EVALUATION OF EXPLOSIVES USING GROUND VIBRATION CRITERION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIRMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

BY

SANJIB KUMAR PRDHAN

And

ASHRIT DAS

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA, ORISSA - 769008
2007

EVALUATION OF EXPLOSIVES USING GROUND VIBRATION CRITERION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIRMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN

MINING ENGINEERING

BY
SANJIB KUMAR PRDHAN
And
ASHRIT DAS

UNDER GUIDANCE OF
Dr. MANOJ KU. MISHRA

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA, ORISSA - 769008
2007

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

CERTIFICATE

This is to certify that the thesis entitled, "Evaluation of Explosives using ground vibration criterion" submitted by Sri Ashrit Das and Sri Sanjib Kumar Pradhan in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any Degree or Diploma.

Date:

Dr. Manoj Kumar Mishra
Dept. of Mining Engineering
National Institute of Technology
Rourkela, 769008

ACKNOWLEDGEMENT

I wish to express my deep sense of gratitude and indebtedness to **Dr. Manoj Kumar Mishra**, Department of Mining Engineering, N.I.T Rourkela for introducing the present topic and for his inspiring guidance, constructive criticism and valuable suggestion throughout this project work.

I would like to express my gratitude to **Prof. B.K.Pal (**Head of the Department), for his valuable suggestions and encouragements at various stages of the work.

I am also thankful to all staff members of Department of Mining Engineering NIT Rourkela. I am grateful to **Mr. N.B.Samal** Blasting incharge of **Bharatpur opencast mines, MCL, Talcher** for helping us for doing measurements in their mine. I am also thankful to **Mr. P.N.Mallick** and other staffs in Department of Mining Engineering for providing all joyful environments in the lab and helping me out in different ways.

Last but not least, my sincere thanks to all my friends who have patiently extended all sorts of help for accomplishing this undertaking.

Date: **Sanjib Kumar Pradhan**

Ashrit Das

CONTENTS

ABSTRACT

Recent times have experienced an increase in infrastructure and mineral resource developments. As a result, mining activities have also increased to supply the needed mineral. Blasting has been the main technique for loosening insitu rock before use. Consequently there is a growing concern of the effects of blasting activities on the environment. These effects are normally nuisances to the neighboring residence as they come in the form of: dust, toxic gases, noise, fly rocks and ground vibration. Of the set of nuisances the one that is of most concern is ground vibrations which can cause damage to structures. In most cases worldwide, after blasting activities there are the usual complaints about damage to residence, and less mining activities which is also a focus of the thesis. A study was conducted to evaluate the effect of heavy blasting in open-pit coal mines on the stability of adjoining under ground coal mine workings.

There have been researches on the subject of ground vibrations to help refute some of these complaints. The works of Lewis Oriard and Charles Dowding are the foundation on which standards and regulations are built as guides to assist blasters in the prevention of creating unnecessary nuisances. Most countries have developed their own regulations with respect to blasting and parameters are set according to the geological conditions. This is of importance as the rock structures determine the transmission of the peak particle velocity. However, most countries in the west adopt standards similar to ones put forward by the United States Bureau of Mines. It my opinion that a whole scale adoption should not take place as the criteria used may not be suitable for other countries' geological conditions.

For this thesis the aim was to identify a vibration level that will not cause damage to structures close to a mining area and increase production by effective blasting. Based on the literature review it was revealed that there are a number of parameters that needed to be considered. These ranges: construction material, age of structures, distance from structures, geology of the location, type and quantities of explosives and the blast design. There was also the review of standards to building threshold with respect to the level of ground vibration.

The case study with its main focus on evaluation of explosive using ground vibration criterion which will not result in any form of damage to the structures. However, having established a PPV limit using the USBM that appears reasonable there is the need for criteria similar to those of the USBM using blasting and geological conditions.

LIST OF TABLES

LIST OF FIGURES

CHAPTER: 1

Introduction

Back Ground

Research Questions

Goal

Objectives

CHAPTER 1

1 Introduction

1.1 Background

Blasting is perhaps one of the most interesting, thought provoking, challenging & controversial areas of the mining industry. It encompasses many areas in the science of chemistry, physics, thermodynamics, shock wave interaction & rock mechanisms. In broad terms rock breakage by explosive involves the action of an explosive & response of the surrounding rock mass. Past, current & new blasting theories are presented along with the factors affecting fragmentation & general blast design criteria by many research people.

The vibrations radiating from the blast holes while passing through surface structures induce vibrations on the structures causing resonance. The components of ground motion can affect the structures through compression and tension and also through vertical and horizontal shearing effects. Blast induced ground vibrations create socioeconomic problems for the mine managements as well as the people residing in vicinity of these mines. As only 20-30 % of energy of commercial explosives used in the mines is utilized for fragmenting the rock, the rest of energy is transmitted through the earth in the form of ground vibrations resulting in damage to the surrounding structures.

The concept of energy balance in rock blasting research has remained a challenging field in the area of rock breakage using commercial explosives. Unfortunately no single piece of work is available in India and abroad which could give a thorough concept of energy partitioning and its effectiveness for proper, scientific and cost effective blasting operation. Knowing well the limitations, the challenge was accepted with a view to obtaining some basic understanding of the process of rock breakage, efficacy of explosive energy and its utilization in the process of rock blasting.

In order to understand ground vibration and their associated problems, a review of elastic theory, seismic wave propagation, geometrical scaling, vibration terminology and development of damage criteria is essential.

1.2 Research Question

However, irrespective of the reason and purpose the blasting activities usually generate some level of annoyance to residents in the nearby population and possibilities of damage to the structures in the proximity. The annoyance from blasting stem from unused energy that was not sufficient to fracture the in-situ material further and lead to these unfavorable activities. These would include, noise, fumes, fly rocks, air and ground vibrations. These annoyances and nuisances usually result in the many complaints from the populates in the neighboring areas. Despite the efforts of the competent blaster to undergo the necessary precautions and design to ensure that the level of vibrations is within the international as stipulated by USBM there will still be complaints. Since the vibration levels obtained in most of the activities are within the stated thresholds and complaints are increasing, this therefore prompts the questions for this research.

- Can the parameters be determined for ground vibrations and air over pressure for maximum allowable PPV and tolerable noise level?
- What will this parameter be with respect to the USBM international standards?

1.3 Goal

The goal of this project is to evaluate explosives used in different mining operations using ground vibration as a criterion. Based on the knowledge of the characteristics and effect of blast vibration we select the type and the amount of explosive to be used in the manner in which they have to be used for optimum result.

1.4 Objectives

The objectives of this project are as follows:

1. To identify the factors affecting blast vibration with the help of literature review.

2. To identify the relation of each factor with blast vibration with the existing literature.

3. To develop a questionnaire for collection of data.

4. To collect blast vibration related data based on the questionnaire.

5. To investigate into the influence of blasting pattern and geotechnical properties of the rock mass on the ground vibration.

6. To know the effects of blast vibration.

7. To identify the remedial measures to reduce or mitigate the negative impacts of blast vibration.

CHAPTER: 2

Literature Review

Blast vibration

Shock wave propagation causing vibration

Peak particle velocity

Blasting damage

Standards regarding ground vibration

Control ground vibrations

CHAPTER 2

Literature Review

It includes the following

i. Study of theory behind blast vibration.

ii. Study of shock wave propagation causing vibration

iii. Study of peak particle velocity concept.

iv. Study of different damage criterion.

v. Consideration of various standards regarding ground vibrations.

vi. Techniques to control ground vibrations etc.

2.1 Blast vibration.

2.1.1 Historical perspective

By far the most common technique of rock excavation is that of drilling and blasting. From the earliest days of blasting with black powder, there have been steady developments in explosives, detonating and delaying techniques and in our understanding of the mechanics of rock breakage by explosives. It is not the development in blasting technology that is of interest in this discussion. It is the application of this technology to the creation of excavations in rock and the influence of the excavation techniques upon the stability of the remaining rock.

As is frequently the case in engineering, subjects that develop as separate disciplines tend to develop in isolation. Hence, a handful of highly skilled and dedicated researchers, frequently working in association with explosives manufacturers, have developed techniques for producing optimum fragmentation and minimizing damage in blasts

2.1.2 What is Blast Vibration?

It can be defined as the shaking of the ground caused by the elastic wave emanating from a blast and consisting of innumerable individual particles. These particles are either body waves or surface waves. Body waves when reflected or refracted to the surface, become surface waves. Ground motion consists of a combination of these waves. These waves affect buildings and structures on the surface and around the vicinity of the excavation through compression and tension and through vertical and horizontal shearing effects.

2.1.3 Parameters influencing blast vibration

The level of ground and structure vibration caused by blasting depends on explosive type and weight, delay timing vibration, blasting technology, site geology, scale distance, parameters of waves propagating at site, susceptibility ratings of adjacent and remote structures and other factors.

Burden: It is the minimum distance between face and blast hole. Too less burden can cause fly rock and air blast problem and too high a burden will produce sever back break and greater vibration. Burden should be 0.5 to 0.8 times of the height of bench.

Spacing: It is the distance between two consecutive blast hole.

Spacing = (1.2 to 1.5) burden

Stemming: It is used after explosive is loaded in blast holes. Stemming affects blown out shot of the hole and also affects fly rocks.

Stemming/burden > 0.6 (for controlling fly rock)

Bore hole depth: It not only affects fragmentation but also the level of vibration. Bore hole depth is a function of spacing and diameter of the hole. Short holes produce blasting at greater violence and also produce greater vibration level of increased frequency.

Sub drilling: It is generally used for eliminating toe formation of the bench. About 10% of sub drilling gives better fragmentation in the rock mass and lesser ground vibration.

Geology of the area: The propagation of energy through vibration waves depends upon the elastic properties of the medium. The rock types of the area and structured features play a great part in propagation of energy.

Types of explosives: Ground vibration is directly proportional to the type of explosives used.

Explosive quantity: The level of vibration produced by a single row instantaneous blast is same as the level of vibration produced by a single or multi row blast with delay if the charge quantity per delay of the blast with delay equals to the total charge of the single row blast. Thus it is the charge per delay that controls the level of blasting not the total charge.

2.1.4 Theory of Blast Vibration

There is always ground vibration due to the blasting operation. The energy not utilized in the breakage process is wasted energy. This energy is dissipated in the form of vibration air blast and water shock. Vibration is wave motion created from an energy source, in the case of rock blasting; the source is explosive energy and rock movement. The damaging potential of vibration caused by blasting is related with maximum velocity of vibration of the blasted particles. When the vibration is transmitted through ground is called propagation. The propagation velocity is the speed at which the vibration waves travel.

Energy balance

It is useful to view the blasting process as an 'Energy Balance' as shown in the diagram below. Essentially, the chemical energy of the explosives must be dissipated as fragmentation, rock movement, vibration and air overpressure. Very few percentage of an explosive is being utilized for breakage of rock mass i.e, about 15 to 20% depending upon the blasting technique. Rest of the maximum energy of the explosive is waste as vibration and air overpressure i.e. around 40% in each case.

