BLAST VIBRATION MONITORING IN OPENCAST MINES

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

BACHELOR OF TECHNOLOGY
IN
MINING ENGINEERING

BY

SHIV SHANKAR KUMAR CHOUDHARY (110MN0389)
&
RAVI RANJAN (110MN0436)

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA
2013-2014

BLAST VIBRATION MONITORING IN OPENCAST MINES

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

BACHELOR OF TECHNOLOGY
IN
MINING ENGINEERING

BY

SHIV SHANKAR KUMAR CHOUDHARY (110MN0389)
&
RAVI RANJAN (110MN0436)

Under the Guidance of
Prof. B. K. Pal

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

2013-2014

National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled, **—Blast Vibration Monitoring in opencast Mines** submitted by Mr. Shiv Shankar Kumar Choudhary and Mr. Ravi Ranjan in partial fulfilment of the requirement 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 University/Institute for the award of any Degree or Diploma.

Date:

Prof. B. K. Pal
Dept. Of Mining Engineering
National Institute of Technology
Rourkela – 769008

ACKNOWLEDGEMENT

The most pleasant point of presenting a thesis is the opportunity to thank those who have contributed to it. Unfortunately, the list of expressions of thank no matter how extensive is always incomplete and inadequate. Indeed this page of acknowledgment shall never be able to touch the horizon of generosity of those who tendered their help to me.

First and foremost, I would like to express my gratitude and indebtedness to Prof B. K.Pal for his kindness in allowing me to do work in the present topic and for his inspiring guidance, constructive criticism and valuable suggestion throughout this project work. I am sincerely thankful to him for his able guidance and pain taking effort in improving my understanding of this project.

An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them.

And my sincere thanks to all my friends who have patiently extended all sorts of help for accomplishing this undertaking.

Date:

Shiv Shankar Kumar Choudhary (110MN0389)

Ravi Ranjan(110MN0436)

Dept. of Mining engineering

National Institute of Technology

Rourkela – 769008

INDEX

CHAPTER-01: INTRODUCTION

CHAPTER 03: EXPLOSIVE

CHAPTER 04: BLASTING

CHAPTER 02: GROUND VIBRATION

CHAPTER 05: DAMAGE CRITERIA & DGMS REGULATIONS

CHAPTER 06: BLASTING SEISMOGRAPHS

CHAPTER 07: CASE STUDY

CHAPTER 08: CONCLUSION

ABSTRACT

In this report the blast vibration monitoring techniques is studied. Ground vibration induced by blasting practices in mines has become a serious environmental issue in today’s scenario. Various factors influence the blast vibration being produced from the blasting practices such as the pattern of blasting, drilling pattern, quality and quantity of explosives being used, delay pattern etc. Also the vibration which is being generated by the blasting practices is comprised of two types of waves, body and surface waves. Some of the after blast features are also required to be studied in order to determine the safe blasting practices. Three types of adverse effects are generally associated with the blasting practices, Air blast, Fly rock and Ground vibration, However the amplitude, frequency and duration of the ground vibration is determined by the non-controllable(local geology, rock characteristic and distances of the structure from blast site) and controllable parameters(Charge weight, Delay interval, Type of explosive ,Direction of blast progression, Coupling, confinement, Spatial distribution of charges, Burden, spacing and specification and specific charge). For the purpose of determination of the safe Charge per Delay a number of researchers have given various theories and equations. The feasibility of the CMRI equation is studied in this report. Also there are various equipment’s available globally for measuring the ground vibration and air blast. In the present study Minimate Blaster specification has been studied in detail. All the blasting operations were obtained at different- different distances.

According graphs were plotted for the data’s available from the blasting practices and the safe Charge per Delay and Peak Particle Velocity is determined for the mine in accordance with the DGMS regulations.

LIST OF FIGURES

LIST OF TABLES

CHAPTER 01

INTRODUCTION

CHAPTER-01: INTRODUCTION

Drilling and blasting combination is still an economical and viable method for rock excavation and displacement in mining as well as in civil construction works. The adverse effects of blasting, i.e. ground vibrations, air blasts, fly rocks, back breaks, noises, etc. are not avoidable and cannot be completely eliminated but certainly minimize up to permissible level to eliminate damage to the surrounding environment with the present structures . Among all the adverse effects, ground vibration is a matter of major concern to the planners, designers and environmentalists. A number of researchers have suggested several methods to lessen the ground vibration level during the blasting operation. Ground vibration directly depends upon the quantity of explosive used and distance between blast face to monitoring point as well as geological and geotechnical conditions of the rock units in excavation area.

