mm/s*	37	42	40
Noise, dB*	145	143	140
Flyrock, m	200	274	300

(* measured at a distance of 300 m from the blast site)

To obviate the imminent dangers from them, the blast design was modified. A perusal of the drilling and charging pattern showed that the normal drilling, charging and firing practice that was being adopted in the mine was in line with the same that was being followed in the neighbouring mines which were not facing these problems. It was therefore thought that the firing sequence of the holes could possibly the cause of ground vibrations. Working on this premise, the firing pattern was changed without varying the drilling and charging patterns. The initial and modified firing patterns are shown in Fig. 5. It is evident from the Fig.s that the delay interval between has been increased substantially from 65 ms to 90 ms between the successive holes. The ground vibrations, noise and flyrocks were once again monitored.



Design Specification

Name: Untitled

Number of Rows: 2

Holes per Row: 15

Spacing: 7

Burden: 4

Fig. 5 Modified Blast Design

The results of the modified blast practice are presented in Table IX. It was found that by changing the pattern of firing there had been drastic reduction the ground vibrations, noise and the flyrock.

TABLE IX
RESULTS ON MODIFIED BLAST DESIGN

Results	Blast No.1	Blast No.2	Blast No.3	Blast No.4
Peak particle velocity, mm/s*	13	16	8	6
Noise, dB*	125	120	115	125
Flyrock, m	10	16	8	22

(* measured at a distance of 300 m from the blast site)

IV. DISCUSSION

Scatter in delay timings of delay detonators is a common feature in many of them and may amount to ± 15 ms. In the earlier practice, since the drilling, charging and connection pattern were in line with the established practice so the scatter was the only reason for the high levels of ground vibration, noise and the flyrock. As a result of scatter, more than one holes would detonate at one time which would in turn, increase the charge per delay. This led to increased levels of ground vibrations and noise. Further, the scatter would cause the burden of the front row to move ahead inadequately leading the broken rcokmass of the second row to be thrown in the air leading to the flyrock. The increase in the delay led to wiping out the possible effect of scatter causing a reduction in the ground vibration, noise and the flyrock.

V. CONCLUSION

The rock blasting leads to a number of impacts on the environment. Opencast mining near the residential areas has become inevitable and therefore environmental impacts are required to be mitigated. Ground vibrations, noise and fly rock are the important environmental impacts as they may damage the properties and fly rock may cause fatalities. The case study discussed in this paper indicates that these effects can be minimized. A proper blast design ensures effective utilization of the energy of the explosives and is therefore the answer to the problem of mitigation of the environmental impacts.

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