From figure:-1 it can be seen that a blast with poor fragmentation is likely to have a higher than expected environmental impact.

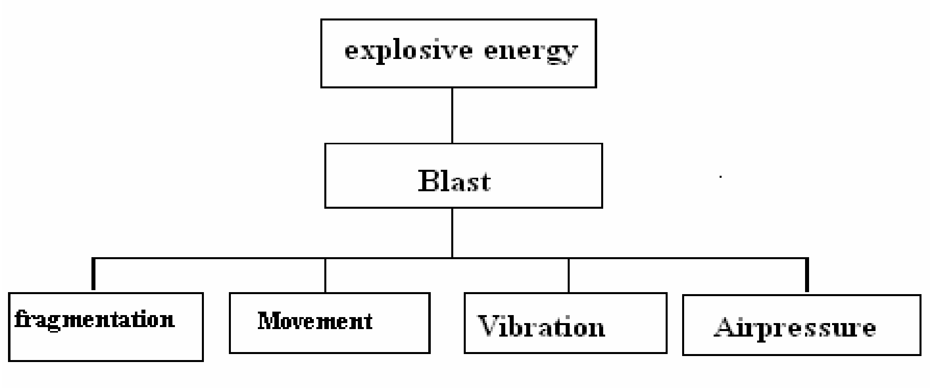

Figure 1: Different modes of release of energy from blasting

As the disturbance passes a given point an individual particle of the medium is displaced from its rest position. It is possible to record or measure this particle displacement; alternatively, one may record the particle velocity or acceleration. Though the three quantities are related, it is not a simple matter to deduce one from another because the wave is not a simple one. It is desirable therefore to measure the quantity that is most simply and generally related to damage.

2.1.5 Factors Taken into Account during Ground Vibration

Three factors of ground vibrations determine how much effect it has: ground vibration amplitude (PPV), ground vibration duration, which is not the same as blast duration and Ground vibration frequency.

Duration is important because the longer ground vibrations continue to shake the structure, the greater the amplitude of the structural response. In addition, studies have shown that human tolerance to vibration decreases the longer the vibration continues. Seismographs report PPV and frequency, but duration often is ignored.

Frequency is the most important of the three factors of ground vibration. When a structure is exposed to ground vibrations near its fundamental frequency, the structure magnifies the vibrations. Besides these, two more things to be taken into consideration are

2.1.5.1 Natural Frequencies

Elements of building construction such as sprung floors, stud partition walls, ceiling and windows can all react as mass-spring systems; each with its own natural frequencies of about 4-24 Hz (low frequencies) Ground vibrations at these frequencies amplified by the structures increase the risk of damage. When the low frequency ground vibration coincides with the natural frequency of the structure resonance in originated. The resonance is a state in which the structure absorbs most energy progressively becoming deformed with time, until plastic deformation occurs. Therefore even the low peak particle velocity of ground vibrations at natural frequency of structure is more harmful to the structure. Natural frequencies of brick and concrete structure generally vary from 8- 16 Hz.

2.1.5.2 Structural response

Structural response is directly and linearly proportional to ground vibration amplitude. The cracking location and the wall material have an influence on the particle velocity at which cracking begins. If the entire structure is not inspected thoroughly, there may be chances of biased opinion on the type of cracks. Thus it is important to place transducer properly for the correct assessment of damage.

In the mud houses, numbers of cracks develop before blasting and these cracks widened and extended with the passage of time. These cracks are further widened and get extended due to blast induced ground vibrations. Concrete structures vibrate for longer duration that brick and mud structures. Concrete walls have free top and show no cracks at vibration levels for which mud and brick walls can damage Cracks develop in concrete walls with large vibration level. Cracks in brick- structures can be observed in junction of walls, roof and at window corners. Brick walls with clay mortar and cement- sand mortar behave in same fashion. Steel structures can sustain more vibration level.

The magnitude of vibration on structures is much more than on the ground. Duration of vibration in structure is also longer than, that of ground vibration. Multi-storied buildings are more sensitive to blast vibration that the single-storied buildings.

2.2 Shock wave propagation causing vibration

2.2.1 Properties of blasting waves

At the immediate site of an explosion the disturbance takes the form of a single pulse, whose peak amplitude and duration depend on the properties of the medium and the properties and size of the explosive charge. The resulting elastic wave usually has a strong initial build-up, followed by an irregular series of oscillations.

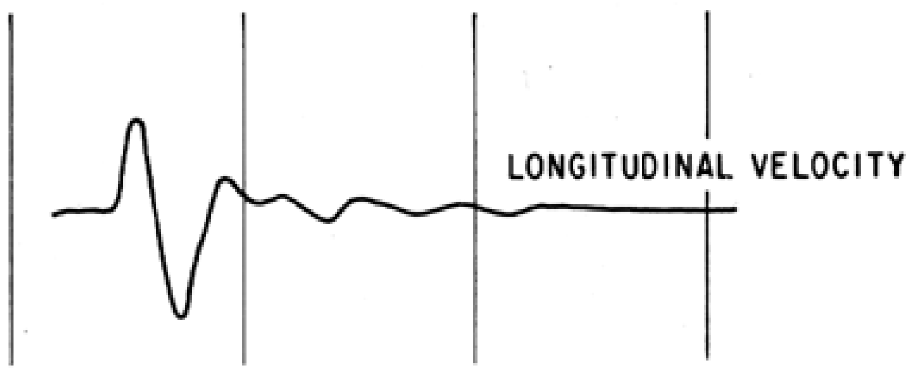

Figure 2. Record of typical blasting vibration

2.2.2 Types of vibration

Vibration in buildings can be caused by many different external sources, including industrial, construction and transportation activities. The vibration may be continuous (with magnitudes varying or remaining constant with time), impulsive (such as in shocks) or intermittent (with the magnitude of each event being either constant or varying with time). Examples of typical types of vibration .Vibration in buildings may also occur from internal sources (within a building structure),such as a road development forming part of the building structure, or mechanical vibration sources in buildings. Vibration and its associated effects are usually classified as continuous, impulsive or intermittent as follows:

Continuous vibration continues uninterrupted for a defined period (usually throughout Day time and/or night-time). This type of vibration is assessed on the basis of weighted rms acceleration values.

Impulsive vibration is a rapid build up to a peak followed by a damped decay that may or may not involve several cycles of vibration (depending on frequency and damping). It can also consist of a sudden application of several cycles at approximately the same amplitude, providing that the duration is short, typically less than 2 seconds.

Intermittent vibration can be defined as interrupted periods of continuous (e.g. a drill) or repeated periods of impulsive vibration (e.g. a pile driver), or continuous vibration that varies significantly in magnitude. It may originate from impulse sources (e.g. pile drivers and forging presses) or repetitive sources (e.g. pavement breakers), or sources which operate intermittently, but which would produce continuous vibration if operated continuously (for example, intermittent machinery, railway trains and traffic passing by).

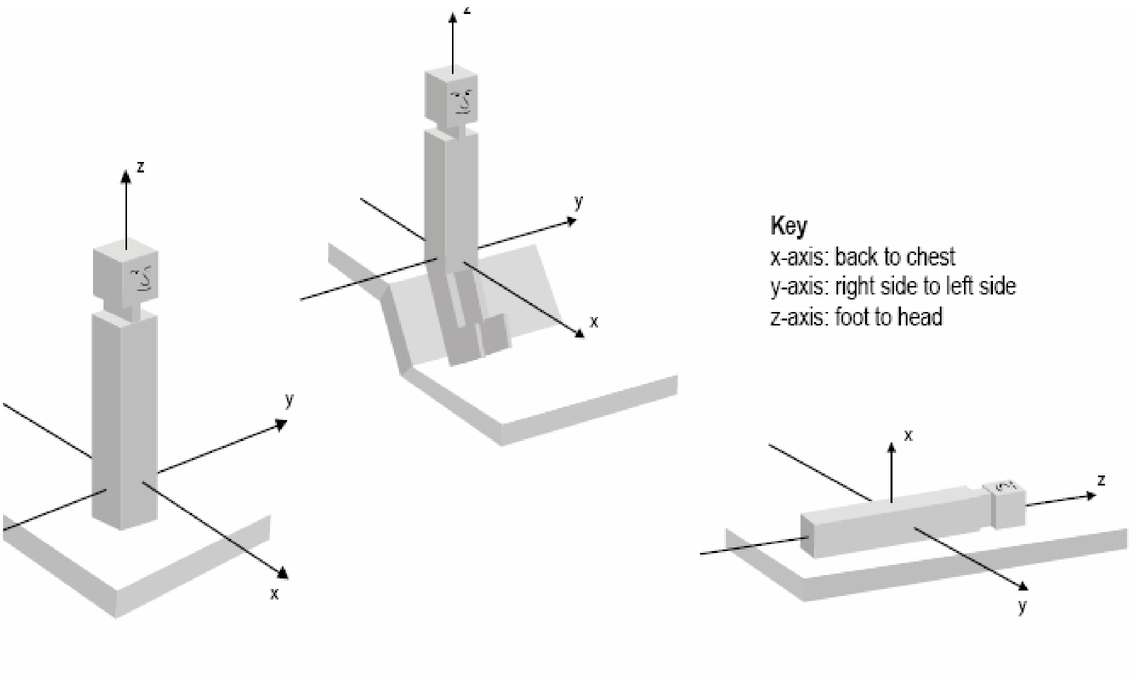

Figure 3: Orthogonal axes for assessment of human exposure to vibration

Table 1: Different Types of vibration

Continuous Vibration	Impulsive Vibration	Intermittent Vibration
Machinery, steady road traffic, continuous construction activity (such as tunnel boring machinery)	Infrequent activities that create up to 3 distinct events in an assessment period (occasional dropping of heave material, occasional loading and unloading)	Trains, nearby intermittent construction activity, passing of heavy vehicles, forging machines, impact pile driving, jack hammers. Where the number of vibration events in an assessment period is three or fewer this would be assessed against vibration criteria.

2.2.3 Types of Waves Generated by the Blast

When an explosive is detonated in borehole, energy is transferred into the surrounding rock as a result of the generated shock and gas pressures. Initially the pressure of the shock wave is higher that the compressive strength of the rock and the rock around the borehole is crushed. However the shock pressure decays quickly to values below the compressive strength. At this point the shock travels inside the rock without breaking it in compression.

Failure of the rock is a result of tension through the tensile component of the shock wave or when the tensile wave is reflected as a tensile wave at media boundaries. With further distance the shock waves attenuates into an elastic wave. In this case the stresses cause the particles of the rock to oscillate about their rest positions as a spring-mass system. There is no bulk movement or transport of matter during the wave motion.

The initial shock front applies a force to the rock in such a way as to compress it and reduce its volume causing a wave similar to a sound wave. Its characteristic is that it compresses and expands the rock by particle vibration in the direction of propagation.

There are two types of wave

1. Body wave
2. Surface wave

Body wave:

P wave (Compression and Tension Waves): This wave type is termed compress ional, dilatational, longitudinal or Primary and is usually designated by the letter P (P-wave).