Blast induced ground vibration is an influence from the use of explosives that has historically been a very difficult problem to effectively diminish. Many variables and site constants are involved in the equation that when get combined, result in the creation of a complex vibration waveform produced by the confined detonation of an explosive charge. The application of proper field controls during all steps of the drilling and blasting operation will help to minimize the ill impacts of ground vibrations, providing a well-designed blast plan that has been engineered. This design will help in bearing in mind the proper hole diameter and pattern that would reflect the efficient utilization and distribution of the explosives energy laden into the blast hole. It would also provide for the appropriate amount of time between adjacent holes in a blast to provide the explosive the optimal level of energy confinement. When the blast is properly designed, then the parameters that have the greatest effect on the composition of the ground vibration waveform are:

- Geology between the blast site and the monitoring location

- Accurate timing between blast holes in a detonation sequence

Geological and geotechnical conditions and distance between blast face to monitoring point cannot be changed but the only factor, i.e. quantity of explosive can be expected based on certain empirical formulae anticipated by the different researchers to make ground vibrations in a permissible limit. A suitable and rock friendly blasting can be only alternate for smooth progress of the rock removal process.

1.1 Objective of the Project

To study the blast vibration which is generated by the surface mine blasting operation and to predict the equation for the safe explosive charge so that surface structures can be protected from the impact of the blast vibration.

CHAPTER 02

EXPLOSIVE

CHAPTER 02: EXPLOSIVE

2.1 Introduction:

Dangerous are chemical mixtures or aggravate that, when subjected to heat, impact or shock are fit for experiencing a quick decomposition that discharge heat and gasses, which thusly expand to form high pressures.

Fuels (or sensitizers) + Oxidizers (oxygen source) → Explosive
{Fuel oil (FO), TNT} {Ammonium nitrate (AN),
Sodium nitrate}

Stabilizers such as magnesium and calcium carbonates are also used and sensitizers like metallic powders are used in explosive mixture. Explosives are classified into three categories:-

I. Low Explosive (LE)
II. High Explosive (HE)
III. Blasting Agent (BA)

2.2 Ammonium Nitrate: It is a very high explosive which is having a good oxidizing and cooling agent. It is very safe to handle. AN is mixed with a sensitizers (fuel oil or NG or Trinitrotoluene) so as to form an explosive which is hygroscopic in nature. It has low temperature of detonation and less Power as compared to NG. It is inexpensive, safe to handle and gives better fragmentation. Generally Prilled AN of fertilizer grade mixed with diesel oil is used for larger diameter hole in opencast mines.

2.3 Ammonium Nitrate and Fuel Oil: It is the mixture of prilled AN and fuel oil, at the nearly oxygen balanced ratio of 94/6 AN/FO. Both the sensitivity and performance depend upon prill properties. It does not get detonated ideally and its performance properties depend upon charge diameter and confinement. For dry hole condition it is excellent, and also it should be initiated as soon as it is loaded. It is initiated by small quantity of O.C.G. or booster.

2.4 Site Mixed Slurry: For blasting on a large scale in an opencast mine these explosives are used. It involves specially designed pump trucks for transport to the blasting site ingredients required for SMS system. It is basically consists of a mother support plant where intermediate non-explosive slurry is, initially, prepared for its application. This intermediate slurry subsequently, is transferred to a 10 ton capacity stainless steel tank.

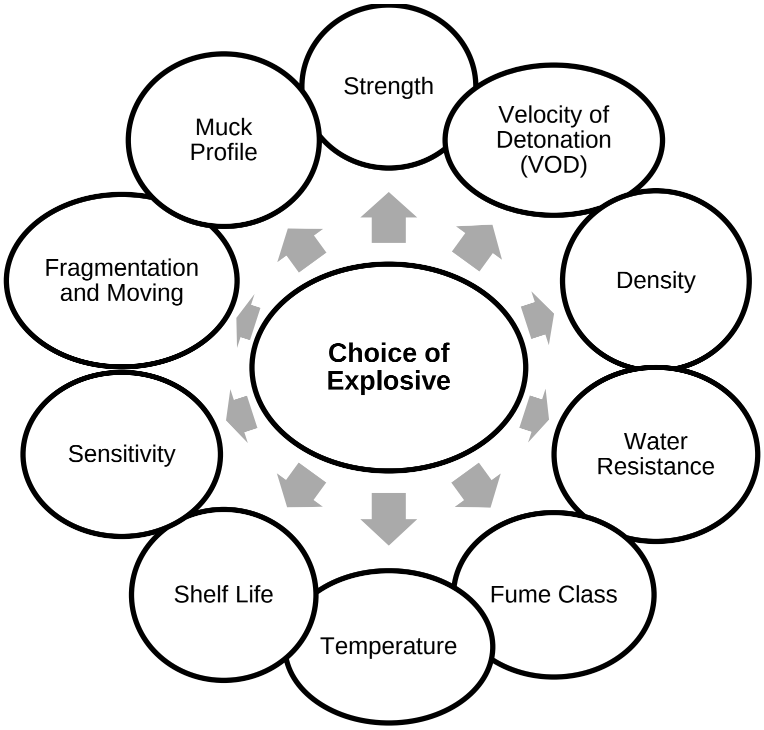
3.5 Emulsion Explosive: It is a liquid mixture of oxidizer and fuel. With the help of emulsifying agent an intimate mix of oil and water is possible. Delivery rate of 200-300 kg/min can be achieved by the Load cells/digital meters. Straight emulsion explosive is considered to have high bulk strength. Support tankers of 10-12 tones capacity or more which can be used for carrying Emulsion matrix which is transferred at site thus saving time. It ensures uninterrupted charging. It is recommended that 500 gm. Pentolite boosters can be used for boosting. Manpower savings are obtained with less deployment of van drivers or helper, blasting crew and magazine staff. Full borehole coupling expanded burden/spacing parameters on blasting efficiency. It does not give explosive pilferage.

Figure No-01: Emulsion explosive

Table No-01: characteristics of SME

Site Mix Emulsion Explosive		
SL.NO	**Characteristics**	**Values**
1.	VOD (m/s)	4500m/s
2	Initial density	1.35g/cc
3	Final density	1.15g/cc
4	Bulk strength	1.37-1.47
5	Water resistance	Excellent
6	Specific energy	750-900
7	Wt. strength	1.00-1.05
8	Pumping rate	120kg/min
9	Booster %	0.1-0.2
10	Sleep time	2weeks

2.6 Choice of explosive depends on the following factors:



2.6.1 Strength

This is a measure of amount of energy released by an explosive during blasting and hence its ability to do useful work. The total energy released from the detonation of explosives includes both useful energy (energy that causes fragmentation or rocks) and waste energy (ground vibration, air vibration, light, heat).

2.6.2 Velocity of Detonation (VOD)

It is the rate at which the detonation wave passé through a column of explosive and this is of consideration importance as the shock energy of detonation increase rapidly with this velocity. Most of the high explosives, slurry explosives and permitted explosives used in the mines have a velocity of detonation between 2500-5000mps. For high explosives which is used as boosters such as Primer VOD is around 7000mps. Velocity of detonation in any borehole can be calculated by placing a gage inside the borehole. This gage is wired to an oscilloscope that logs the speed of the detonation wave in the borehole.

- **The VOD values were highest near the primer and decaying towards the top of the holes, as the density of the explosive decreased.**

2.6.3 Density

The density is important when selecting an explosive for a particular use. With a high density explosive the energy of the shot is concentrated- a desirable feature in tunneling and mining operations. On the other hand when the output of lump coal from mine is important, it is advisable to use a low density explosive, which distributes the energy along the shot hole.

2.6.4 Loading Density (LD)

An explosive loading density is defined as the weight of explosive per unit length of borehole at a specified diameter of hole.

$$\mathbf{LD = W/L \text{ or } LD = 0.3405£D^2}$$

Where D is the borehole diameter and L is the length of the charge £ is the explosive density.

2.6.5 Water Resistance

The ability of an explosive to withstand exposure to water without either losing power or becoming desensitized is termed as water resistance explosives. The detonation energy of ANFO mixtures that have been exposed to water in blast holes is far less than that of such mixtures placed in dry holes. When blasting is to be performed under wet conditions a gelatinous or slurry explosive should be used. The higher the nitroglycerine contents of an explosive, the better its water resistance properties.

2.6.6 Fume Class

Fume class is a measure of amount of toxic gases, primarily CO and NO_X, produced by the detonation of an explosive. Slurry explosive and AN based explosives are preferable to the NG based explosives. Any factor that may change the chemistry of an explosive during detonation (such as balance of fuel to oxidizer) has the chance to upset the oxygen balance designed for the mixture. Such factors include:-

I. Insufficient charge diameter
II. Inadequate priming
III. Improper delay timing
IV. Water deterioration

2.6.7 Temperature

Extremely low temperatures can affect the performance of water- based explosives, the ingredients of which can solidify and aggregate, thereby reducing the particle surface area available for reaction. At high temperature, the crystal structure of AN cab be affected. Temperature fluctuations under this scenario can result in high density stages at which the explosive may no longer detonate.

2.6.8 Shelf Life

The chemical stability and performance of an explosive change with age. The extent of instabilities and rate of aging will depend upon the formulation and storage conditions of the explosives; accordingly. Modern explosives material contains inhibitors and/or stabilizers that lengthen their shelf life.

2.6.9 Sensitivity

The term sensitivity, as it pertains to explosives, has two meaning, the first meaning of the sensitivity as it relates to explosives refers to various safety aspects and describes the ease with which an explosive may be detonated or its sensitivity to accidental detonation from shock, impact, friction, electrostatic discharge and heat. The second meaning has to do with sensitiveness or an explosive's ability to propagate. The two tests that are most applicable to commercial explosives are:-

I. Cap sensitivity
II. Gap sensitivity

2.6.10 Fragmentation and Moving

A proper blast design will yield adequate fragmentation, which will lower downstream costs related to hauling, equipment maintenance and crushing. Fragmentation distribution can be determined by running a particle distribution on the muck pile. The general (conservative) thumb rule is "2 millisecond per foot of burden" for designing delay times required for maximum fragmentation.