S wave: Another type of wave which is produced by the initial pressure pulse and the later P wave interacting with discontinuities in the rock is the S-wave. This type of wave is caused when the medium particles oscillate perpendicular to the propagation direction. Sometimes it is referred to as shear, transverse or secondary.

Surface wave:

Introduction of one or more boundaries across which there are differences in elastic properties can cause the introduction of other types of waves. The most significant boundary is the surface of the earth. Two basic surface waves exist. These waves are guided by the surface and are characterized by an exponential decrease in particle oscillation amplitude with increasing distance from the boundary and by the propagation of the wave from along the boundary. The two fundamental types of surface waves are the Raleigh waves and the Love waves.

Raleigh wave: The Raleigh wave causes surface particles to describe an elliptical counter clockwise orbit. These waves exist in the vertical radial plane and have no transverse component.

Q wave: The Love wave (Q-wave) is characterized by particle vibration of the shear type and only in the horizontal transverse direction. These waves are confined to a shallow surface zone.

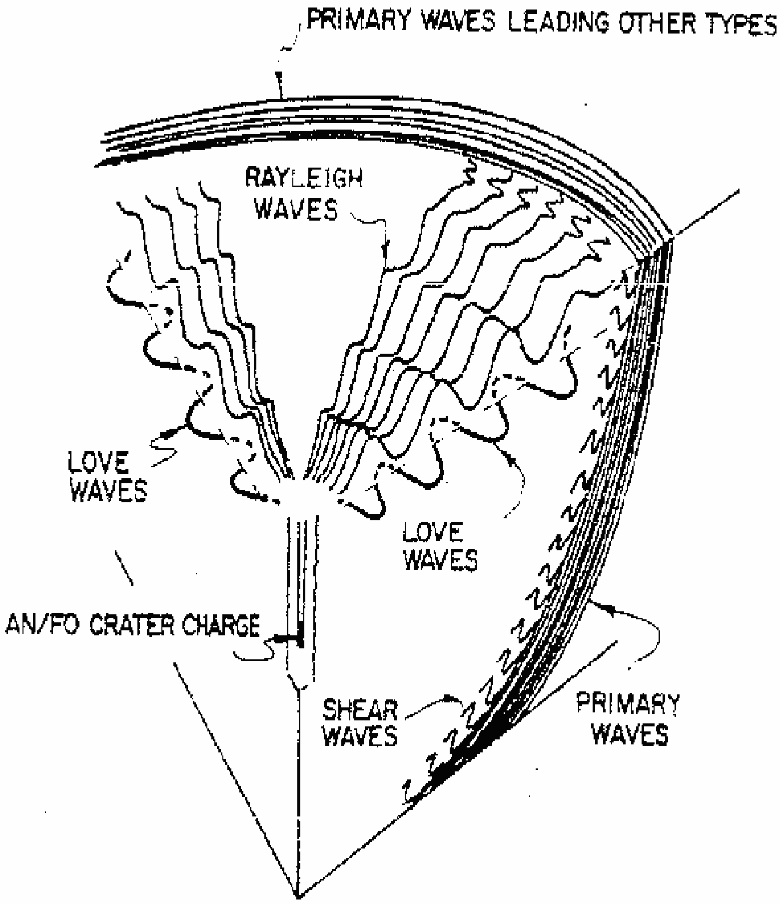

Figure 4: Vibration waves from a cratering charge (Bauer 1981)

Figure shows the main wave types associated with blasting. These are produced by a hypothetical cratering charge. The P-waves are moving faster than the S-waves which are moving faster than the surface waves. The table (4.3.1) shows velocities of P and S waves in different rocks.

Table2: Typical P and S wave Velocities of Rocks

Material	P Velocity, m/s	S Velocity, m/s
Granite	4000-6000	2000-3000
Basalt	5500	3000
Sandstone	2000-3500	1000-2500
Limestone	3000-6000	2000-3000
Schist	4000-5000	2500-3000
Soil	150-1000	100-700

In general the S wave travels at a velocity of ½ to 1/3 of that of the P wave and the Raleigh wave at a velocity of 0.9 to 0.95 of that of the S wave (Oriard1996),(Bauer1981). At small distances all these waves arrive simultaneously while at greater distances they separate and identification is possible. However in mining most blasts consists of a series of explosions which are delayed by millisecond delays. This results in overlapping of the waves. To describe the motions completely, three perpendicular components are necessary. The longitudinal which has the direction of a horizontal radius to the blast, the transverse which is perpendicular to the longitudinal on the horizontal plane and the vertical, which is perpendicular to both the longitudinal and the transverse.

2.2.4 Vibration Waves

To understand vibration control in tight blasting, the explosives engineer must understand vibration wave construction and phenomenon.

Blast induced vibration waves can be divided into three main categories: compressive, shear, and surface. To measure the motions, three perpendicular components of vibration motion must be measured. They are as follows:

Ground vibration direction

1. **Transverse-** horizontal motion at right angles to the blast.
2. **Vertical –** Up and down movement
3. **Longitudinal (Radial***)* - Horizontal movement along a line between the recorder and the blast.

The main vibration wave types can be divided into **body waves** and **surface waves.**

Body wave: Body waves propagate through the body of the rock or soil.

P wave (Compression and Tension Waves): One type of body wave is known as P-Waves. P-Waves are Push/Pull waves and they are the compression/dilatation in the direction of wave travel. They travel in the following mediums: solids, liquid, gas. The compression creates a change in volume of the medium. An example of these types of waves occurs when a rope or string is stretched and vibrates.

S-Wave: The other type of body wave is the *S-Wave*. This is a transverse wave that moves at right angles to the direction of wave travel. These waves can only travel in a solid medium. S-Waves create a change in shape of the medium. An example would the flexing a rope. The rope moves up and down, but the wave travels to the other end.

Surface wave: Surface Waves travel along the outer surface layer of rock. They do not penetrate into the rock mass. The wave motion of surface waves decreases with depth. 1 wavelength in depth is equal to zero motion or no surface wave. Surface waves are larger than body waves but travel slower (Frequency). These are the waves, which cause most of the vibration problems and complaints. These waves are the large energy carriers and produce the largest motions. There are two basic types of surface waves, the Love Wave and the Rayleigh Wave.

Love Wave: Love Waves are transverse waves that propagate in a surface layer on top of another medium (Soil overlying rock). Rayleigh waves travel in the free surface and the particle motion is elliptical.

Rayleigh Wave: The Rayleigh wave causes surface particles to describe an elliptical counter clockwise orbit. These waves exist in the vertical radial plane and have no transverse component. Rayleigh waves travel in the free surface and the particle motion is elliptical.

When blasting in the extreme near field (under 20 feet) without a soil layer, these surface waves are almost non-existent. For the development of regulations, the studies and research performed mostly involved the measurement of surface waves at large distances. In tight blasting situations, the body waves are the dominant waves and create surface waves when interacting with structures. Normally when body waves interact with a free surface, the peak particle velocity is doubled.

2.3 Peak particle velocity

As the seismic waves travel through the rock, there are movements of the particles.
This is commonly referred to as vibration. The motion of the ground particles (vibration) occurs in three dimensions which are vertical, radial and transverse. When there is vibration each particle has a velocity and the maximum velocity is referred to as the peak particle velocity. This motion is usually captured by the use of a seismograph and the maximum velocities of all three directions are given. The practice by most is to use the reading of the peak particle velocity as the standard for measuring the intensity of the ground vibration. In reporting, the maximum measurement of any of the three components is used rather than the resultant vector of all three components combined. In most cases the PPV is closely linked to the potential to damage structures rather than the acceleration or displacement of the rock. A standard unit is used to measure this peak vibration, it is either inches per second or millimeters per second (1.0 isp = 25.4mm/s).
Transmission and reflection of vibration waves also affect the peak particle velocities. In the case of two equal compression waves colliding, the stresses will add and double. Once they pass, they will resume their initial form and continue. In conditions where two opposite waves (compression and tension) collide, the stresses will cancel one another and then continue on and resume their initial form.

Table 3: Permissible Peak Particle Velocity (ppv) at the foundation level of structures in Mining areas in mm/s

Type of structure	Dominant excitation Frequency, Hz		
(A) Buildings/structures not belong to the owner	<8 Hz	8-25 Hz	>25 Hz
(i) Domestic houses/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

2.3.1 Major factors affecting particle velocity of ground vibration

- Type and amount of explosive charge used.
- Distance from the charge to the point of observation (surface structures).
- Geological, structural and physical properties of the rock that transmits the vibrations.
- Height of structures and blast geometry.

- Delay-timing variations.
- Blasting technology.
- Site geology.
- Parameters of waves propagating at a site.

Table 4: Limiting blasting vibration criterion

Distance from blasting site (ft)	Maximum allowable peak particle velocity (in/sec)
0-300	1.25
301-5000	1.0
>5000	0.75

Table 5: Threshold Value of vibration for the safety of underground workings

RMR of roof rock	Threshold value of vibration in terms of peak velocity (mm/sec)
20-30	50
30-40	50-70
40-50	70-100
50-60	100-120
60-80	120

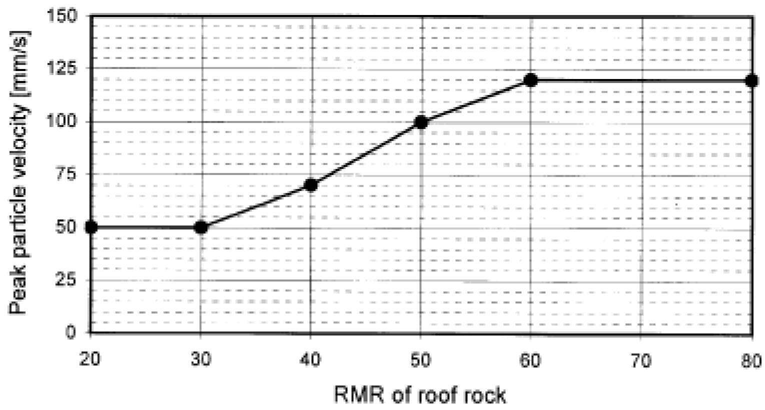

Figure 5: Threshold values of peak particle velocity at different RMR of roof rock.

Source: P.K. Singh (2002)

Table 6: Effects of ground vibration on human beings:

Peak Particle velocity (mm/sec)	Effects
0.1	Not noticeable
0.15	Nearly not noticeable
0.35	Seldom noticeable
1.00	Always noticeable
2.00	Clearly noticeable
6.00	Strongly noticeable
14.00	Very strongly noticeable

2.3.2 Blasting – Limiting Vibration – Methodology

When an explosive charge is detonated, a large amount of energy is released. Correctly designed blasts use the majority of the energy to fragment and displace the rock mass. Improperly designed blasts waste some of the available explosive energy and produce excessive ground or air vibrations. The key factor that controls the amount and type of blast vibration produced is explosive energy confinement. If the energy is over-confined then excessive ground vibrations can occur. On the other hand if the explosive energy is under-confined then excessive air blast levels may be produced.