2.6.11 Muck profile

The shape and location of the muck pile is an important element of shot design. Requirements ranges from a need to extreme throw for example, to cast overburden under a coal- stripping scenario; to buffer shooting, where the muck pile is confined to a certain area by rock that has been previously blasted. The confined muck pile provides a high bank shot materials that will increase shovel productivity. Mines with a high face that use front-end loader will often blast for a low muck pile for the sake of safety consideration on the ground.

CHAPTER 03

BLASTING

CHAPTER 04: BLASTING

3.0 Blasting:

The blasting operation must be carried out to provide quality and quantity requirements of production. The production of a well fragmentation and loosely packed muck pile that has not been scattered around the excavation area facilitates loading and hauling operations. Fragmentation characteristics influence mucking productivity, crusher throughput and energy consumption, plant efficiency, yield and recovery, or the price itself of the end product in the case of industrial minerals and aggregates. There are controllable parameters and the uncontrollable parameter to control the fragmentation. Control parameters are types of explosives, delay time, bench parameter, firing pattern etc. and the uncontrollable parameters are the properties of rock, properties of explosives etc. The controllable parameters are adjust such that to get optimum fragmentationThe production of riprap will involve the use of holes with a spacing greater than the largest block size required.

3.1 Optimum results of blasting of the following parameters is required:

I. Type, weight, distribution of explosive
II. Nature of the rock
III. Bench height
IV. Blast hole diameter
V. Burden
VI. Spacing
VII. Sub-drilling
VIII. Initiation sequence for detonation of explosive
IX. Powder factor

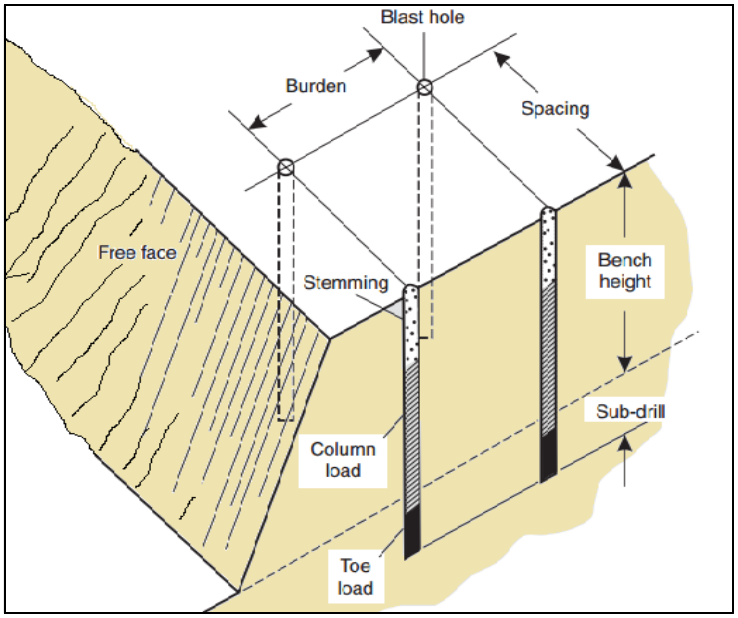


Figure No: 02: Blast geometry

3.2 Mechanism of rock fracturing by blasting

The mechanism by which rock is fractured by blasting is based on the design of blasting patterns, whether for production. When an explosive is detonated, it is converted within a few thousands of second into a high temperature and high pressure gas. When confined in blast hole, this rapid reaction produces pressures, to be exerted against the blast hole wall. This energy is transmitted into the surrounding rock mass in the form of a compressive strain that travels at a velocity of 2000-6000m/s.

Figure No-03: After-blast fractured rocks

3.3 Drilling

Drilling is the process of making a hole into a hard surface where the length of the hole is very large compared to the diameter and for making holes, for placement of explosives for blasting. The objective of drilling and blasting is to prepare well-fragmented loose rock amenable to excavation with better productivity from the excavation machinery. The holes drilled for this purpose are defined as blast hole.

3.3.1 Classification of Drilling Systems:-

Drilling machines used in surface mining projects, construction work, etc., can be classified in the following ways (Dey, 1995):

1) Depending upon the principle of working

i) Percussive Drilling

ii) Rotary Drilling

iii) Rotary-percussive Drilling

2) Depending upon types of prime mover

i) Used diesel driven drilling machine

ii) Electrically driven drilling machine

3) Depending upon the means of power transmission

i) Pneumatically operated machine

ii) Hydraulically operated machine

iii) Electrically operated machine in combination with hydraulic and pneumatic system.

3.3.2 Rotary Drilling

The boring tools used in this method are rotated and they crush, cut or abrade the rock. The rate of drilling depends on:-

I. Nature of the rock
II. Pressure exerted by drilling bits and rods
III. The rpm of the bit
IV. Type of drilling bit

The simplest form is the hand augur. These are attached to rods and rotated by means of a simple cross bar. In this method hollow drill rods of steel or aluminum are used. These are thread connected and transmit torque and feed pressure to the drilling bit or drilling tool, which is attached at the end of column of the drill rods. Rotation of the drill rods is through gearing driven by a prime mover at the surface. The drill bit attacks the rock with energy supplied to it by a rotating drill rod, while a thrust is applied to it by a pull down mechanism using up to 65% of the weight of the machine, forcing the bit into the rock. As the rods rotate, the drilling tool/bit breaks the rock and the cuttings are cleared by compressed air down the hole through the hollow drill rods. The air both cools the bit and provides a medium for flushing the cuttings from the hole. The air, along with the cuttings, comes to the surface through the space between the drill rods and the sides of the drill hole. The bit moves forward by the effect of torque and thrust simultaneously applied to the rock surface. The mechanism of penetration rate are related to shearing and friction processes. The shearing action of the leading edge of the cutting component produces chipping, whereas friction creates wear of the bit-rock interface. Blast hole sizes produced by rotary machines vary in the size range of 100 to 445mm diameter with the most common sizes being 200, 250, 311, and 381mm in diameter. These drills usually operate in the vertical position although many types can drill up to 25 or 300 off the vertical. To achieve high drilling speeds , and to drill holes to greater depths.

Air Pressure: For conventional rotary drilling upto depth of 80 m the air pressure is not very high. 3.5 kg/cm^2 may be sufficient. In DTH the penetration rate is proportional to the air pressure in exploratory drilling pressure up to 24kg/cm^2 has been tried. Commonly, used DTH work at 7.5 kg/cm^2.

Table No 02: Factors that affect the performance of drill

Type of Drilling	Directly Proportional	Inversely Proportional
Rotary	1. Thrust 2. Rotary Speed 3. Rock Hardness	1. Bit cutting angle 2. Bit hardness 3. Fluid flow rate

3.4 Drilling pattern: -

Basically three types of drill pattern.

I. Square pattern
II. Rectangular pattern
III. Staggered pattern

Square or Rectangular drilling pattern are used for firing V-cut rounds. The burdens and subsequent rock displacement are at angle to the original free face either side of the blast round in V-cut. The staggered drilling pattern is used for row-on-row firing where the holes of one row are fired before the holes in the row immediately behind them with the burdens developed at a 45-degree angle to the original free face.

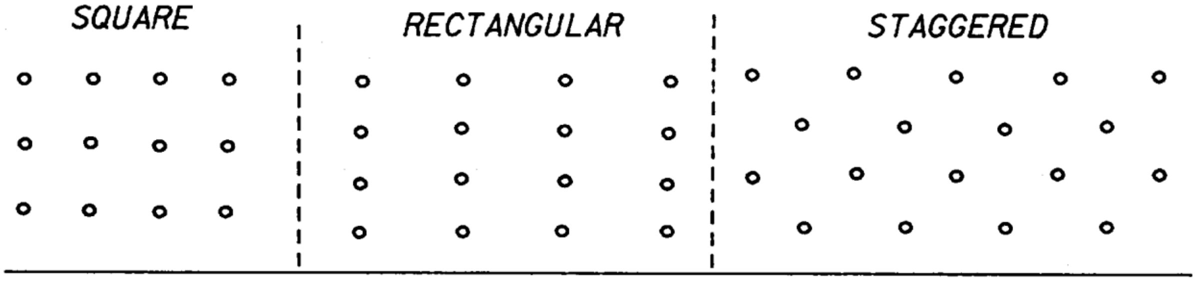


Figure No. 04: Drilling pattern

- **Optimum blast hole diameter increases with the height. In general an increase in blast hole diameter decreases in drilling costs.**

3.5 Blasting Pattern Followed in Opencast Mines

Row of the holes may be in single or multiple. So there are mainly two types of blasting pattern followed in opencast mines. These are

a) Single Row blasting pattern
b) Multiple Row blasting pattern

3.5.1 Single row firing pattern

In single row blasting the fragmentation is low and specific explosive consumption is more than multi-Row blasting, so multi-Row Blasting pattern is preferred.

In this the following pattern are used

I. The alternative delay pattern (used for softer rocks),
II. Consecutive shot delay pattern (rock with medium hardness),
III. Short delay firing with a cut (used for hard rocks).