2.3.2.1 Scaled Distance (SD) is a scaling factor that relates similar blast effects from various charge weights of the same explosive at various distances. Scaled distance is calculated by dividing the distance to the structure of concern by a fractional power of the weight of the explosive material.

$$\mathbf{SD=DW^{-1/2}}$$

Where,

SD = Scaled distance in m $kg^{-1/2}$

D = Separation distance (blast to receiver) in meters.

W= Maximum instantaneous charge weight in kg. i.e., maximum Weight of explosive per delay in kg

The scaled distance equation takes into account the distance from the blast to the point of concern and the amount of charge weight detonated during any 8 ms interval. When ground vibrations are monitored with seismographs the ground motion is typically measured in terms of displacement, peak particle velocity and frequency.

Table 7: Ground Vibration limits

Distance (ft)	Scaled Distance
0 to 300	50
301 to 5000	55
Over 5000	65

Source: Determination of Blast Vibrations Using Peak Particle Velocity by Roy Nicholson

There are two excepted scaled distance formulas used in blasting, square root scaling and cube root scaling. Square root scaling is the general formula used in most regulations and general blasting situations, where the charge can be considered linear. Cube root scaling is used for blasting in the extreme near field where the charge can be considered a point charge or in explosions involving very large quantities, such as those created by nuclear explosions. Ambraseys and Hendron first suggested cube root scaling for use in prediction of blast vibrations in the year 1968.

2.3.2.2 Square Root Scaling

Many times when construction-blasting specifications are encountered, designing to a certain square root scaled distance factor is required. This is useful as a beginning estimate for vibration control and provides a conservative and safe charge weight for the test blast program. Since explosives confinement is not taken into consideration, there can and usually is a large variation in results, especially in tight blasting situations. It should be noted that small charges generate vibrations with higher frequencies and smaller displacements.

Square Root Scaled Distance Formula

Scaled Distance (SD) = (Distance Structure)/ $(\text{Weight})^{0.5}$

Or,
Weight = $(D/SD)^{2}$

2.3.2.3 Cube Root Scaling

Cube root scaling should be used for vibration prediction in the extreme near field (under 20 feet) in construction blasting. Cube root scaling can also be used as the basis for the prediction of frequency, but that will not be discussed here.

Cube Root Scaled Distance Formula

Scaled Distance (SD) = (Distance Structure)/ (Weight) $^{0.33}$

Or,

Weight = (D/SD) ^{3}

Ground Vibration is one of the major side effects of rock blasting which causes structural damage. It cerates a great socio-economic problem for mine management as well as the people residing in the vicinity of the blasting area. Hence, pre–operational judicious planning is the key of efficiency, economy and environmental safety and it calls for in-depth understanding of the character of ground, stability of the structure involved and behaviors of explosives to be used.

2.4 Blasting damage

It appears that theoretical papers on blasting, that the precise nature of the mechanism of rock fragmentation as a result of detonation of an explosive charge is not fully understood. However, from a practical point of view, it seems reasonable to accept that both the dynamic stresses induced by the detonation and the expanding gases produced by the explosion play important roles in the fragmentation process.

Work on the strength of jointed rock masses suggests that this strength is influenced by the degree of interlocking between individual rock blocks separated by discontinuities such as bedding planes and joints. For all practical purposes, the tensile strength of these discontinuities can be taken as zero, and a small amount of opening or shear displacement will result in a dramatic drop in the interlocking of the individual blocks. It is easy to visualize how the high pressure gases expanding outwards from an explosion will jet into these discontinuities and cause a breakdown of this important block interlocking. Obviously, the amount of damage or strength reduction will vary with distance from the explosive charge, and also with the in situ stresses which have to be overcome by the high pressure gases before loosening of the rock can take place. Consequently, the extent of the gas pressure induced damage can be expected to decrease with depth below surface, and surface structures such as slopes will be very susceptible to gas pressure induced blast damage.

Hoek (1975) has argued that blasting will not induce deep seated instability in large open pit mine slopes. This is because the failure surface can be several hundred meters below the surface in a very large slope, and also because this failure surface will generally not be aligned in the same direction as blast induced fractures. Hence, unless a slope is already very close to the point of failure, and the blast is simply the last straw that breaks the camel's back, blasting will not generally induce major deep seated instability.

On the other hand, near surface damage to the rock mass can seriously reduce the stability of the individual benches which make up the slope and which carry the haul roads. Consequently, in a badly blasted slope, the overall slope may be reasonably stable, but the face may resemble a rubble pile. In the case of a tunnel or other large underground excavation, the problem is rather different. In this case, the stability of the underground structure is very much dependent upon the integrity of the rock immediately surrounding the excavation. In particular, the tendency for roof falls is directly related to the interlocking of the immediate roof strata. Since blast damage can easily extend several meters into the rock which has been poorly blasted, the halo of loosened rock can give rise to serious instability problems in the rock surrounding the underground openings.

It is a known fact that the safety and stability of underground mine openings, coal pillars, water dams, ventilation and isolation stoppings close to operating open-pit mines is often affected by blast induced vibration. As of today, there is an increasing trend in India to win top coal seams, whether it is virgin or developed, by opencast workings wherever it is economical. Mine operators attempt to get better fragmentation of rock even if a blast requires high consumption of explosives per tonne of the mineral produced, as improved fragmentation reduces the cost of loading, conveying and crushing of minerals. These blasts generate seismic disturbances, which in turn may damage the support system, ventilation/isolation stoppings, and water dams in underground mines. It may induce opening of cracks in the strata rendering them unstable. Also, there is possibility of spalling of coal in some adjoining workings that may lead to spontaneous heating over a period of time. The seismic disturbances induced by blasting depend on the total explosive energy released during blasting and the nearness of the underground workings to operating open-pit mines. The quality of rock in which an opening has been created can have a significant influence on the amount of damage done by open-pit blasting. The size of bord and pillars, immediate roof rocks whether laminated or shaley and the age of underground workings have significant influence in sustaining the damage from seismic loading. Geo-mining conditions vary from place to place. This introduces wide differences in effects produced by blasting from mine to mine, necessitating individual study at different collieries. Therefore, under the programme of study, seven sites were selected as experimental sites. The RMR of each site was determined for evaluating its influence on damage resistance potential of rock based on the CMRI-RMR classification

Rupert and Clark concluded that only minor damage in the form of localized thin spalls and collapse of previously fractured coal ribs resulted from blast vibration exceeding 50 mm/s. Jensen et al. reported no roof failure even at vibration level of 445 mm/s and only few loose stones at 127 mm/s. Kidybinski reported that damage to underground coal mine openings in the form of small roof falls or floor heave may occur when the PPV lies in the range of 50–100 mm/s and large roof falls at PPV of 100–200 mm/s. Fadeev et al. reported allowable values of vibration for various types of surface and underground structures. In the case, of primary mine –openings (service life up to 10 years), viz. pit bottom, main cross entries and drifts, the allowable values reported were 120 mm/s for one fold blasting and 60 mm/s for repeated blasting. For secondary mine openings (service life upto 3 years), viz. haulage breakthrough and drifts, the allowable values suggested were 240 mm/s for repeated blasting and 480 mm/s for one fold blasting. Fourie and Gree concluded that the PPV of 110 mm/s produced only minor damage and extensive damage resulted when PPV was 390 mm/s. Singh et al.found that the peak particle velocity of 48 mm/s did not cause any damage to the underground workings. Tunstall suggested that peak particle velocity of 175 mm/s did not contribute any damage to underground opening where very good quality rocks (RMR=85) were encountered. On the other hand, the poor quality rock (RMR=49), which had been loosened by previous open-pit blast vibration, sustained minor visible damage at a peak particle velocity of 46 mm/s and major damage at a peak particle velocity of 379 mm/s. Singh et al.observed that cracks in the coal roof occurred at peak particle velocity of 296.69 mm/s but spalling of coal chips from pillars and roof started at a vibration level of 125.3 mm/s. Lewandowski et al. set a conservative criteria of targeted maximum PPV of 50 mm/s for the safety of coal underground heading. They further clarified that this conservative value of PPV was based on the damage observed at 250 mm/s.

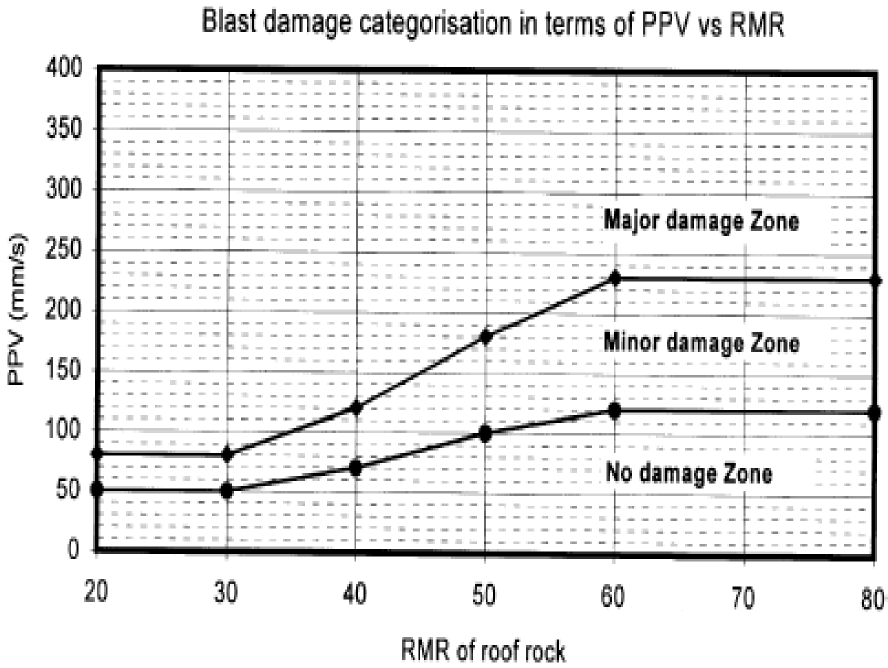

Figure 6: Different damage zones based on ppv and rmr

Source: P.K. Singh (2002) 959–973

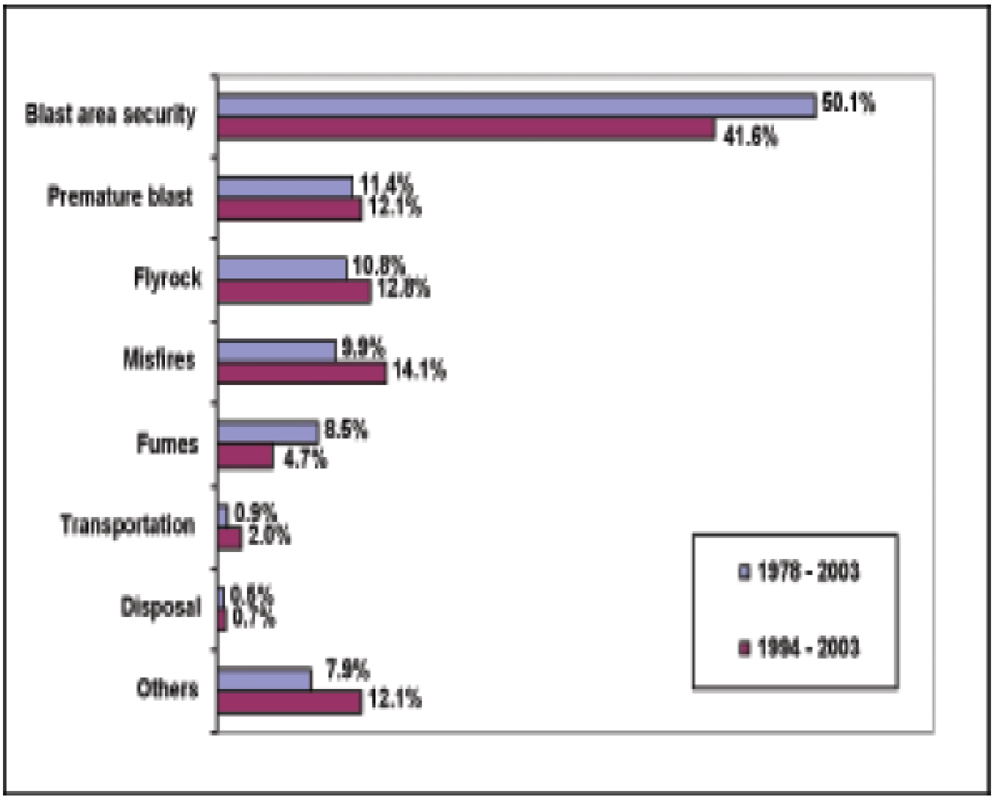

Figure 7: Distribution of blasting-related injuries in the mining industry.