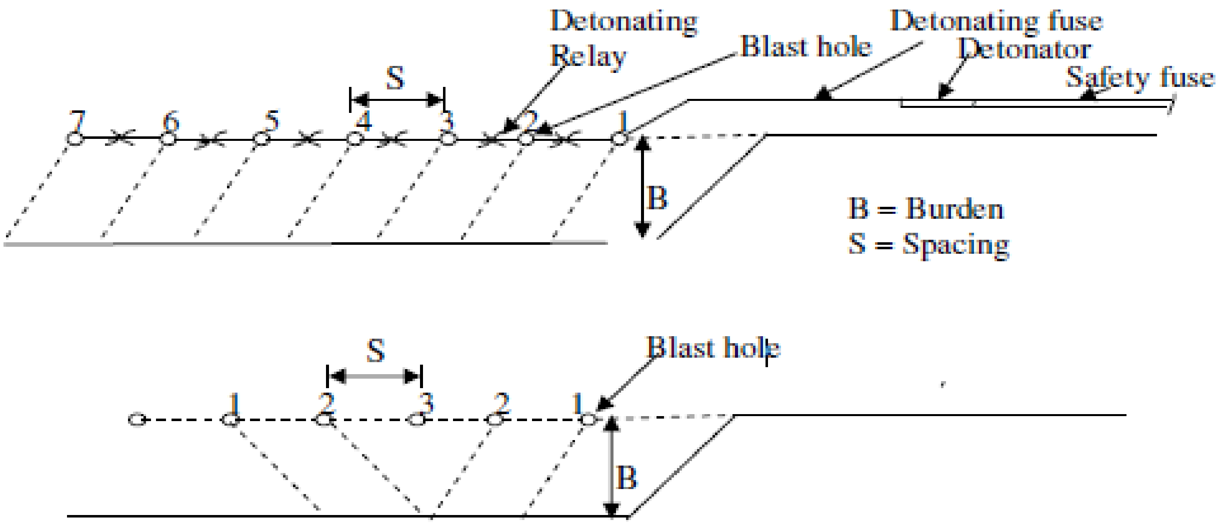


Figure No-05: Sequence of initiation in single row blasting

3.5.2 Multi Row firing pattern

The Multi Row firing pattern is of mainly five types

- I. Square grid in-line initiation (spacing (S) =Effective burden(B).)
- II. Square grid ‘V’ pattern (S=B; S_E=2.B_E).
- III. Square grid ‘V_1’ pattern (S=B; S_E=5.B_E).
- IV. Staggered grid ‘V’ pattern (S=B; S_E=1.25B_E).
- V. Staggered grid ‘V_1’ pattern (S=B; S_E=3.25B_E).

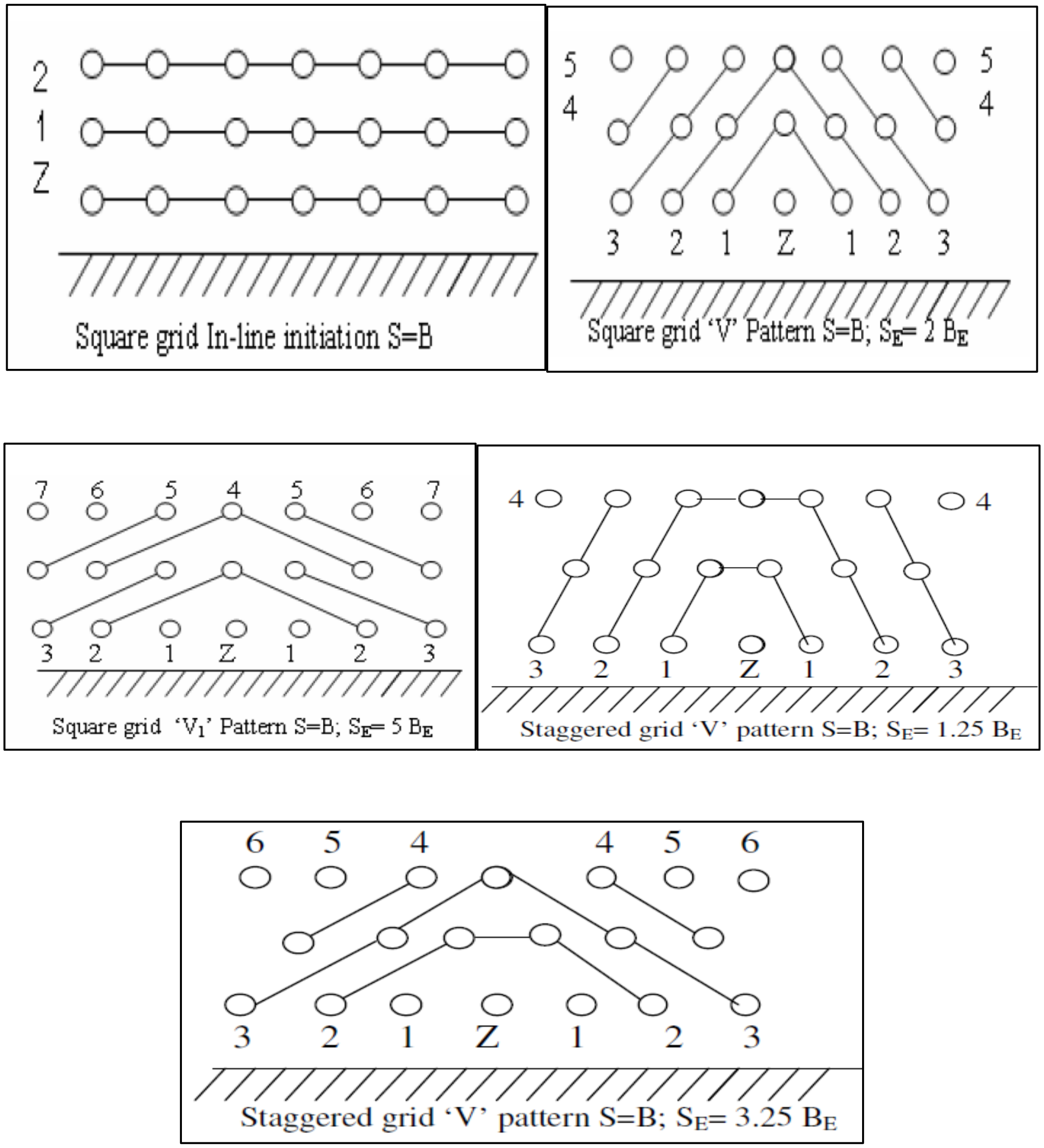


Figure No-06: Multiple row firing

3.5.3 Beside cut pattern other pattern of blasting in multiple row of firing are as given below :

I. Transverse cut pattern

They are used where smaller width of muck pile is desired.

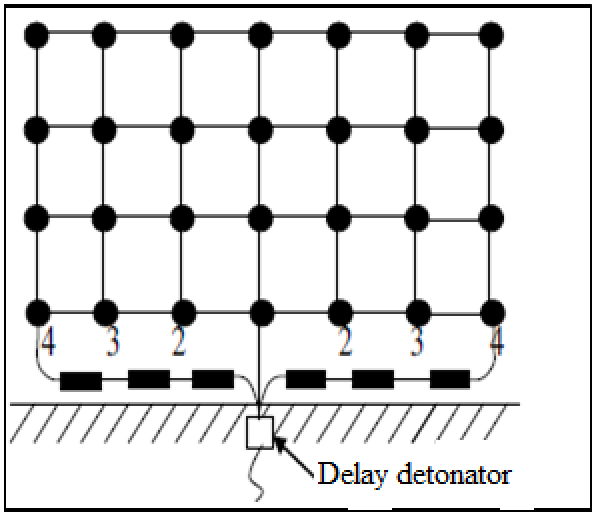


Figure No-07: Transverse

II. Wedge or Trapezoidal blasting pattern

They are used when the rock are medium hard and hard one. Due to motion in opposite direction in case the big boulders are broken by supplementary collision.

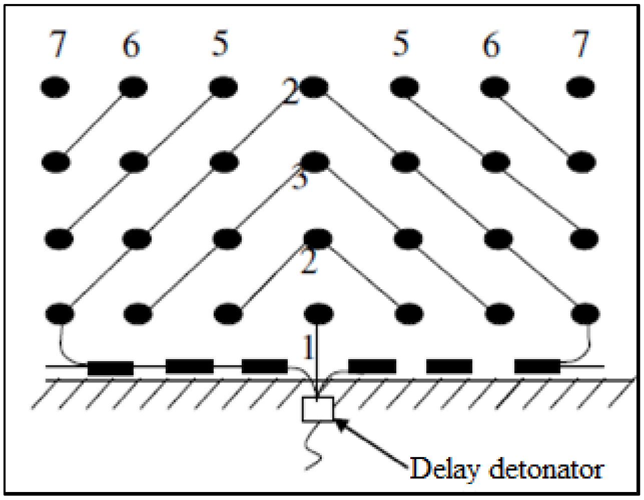


Figure No-08: Wedge blasting pattern

III. Diagonal blasting pattern

With this it is possible to blast the rock towards the least resistance and improve the fragmentation of rock.