Source: Blasting Safety - Revisiting Site Security By T. S. Bajpayee, Harry C.Verakis, and Thomas E. Lobb

Table 8: Classification of blasting damage

Sl. No	Category	Description of damage
(i)	No appreciable damage	No formation of noticeable cracks.
(ii)	Threshold damage	Formation of fine cracks, fall of plaster, opening & lengthening of old cracks, loosening of joints, dislodging of loose objects etc
(iii)	Minor damage	Superficial not affecting the strength of structure(s). Hair line cracks in masonry around openings near partition, broken windows. Fall of loose mortar etc.
(iv)	Major damage	Formation of several large cracks, serious weakening of structures, shifting of foundation, fall of masonry, ruptures of opening vaults etc.

2.5 Various standards regarding ground vibration

Here we describes in detail the results and findings of statistical analysis of data recorded during blasting in various types of rock mass *in situ*. It include limestone (fissured and highly jointed), sandstone – alluvium, iron ore, basalt (Closely Jointed), sandstone (Weathered), dolomite, granite (hard and fresh) and coal. Five empirical equations are considered in predicting ground vibrations due to blasting. These include a general form, inelastic attenuations characteristics and modified form of empirical equations developed by CMRS. The finding would be helpful in designing blasting patterns to protect nearby structures.

1. **USBM PREDICTOR EQUATION**

Considering Cylindrical explosive geometry for long cylindrical charges, Duvall and Petkof (1959), Duvall and Fogelson (1962) and Duvall et al (1963) concluded that any linear dimension should be scaled with the square root of the charge weight. They assumed the relationship in the following form:

$$\text{USBM: } V = K\,(D/Q^{1/2})^{-B} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where

V = Peak particle Velocity

D = Distance of measuring point

Q = Maximum Charge per delay in a round Blast

B= Slope of the best – fit straight line of the V versus $D/Q^{1/2}$ plot in a log – log scale, and K is the intercept on the particle velocity axis when $D/Q^{1/2} = 1$

2. LANGEFORS – KIHLSTROM EQUATION

Langerfors – Kihlstrom (1973) suggested the following relationship for various charging levels $\{(Q/D^{3/2})^{1/2}\}$ to estimate Peak Particle Velocity.

$$\text{LFKH: } V = K\,\{(Q/D^{3/2})^{1/2}\}^{B} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{.. }(2)$$

B is the slope of the best – fit straight line of the V versus $(Q/D^{3/2})^{1/2}$ plot in a log – log scale and K is intercept on the ordinate.

3. AMBRASEYS – HENDROM EQUATION

For spherical symmetry, Ambraseys – Hendron (1968) suggested that any linear dimension should be called to the cube root of the charge weight. They also proposed an inverse power law to relate amplitude of seismic waves and scaled distance . The equation is –

$$\text{AMHEN: } V = K\,(D/Q^{1/3})\text{-}B \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{.. }(3)$$

The empirical constants K and B are derived from the best - fit straight line of V versus $(D/Q^{1/3})$ in a log – log plot.

4. INDIAN STANDARD EQUATION

The empirical relation suggested by Indian Standard (1973) uses a parameter in which blast is scaled to the equivalent distance or scaled distance. It is defined as the actual distance divided by the cube root of the square of the charge weight. The relationship is of the following form –

IS: $V = K (Q^{2/3}/D)^{B}$ ………………………. (4)

5. CMRS PREDICTOR EQUATION

CMRS has established an efficient blast vibration predictor (pPal Roy, 1991) based on wave propagation law. The equation considers only geometrical spreading as the cause of the decrease amplitude of ground vibration.

The equation is –

$V = n + K (D/Q^{1/2})^{-1}$ ……………………. (5)

The empirical constants "n" is related to the category of parameters, which are influenced by rock properties and geological discontinuities. But, the empirical constant "k" is related to the category of parameters which are influenced by design parameters including charge weight, distance from the explosion source, charge diameter, delay interval, burden, and spacing, sub drilling and stemming length. Table 1.9 lists the values of empirical constants as well as the index of determination for different type of rock mass insitu. The CMRS equation involves a very simple calculation for the determination of charge per delay at any specific distance and the equation is as follows.

$Q = [\{D (v – n)\}/K]^{2}$

2.6 Control ground vibrations

Blast design can be altered to result in reduced levels of ground vibration by:

- Reducing the maximum instantaneous charge (MIC) by using delays, reduced hole diameter and/or deck loading.

- Blast vibration research shows the level of ground vibration is proportional to the Scaled Distance (vibration), which is defined as the distance to the blast divided by the square root of the MIC. So, at a given distance, reducing the MIC will generally result in lower levels of vibration.

- Changing the burden and spacing by: altering the drilling pattern, and/or delay layout, or altering the hole inclination.

- The optimum use of explosives in blasting occurs when the available energy is efficiently used in fragmenting and moving the rock. When the hole inclination (relative to the force angle) is decreased or the burden and/or opening are increased, the explosive energy cannot fully fracture the rock and the energy instead dissipates through the ground in the form of vibration.

- Exercise strict control over spacing and orienting all blast drill holes.

- Use the minimum practicable sub-drilling, which gives satisfactory toe conditions. Less than optimum sub-drill in blast holes results in "toe" being left after the blast, i.e. rock remains intact above the level of the previous bench floor. Too great a sub-drill will result in higher levels of ground vibration due to confinement of the explosives.

- Establish times of blasting to suit local conditions.

Here describes a method for controlling of blast vibration

2.6.1. Combination inter hole and inter row delays to minimize vibration

The method utilizes the existence of the local minimums in the frequency spectrum of single-hole blast vibration. The results are presented as a delay map showing maximum ground or structural vibration velocity for many combinations of inter hole and inter row delays. A blast engineer can use this map to select an optimal combination of delays that will produce a low vibration velocity at a selected location and, at the same time, will be acceptable from the point of view fragmentation or muck pile shape.

2.6.2. Prediction and modeling of blast-induced vibrations

This method of predicting blast-induced ground vibration is based on the establishment of an attenuation curve of vibration amplitudes. To develop a statistically reliable curve, it is necessary to record as many blast-induced vibrations as possible. The recorded maximum amplitudes of ground vibrations (PPV) are plotted as a function of scaled distance. Scaled distance is usually defined as the ratio of the distance between the blast location and the recording-station and the square root or cube root of the explosive mass initiated within a certain time interval, usually 8 ms. The 8 ms interval is based on the results of investigations that show longer time intervals effectively separate the dominant part of the ground vibration due to individual holes in a single-row blast. However, it is quite clear that this interval is site and blast-design specific (Anderson, 1989).

The second approach to blast-vibration modeling is limited to the linear aspects of the generation and propagation of ground vibration. The essential part of this modeling approach is the assumption that the vibration due to a single-hole blast can be used as an elemental part of a multi hole blast-vibration model. In other words, the vibration induced by the small blast can be used to build up a vibration signal for a large blast. A key element in this approach is the assumption of a linear relationship between the elements that constitute the model. A blast-vibration simulation model, based on superposition, is illustrated in Figure 8. Basically, the model uses simple algebraic addition of vibration waveforms due to each blast hole in the multi hole blast, shifted by appropriate delay and travel times to build up the total blast-induced waveform.

2.6.3. Minimization of blast-induced ground vibrations

The difficulty in reducing ground vibration is that the minimization should be achieved without adversely affecting the blast performance in terms of the volume of blasted material, rock fragmentation and muck-pile shape. Assuming validity of the single-hole blast linear superposition principle, the modulation function of a blast design (amplitude spectrum of the initiation sequence) is an independent element of a blast-induced vibration model. This function is not influenced by the single-hole blast vibration. Minimization of a multi hole blast-induced vibration can be achieved by minimizing the blast-design modulation function (initiation sequence). This function is determined, for a given frequency range, by the amplitude scaling parameters and effective delay times.

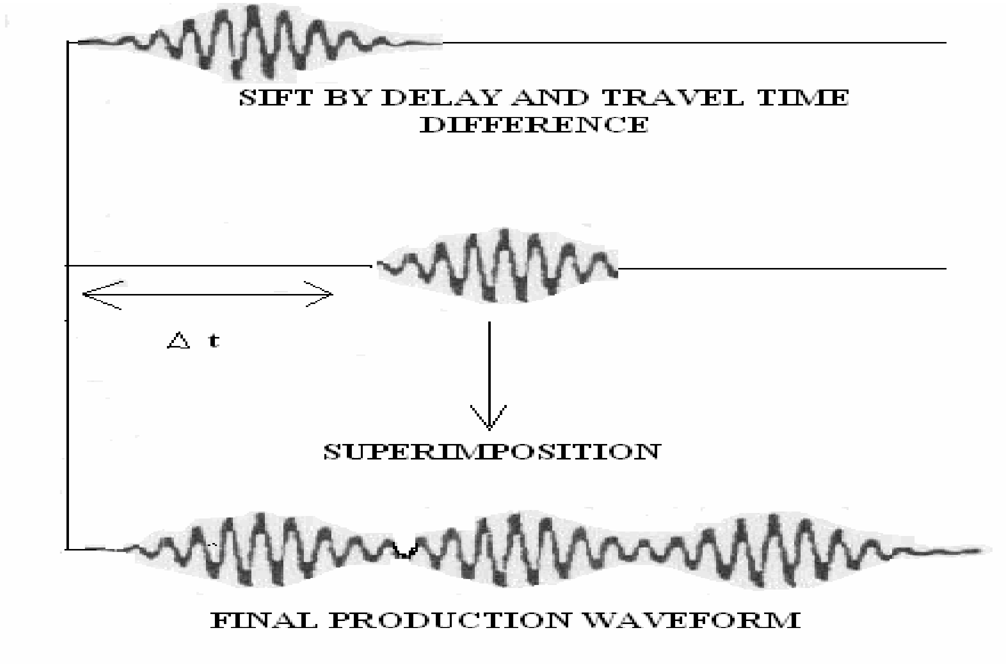

Figure 8: Principle of superposition of blast vibration waveforms

Minimization of blast vibration is restricted by the production requirements, such as good fragmentation and muck-pile shape. This means short inter hole and inter row delay times are not suitable. Hence, a practical blast design must use a delay combination whose initiation-sequence spectrum has low frequency peaks that overlap with the spectrum of a single-hole blast vibration. Hence, relatively small changes in the delay times may cause either amplification or minimization of a multi hole blast-vibration energy or amplitude relative to the same parameter for the single-hole blast.

This above method can be used to determine the optimal delay combination for the blast design shown in Figure 9.The inter hole spacing and the burden are 10 m and the reference location is 1,410 m from the nearest blast hole. The propagation velocity of the seismic waves was 3,000 m/s. The maximum amplitude of the simulated vibration velocity was used as the parameter for minimization. The single-hole blast vibration used as a seed in the simulation has maximum amplitude of 0.08 mm/s.

Vibrations were modeled for inter hole and inter row delays ranging from 10 to 200 ms in steps of 10 ms. The result of the simulation is presented in the form of a delay map shown in Fig. 9. This map shows a great diversity in the maximum values of the blast-induced vibration caused by similar delay combinations. To compare two similar delay combinations the blast vibration was modeled using a constant inter row delay of 100 ms and inter hole delays of 50 and 60 ms. The delay map indicates these two similar inter hole delays produce very different maximum vibration velocities. The maximum vibration amplitudes for the 50 and 60 ms inter hole delays are 0.55 and 0.18 mm/s respectively. Both the above blast delay combinations are almost equally acceptable from the point of view of burden relief and fragmentation. However, the second delay combination is obviously a much better choice for minimizing vibration.

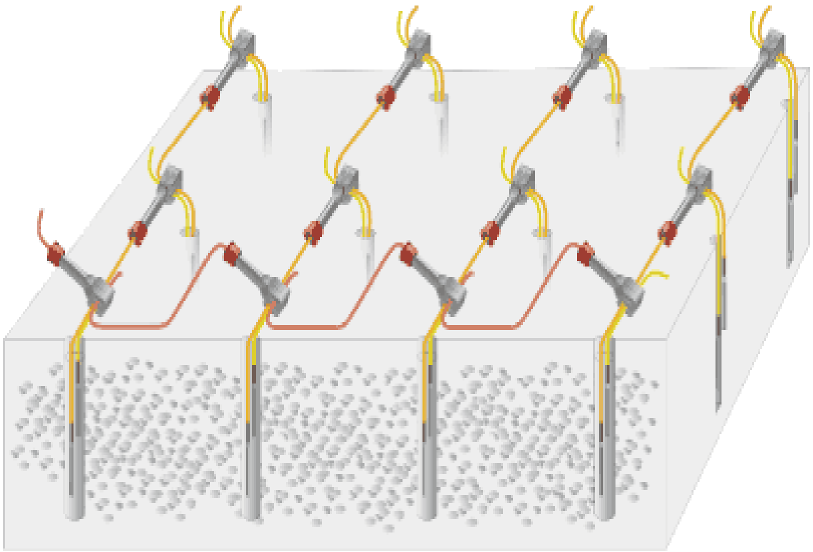

Figure 9: Bench blast design with delay

2.6.4. Presplitting Rock Excavation Slopes to reduce ground vibration

Presplitting is defined as the establishment of a free surface or shear plane in rock along the specified excavation slope by the controlled use of explosives and blasting accessories in appropriately aligned and spaced drill holes.

The presplitting technique, as covered herein, shall be used for forming rock excavation slopes at the locations shown on the plans.

It has to remove overburden soil and weathered rock along the top of the excavation for a distance of at least 15 m beyond the drilling limits, or to the end of the excavation, before drilling the presplitting holes. Particular care and attention shall be directed to the beginning and end of excavations to ensure removal of overburden soil and weathered rock and to expose fresh rock to an elevation equal to the bottom of the adjacent lift of the presplitting holes being drilled.

Slope holes for presplitting shall be drilled along the line of the planned slope within the tolerances specified herein. The drill holes shall be not less than 65 mm, and not more than 75 mm in diameter. The Contractor shall control the drilling operations by the use of proper equipment and techniques to ensure that no hole shall deviate from the plane of the planned slope by more than 300 mm nor shall the holes deviate from being parallel to an adjacent hole by more than 67 percent of the planned horizontal spacing between holes.

The length of presplit holes for an individual lift shall not exceed 9 m, unless the Contractor can demonstrate to the Engineer that the Contractor can stay within the above tolerances and produce a uniform slope. The length of holes may then be increased to a maximum of 18 m. The spacing of presplit holes shall not exceed 0.9-m on centers and shall be adjusted to result in a uniform shear face between holes.

Auxiliary drill holes along the presplit line, not loaded or stemmed, may be ordered by the Engineer. Except for spacing, auxiliary drill holes shall conform to the provisions for presplit holes.

It shall have to place the adjacent line of production holes inside the presplit lines in such a manner that avoids damage to the presplit face. If necessary to reduce shatter and over break of the presplit surface, the first line of production holes shall be drilled parallel to the slope line at the top of the cut and at each bench level thereafter. Blasting techniques that result in damage to the presplit surface shall be immediately discontinued.

No portion of the production holes shall be drilled within 2.5 m of a presplit plane except as approved by the Engineer. The bottom of the production holes shall not be lower than the bottom of the presplit holes.

A maximum offset of 600 mm will be permitted for a construction working bench at the bottom of each lift for use in drilling the next lower presplitting pattern. The Contractor shall adjust the drilling operations to compensate for drift of previous levels and for the offset at the start of new levels to maintain the specified slope plane.

If at times the methods of drilling and blasting do not produce the desired result of a uniform slope and shear face without over break, within the tolerances specified, the Contractor shall drill, blast, and excavate in short sections, up to 30 meters, until a technique is arrived at that will produce the desired results. The maximum diameter of explosives used in presplit holes shall not be greater than 50 percent of the diameter of the presplit hole.

Only standard cartridge explosives prepared and packaged by explosive manufacturing firms shall be used in the presplit holes. These shall either consist of fractional portions of standard cartridges to be affixed to the detonating cord in the field or of solid column explosives joined and affixed to the detonating cord in the field.

If fractional portions of standard explosive cartridges are used, the cartridges shall be firmly affixed to a length of detonating cord equal to the depth of the drill hole so that the cartridges will not slip down the detonating cord nor cock across the hole and bridge the flow of stemming material. Spacing of cartridges along the length of the detonating cord shall not exceed 750 mm center to center and shall be adjusted to give the desired results.

The bottom charge of a presplit hole may be larger than the line charges but shall not be large enough to cause over break. The top charge of the presplitting hole shall be placed far enough below the collar to avoid overbreaking the surface.

Before placing the charge, the hole shall be free of obstructions for the hole's entire depth. Necessary precautions shall be exercised so that placing of the charge will not cause caving of material from the walls of the holes.

Stemming may be required by the Engineer whenever necessary to achieve a satisfactory presplit face. Stemming materials shall be dry free-running material 100 percent of which passes a 9.5-mm sieve and 90 percent of which is retained on a 2.36-mm sieve. Stemmed presplit holes shall be completely filled to the collar. Charges in each presplitting pattern shall be detonated simultaneously.

The presplit face shall not deviate more than 0.3-m from the plane passing through adjacent drill holes, except where the character of the rock is such that, as determined by the Engineer, irregularities are unavoidable. When completed the average plane of the slopes shall conform to the slopes indicated on the plans and no point on the completed slopes shall vary from the designated slopes by more than 0.3-m. These tolerances shall be measured perpendicular to the plane of the slope. No portion of the slope shall encroach on the roadbed.

As long as equally satisfactory presplit slopes are obtained, either presplit the slope face before drilling for production blasting or shall presplit the slope face and production blast at the same time, provided that the presplitting drill holes are fired with zero delay and the production holes are delayed starting at the row of holes farthest from the slope and progressing in steps to the row of holes nearest the presplit line, which row shall be delayed at least 50 milliseconds. In either case, the presplitting holes shall extend either to the end of the excavation or for a distance of not less than 15 m beyond the limits of the production holes to be detonated.

Those holes that fail to meet the alignment controls specified herein will not be accepted for payment. Holes that are drilled where the finish slope does not meet the slope tolerances specified herein will not be accepted for payment. Only those holes that qualify as to alignment and slope finish and which show a hole trace for approximately 50 percent of the drilled length will be accepted and measured for payment. No compensation will be allowed for unacceptable presplit work. Evaluation of presplit holes to determine if the holes qualify for payment will be made after excavation but before slope trimming or cleanup work.

For fully acceptable presplitting holes, the length to be paid for will be the theoretical slope length as computed from elevations, taken before detonating each lift, and a plane one meter below finish grade. No payment will be made for drilling more than one meter below finish grade unless additional drilling is directed by the Engineer. For those holes which produce an acceptable slope and conform to all the tolerances and requirements, except alignment within the plane of the slope, the length to be paid for will be 75 percent of the theoretical slope length.

No adjustment of compensation which results in an increase in the contract price will be made for any decrease in the final pay quantity for presplit drilling if the decrease is a result of nonpayment for unacceptable drill holes or unacceptable work. The provisions in Section 4-1.03B, "Increased or Decreased Quantities," of the Standard Specifications shall not apply to increased prices because of decreases resulting from nonpayment for unacceptable work.

2.6.5 Minimization of blast-induced structural vibrations

The important goal of blast-vibration monitoring is the minimization of blast-induced vibration of structures. Minimization of induced structural vibration is a more complex task than minimization of ground vibrations. The complexity is due to the addition of two more parameters: the resonant frequency and the damping ratio.

A surface structure will amplify a ground vibration whose frequency is close to its resonant frequency, and the intensity of amplification depends on the damping ratio of the structure. Ground vibration with frequencies significantly higher than the resonant frequency of a structure, will be effectively attenuated in the structure. Ground vibration with frequencies lower than the resonant frequency of the structure will not be attenuated, but amplification in the structure gradually decreases with the increasing difference between two frequencies. Minimization of induced structural vibration can be performed in two ways. The first involves determining the delay combination that will induce a minimum value of the product between the complex valued spectrum of the simulated ground vibration and the frequency-response function of the SDF system for a given resonant frequency and damping ratio. This method is more suitable for cases where the resonant frequency is not known or where more than one structure needs to be protected from a strong blast-induced vibration. In such cases, the average value of the response spectrum in the given frequency range is calculated, as is a constant value of damping ratio. This parameter of the response spectrum is calculated for every simulated ground-vibration record.

This method was used with the blast design presented previously (Fig. 5). For each delay combination, the ground-vibration acceleration record was modeled and used to calculate the related response spectrum. In the case when the exact resonant frequency of the structure is not known or when more than one structure exists at the same location, the optimal delay combination is one that will induce the lowest average vibration for all structures. The average maximum vibration amplitude can be calculated as the average value of the SDF-response spectrum within a predefined frequency range.

In this case, the resonant-frequency range of 10 to 20 Hz and a constant damping ratio of 3% were chosen. The result of minimization is presented in the form of a delay map. This delay map immediately shows which delay combinations should not be used. For instance, the inter row delays of 40 to 90 ms with inter hole delays 50 to 100 ms induce relatively large structural vibration. On the other hand, a delay combination consisting of 40-ms inter row and 25-ms inter hole or 110-ms inter row and 40ms inter hole induce structural vibrations with very low maximum amplitudes.

CHAPTER: 3

Data Collection

Introduction

Description of Quarry Site

Surrounding Structures

Data Collection

Instrument used for Vibration Monitoring

Data analysis

CHAPTER 3

DATA COLLECTION:

3.1 Introduction:

This area lies at distance 170 km from Bhubaneswar. The nearest railway station is Talcher on South Eastern railway at a distance of about 6 km from the project site. The block is gently undulating with general slope towards north; small hillocks of conglomerate horizon are prominent physical features to the south and south east.

It is said that only approximately 15% of the total energy of is utilized for actual breakage and displacement of the mass while the remainder is spend on undesirable activities. These undesirable activities are ground vibration, fly rock, noise fumes and heat. Ground vibration is a major concern, as it can cause damage to surface structure and extreme annoyance to residents within the vicinity of where the quarry situated. The purpose of this study also was to establish some parameters and some form of criteria to suggest optimal blast design considering the safety of these structures and the equipment within.

3.2 Description of Quarry Site:

The Quarry is strategically located in terms of easy access and short haul distance to the company's coal handling plant. This quarry is surrounded by villages. The strike of the beds is in east and west direction in general. The gradient of beds 1in 7 to 1 in 10 towards north. The block is by 10 faults; throw ranging from 0m to as much as 100m.

Figure 10: Bharatpur opencast mine, M.C.L.

3.3 Surrounding Structures:

The structures that were of much concern are those residences that were in close proximity to the quarry. Houses are closer than 200meters to the quarry hence the need to be concerned about all possible nuisance from the activities in the quarry. All the structures in the village north of the quarry were constructed of reinforced concrete with steel.

3.4 Data Collection:

Due to the sensitivity of the location of the quarry with respect to the houses, a decision was taken by the Mines and Geology Division that all blasting activities must be monitored for vibration levels. The purpose of this form of regulation was part and parcel to help to prevent property damage as a result ground vibrations and air blasts from blasting activities. Seismographs are the instruments used to ensure compliance for blasting activities.

Adequate time was allowed for the setting up of the equipment. The instrument at no time was placed closer than 1.3m away from the foundation of the closet structure with the microphone mounted about 1m above ground with adequate air muff to prevent pre mature trigger by high winds. The trigger levels were set at 1.2 mm/s for the geophone and 0.03625 psi for the microphone. The location and distance from the quarry to the closest building. The sensor was always adequately coupled to the ground and as level as is possible with the radial channel pointing directly at the blast site. All the necessary information with regards to explosive weight, atmosphere condition and any other information that will ensure a true reading were done.

Explosives used: Emulsion type

Manufacturer: NGF (Nababharat Fuse)

Depth: 8 – 8.5

3.5 Instrument used for Vibration Monitoring

To collect all these data three seismographs were used at different time. The Blastmate III of Instantel origin, have similar operation features to those of the Geosonicbrand. They are all fitted with four channels, three channels for which, one triaxial transducers for monitoring vibration in the Longitudinally, Transverse and Vertical direction and one channel to monitor the sound.

A single instrumentation system is unlikely to meet all the requirements of frequency and dynamic range under the wide range of situations for which this guideline applies. In general, a vibration measuring system usually includes the following instrumentation: transducers, typically piezoelectric accelerometers or geophones signal-conditioning equipment a data recording and analysis system.

Consultants, engineers and contractors the world over recognize the **Instantel® Blastmate® III** vibration and overpressure monitor as the most versatile and most reliable full featured monitor available. It provides all of the industry-leading features of the **Instantel Minimate® Plus** monitor, conveniently packaged with a full keyboard and a high-resolution printer. This allows you to setup add notes and print complete event reports in the field, without a computer.

INSTANTEL BLASTMATE III DS677

Key Features

Ø Fast high-resolution thermal printer for event reports in the field without the need for a computer.

Ø Full keyboard simplifies entry of job-specific notes and information.

Ø Dedicated function keys and intuitive menu-driven operation enable quick and easy setup.

Ø Histogram Combo mode allows capture of full waveform records while recording in histogram mode.

Ø Sample rates from 1,024 to 16,000 S/s per channel up to 65,000 S/s available on a single channel.

Ø Available 8-channel option allows for 2 standard triaxial geophones and 2 microphones to be used on a single **Blastmate III** monitor.

Ø Continuous monitoring means zero dead time, even while the unit is processing.

Ø Any channel can be matched to a wide variety of sensors - geophones, accelerometers, or hydrophones.

3.5 Data analysis

SITE 1:

INSTANTEL DS677 BLASTMATE

SERIAL: 1856 U 5.52

CLIENT: MCL TALCHER

LOCATION: TALCHER

USER: ASHRIT- SANJIB

TRIGER SOURCE: GEO OR MIC

TRIGER LEVEL: 1.010 in/sec 0.03625 psi (L)

RECORD TIME: 4 s AUTO

CALIBRATED 27 JAN 2005 by CMRI DHANBAD

NOTES:

WET SOIL CONDITION

SCALES DISTANCE: 6.1

DISTANCE: 393.7 ft

WEIGHT/DELAY: 165 lb

TRIGGERED: AUTO AT 1:20:35 25 JAN 2007

	TRAN	**VERT**	**LONG**	
PPV	0.260	0.040	1.280	in/s
FREQ	3	N/A	N/A	Hz
TIME	2514	2744	3087	ms
ACCEL	0.21	0.05	0.21	
PK DISP:	0.0266	0.0000	0.1345	ln

PVS 1.283 in/s AT 3087 ms

USBM RI8507 AND OSMRE ANALYSIS

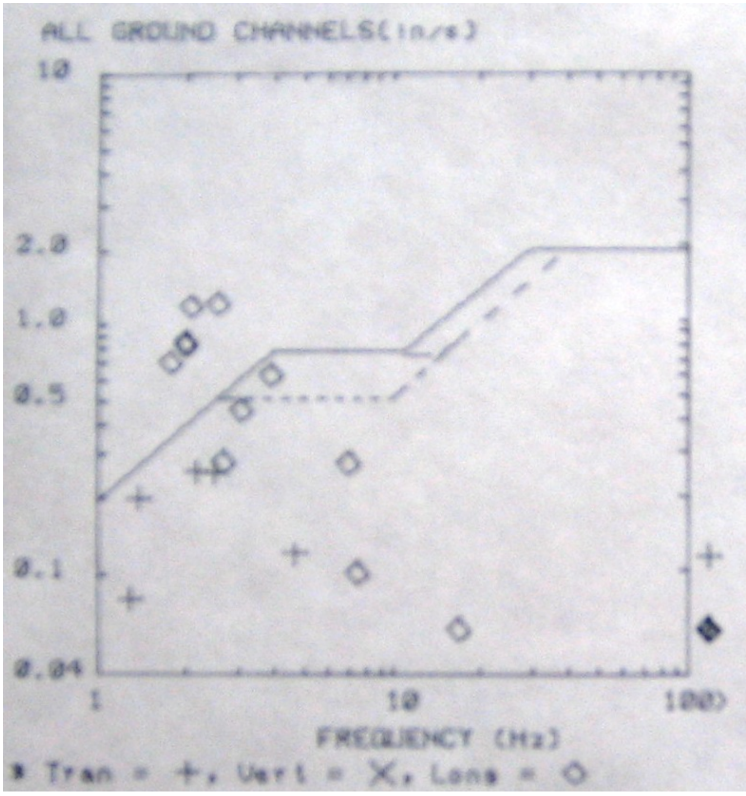

Figure 11: Diagram showing data as against USBM criteria

SITE 2:

INSTANTEL DS677 BLASTMATE

SERIAL: 1856 U 5.52

CLIENT: MCL TALCHER

LOCATION: TALCHER

USER: ASHRIT- SANJIB

TRIGER SOURCE: GEO OR MIC

TRIGER LEVEL: 1.010 in/sec 0.03625 psi (L)

RECORD TIME: 10 s

CALIBRATED 27 JAN 2005 by CMRI DHANBAD

NOTES:

WET SOIL CONDITION

SCALES DISTANCE: 6.1

DISTANCE: 229.6 ft

WEIGHT/DELAY: 179.1 lb

TRIGGERED: AUTO AT 1:22:30 24 JAN 2007

	TRAN	**VERT**	**LONG**	
PPV	4.700	2.380	4.420	in/sec
FREQ	2	N/A	2	Hz
TIME	1979	514	1615	ms
ACCEL	1.06	0.80	0.80	
PK DISP:	0.3508	0.3464	0.4067	ln

PVS 4.980 in/s AT 9229 ms

USBM RI8507 AND OSMRE ANALYSIS

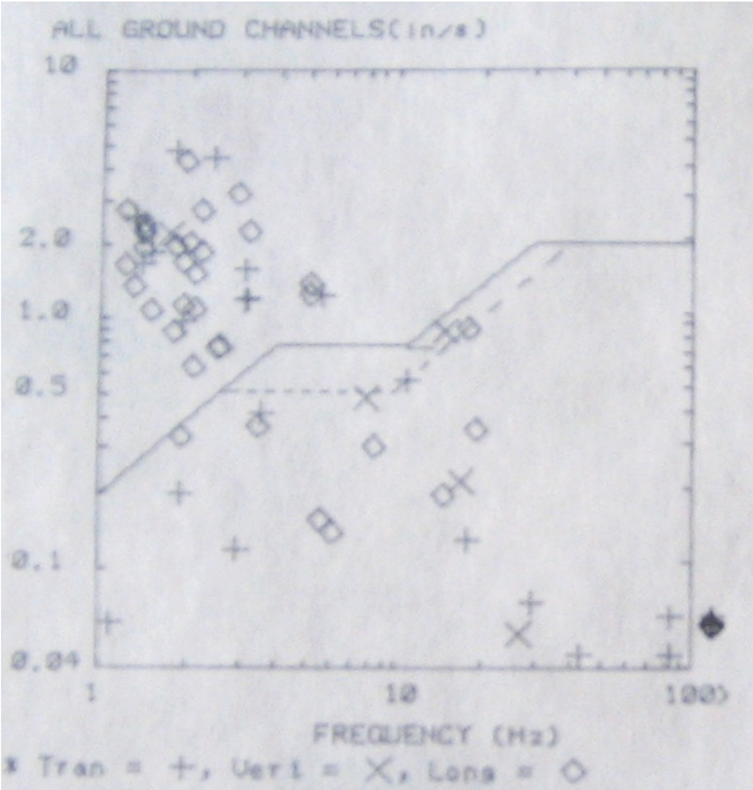

Figure 12: Diagram showing data as against USBM criteria

SITE 3:

INSTANTEL DS677 BLASTMATE

SERIAL: 1856 U 5.52

CLIENT: MCL TALCHER

LOCATION: TALCHER

USER: ASHRIT- SANJIB

TRIGER SOURCE: GEO OR MIC

TRIGER LEVEL: 1.010 in/sec 0.03625 psi (L)

RECORD TIME: 1 s

CALIBRATED 27 JAN 2005 by CMRI DHANBAD

NOTES:

DRY SOIL CONDITION

SCALES DISTANCE: 5.3

DISTANCE: 246.9 ft

WEIGHT/DELAY: 367 lb

TRIGGERED: AUTO AT 1:29:09 23 JAN 2007

	TRAN	**VERT**	**LONG**	
PPV	1.570	0.200	1.330	in/s
FREQ	7	8	2	Hz
TIME	10	-6	60	ms
ACCEL	0.29	0.19	0.27	
PK DISP:	0.0458	0.000	0.0323	ln

PVS 1.752 in/s at 11 ms

USBM RI8507 AND OSMRE ANALYSIS

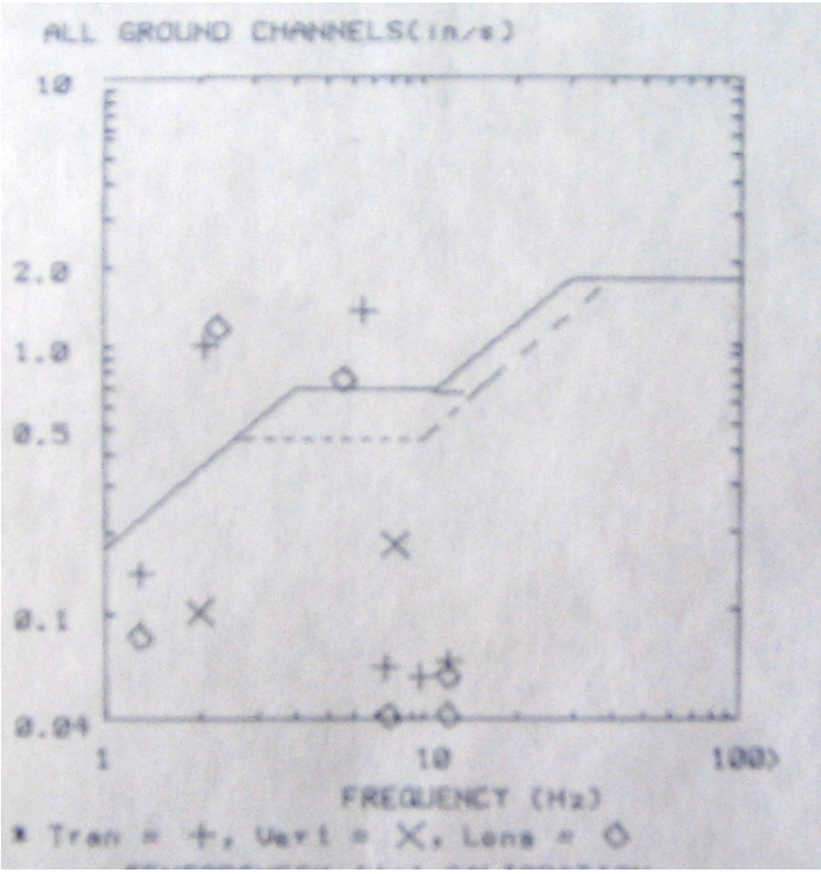

Figure 13: Diagram showing data as against USBM criteria

3.6 Results

The data collected for blasting activities have shown that the PPV was sufficient to cause any structural damage according to the standards put forward by the USBM. The PPV ranges from a low of 32.5mm/s to a high of 126.4 mm/s which revealed that the vibration intensities were not at bearable levels. In comparing such range with other standards it is unlikely for such vibration to cause any structural damage to the buildings in close proximity to the quarry.

The vertical waves recorded the highest PPV value at maximum at a level of 60.42 mm/s which is above the 50mm/s recommended by the USBM standards. The vibrations were monitored in terms of the peak particle velocity and from data collected it varied from a low of 32.5 to126 mm/s. These were dependent on the amount of explosive detonated per delay, the distance from the blast face the set up of the monitoring instrument on the particular day. The highest level of vibration recorded was 126.4 mm/s at a distance of 70metres from the blast face. This 126.4 mm/s PPV lasted for approximately 0.025 of a second. Although this level of vibration is tolerable for reinforced concrete structures there is some concern. The reported quantity of explosives per delay was 81.3kg; one will want to attribute the high vibration level to possible cooperating of charges or improper coupling of transducers with ground.

CHAPTER: 4

Recommendations and Conclusion

Recommendations

Conclusion

CHAPTER4

Recommendations and Conclusion:

4.1 Recommendations

As stated previously, one of the major nuisances to human beings from blasting activities is ground vibrations. Residents are at times more concerned about their property than health. The slightest of vibration will lead to complaints related to property damage. The blaster must ensure that all precautions are taken to minimize this vibration problem. Residents rarely have any close observation and inspection to their property. As soon as there is a blast and any vibration is felt, then all the cracks are now visible. To try and alleviate the many complaints that might occur as in depth preblast inspection of the property must be carried out. In doing this preblast inspection clear documentation of all the visible cracks or any observed damaged to the structure must be made.

In doing this the blaster will have this document to refute any alleged complaints of damage for blasting activities. Should there be a complaint the blaster may also apply the strategy of setting up a seismograph at the complainant's home on his next blast. Using such a strategy along with the preblast document the blaster may be able to convince the complainant that the property was not damaged by blasting activities.

When using a seismograph to monitor the vibration or air pressure there are guidelines that must be followed. In following these guidelines it is quite likely that a correct and authentic reading will result. Aspects such as the proper coupling of transducers, the correct information typed into the machine and the correctly set trigger levels are all necessary for accurate readings. In the reading of a seismograph, it is important to note the frequency of each wave. Aves with low vibrations usually travel far distance and can cause annoyance at distance where the PPV is very low.

These are not the only criteria that are necessary for the correct use of the seismograph. More detailed information can be obtained from the USBM website. It is also necessary to note that not all seismographs are programmed in the same way. The user must have a good knowledge of how the specific monitoring machine functions. The type of explosives and/or initiation system in a blast can influence the air pressure and ground vibration. It is therefore necessary to have the specification by the manufacturer as to his product. This may stem from shelf life to its sensitivity. With regards to the Nobel shock tube air over pressure system is recommended over the traditional detonating cord. It is likely to reduce the level of air over pressure. This Nonel system is also a reputable substitute for the electric initiation system. It will do the work of the electric detonators but are not vulnerable to the many electric hazards.

The blaster should ensure that he has a well designed blast. In doing so all precautions must be taken into consideration. The entire blasting activity should be a process starting from the drilling of the holes. A thorough record of each hole must be available for the proper loading of each hole to prevent over loading of the explosives.
Use the appropriate explosives and initiation system that will foster maximum use of energy and limited amount of nuisance.

Finally it is necessary for all users to be familiar with the latest technology in the use of explosives. They should aware of international limitations and criteria and be knowledgeable about those that are stipulated for your area. This is likely to provide you with the necessary knowledge to produce better blasts with limited nuisances.

4.2 CONCLUSION

The blast vibrations generated and propagated were high to cause damage to the structures in the nearby village. The Maximum Vertical Peak Particle Velocity of 60.42mm/s was recorded near the foundation of the security house. In conclusion, it was not possible to cover all the aspects that contribute to ground vibration. All the blasts recorded did not fall well within the safe limit. The analysis of the data has lead to the conclusion that the quarry can not be expanded in the direction of village side.

The environmental problems arisen from ground vibration and air blast have been faced and discussed frequently in various industries such as mining, construction, quarry etc. where blasting operations are unavoidable. So the ground vibration effects induced by blasting on structures and human beings need to be predicted, monitored, and controlled. With the increase of the environmental constraints on the levels of disturbance induced by blasting operations nearby residents, there is also an increasing necessity to design cautious blasting with greater precision. Therefore, the determination of maximum amount of explosive per delay for a certain distance, especially in large blasts, has a great importance for the elimination of these environmental problems.

Evaluation of the damage risk of the ground vibration induced by blasting Therefore it will be necessary to control the blasting and to predict the level of vibration in order to prevent the damage to the buildings located nearby this site and to reduce these complaints within the scope of the study, ground vibration components were measured for 3 events using Blastmate III considering the directions of the village, in order to predict the peak particle velocity ,the maximum charge per delay, and for the evaluation of the damage risk.

REFERENCES:

1. Anderson, D.A., 1989, "The 8 millisecond 'criterion': Have we delayed too long in questioning it?," Proc. 15th Conf. on Explosives and Blasting Technique, Soc. of Explosives Engineers, New Orleans, LA

2. Blair, D.P., 1987, "The measurement, modeling and control of ground vibrations due to blasting," Proc. 2nd Int. Symp. on Rock Fragmentation by Blasting, Keystone, CO

3. Pilant, W.L., and L. Knopoff, 1964, "Observations of multiple events," Bull. Seismol. Soc. Am., Vol. 54, No.1, pp.19-39. Siskind, D.E., M.S. Stagg, JW. Kopp, and C.H. Dowding,1980, "Structural Response and Damage Produced by Ground Vibrations from Surface Blasting," USBM Ri 8507.

4. Stump, B.W., and R.E. Reinke,1988,"Experimental confirmation of superposition from small-scale explosions," Bull. Seismol. Soc. Am., Vol. 78, No. 3, pp.1059-1073.

5. DGMS (Tech) (S&T) Circular No.7 of 1997 Dhanbad, dated the 29th August, 1997.

6. Northwood, T.D., R. Crawford and A.T. Edwards. Blasting vibrations and building damage. The Engineer, Vol. 215, No. 5601, 31 May 1963, p. 973-9.

7. Indian Standard: Criteria for safety and design of structures subjected to blast, ISI BUL. NO IS – 6922, (1973).

8. Duvall W I and fogelson D E: Review of criteria for estimating damage to residence from blasting vibrations, USBM – Rl 5968, (1962)

9. Assessing Vibration: a technical guideline (February 2006) by: Department of Environment and Conservation 59–61 Goulburn Street Sydney NSW 2000

10. Blast vibration damage to underground coal mines from adjacent open-pit blasting by: P.K. Singh, Central Mining Research Institute, (6 September 2002).

11. Research papers from NIOSH website.
12. Determination of Blast Vibrations Using Peak Particle Velocity
By: Roy Fitzgerald Nicholson.