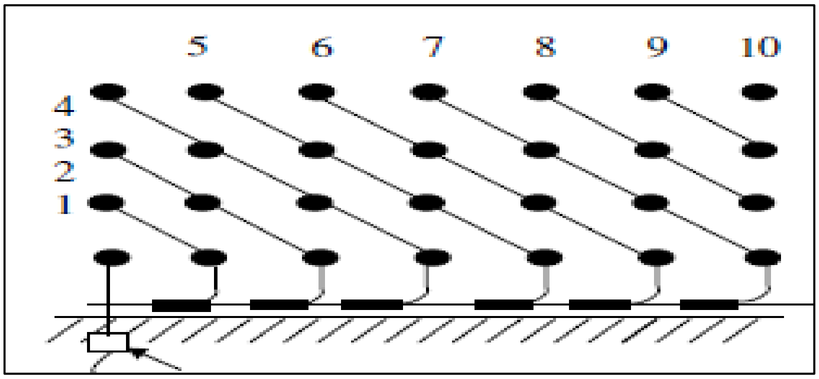


Figure No-09: Diagonal pattern

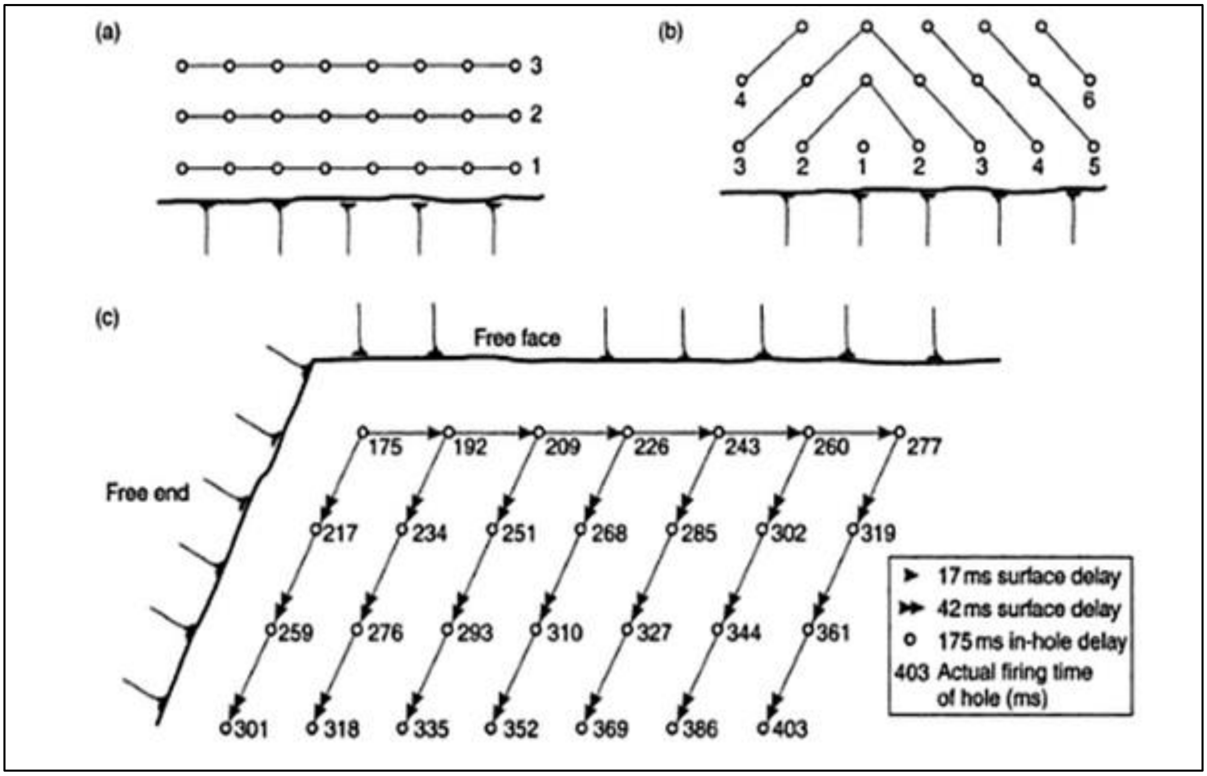


Figure No-10: Typical detonation sequences (a)square “row-by-row” detonation; (b) square “V” detonation sequence; (c) hole detonation using both surface and in-hole non-electric delays (W.Forsyth)

CHAPTER 04

GROUND VIBRATION

CHAPTER 04: GROUND VIBRATION

4.1 Blast Vibration

It can be defined as the shivering of the ground caused by the elastic wave coming from a blast and consisting of numerous individual particles which are either body waves or surface waves. As the body waves reflected or refracted to the surface, become surface waves. Basically these ground vibration combines for the Ground motion. These waves have effect on buildings and structures of the surface and around the area of the excavation through compression and tension and through vertical and horizontal shearing effects.

4.2 Ground Vibration

The movement of any particle in the ground can be described in three ways; displacement, velocity and acceleration. Velocity transducers (geophones) produce a voltage which is proportional the velocity of movement, and can be easily measured and recorded. They are robust and relatively inexpensive and so are most frequently used for monitoring. It has been shown in many studies, most notably by USBM that it is velocity which is most closely related to the onset of damage, and so it is velocity which is almost always measured. If necessary, the velocity recording can be converted to obtain displacement or acceleration. Each trace has a point where the velocity is a maximum (+ve or -ve) and this is known as the Peak Particle Velocity (or PPV) which has units of mm/s. Geophones are only able to respond to vibration in one dimension and so to capture the complete signal it is necessary to have three geophones arranged orthogonally (at right angles). One will always be vertical and the other two will be horizontal, but the horizontal geophones can either be aligned with the cardinal points of the compass or they can be arranged with reference to the blast position. In the latter case, one geophone would be set along the line from blast to monitor (this is known as the longitudinal or radial) so that the other would be perpendicular to this line (this is known as the transverse).

4.3 Generation of blast vibration

At the point when an explosive charge detonates, intense dynamic waves are generated around the impact hole, because of sudden acceleration of the rock mass. The energy freed by the explosive is transmitted to the rock mass as strain energy. The transmission of the energy happens as the waves. The energy conveyed by these waves crushes the rock, which is the prompt region of the hole, to a fine powder. The district in which this happens is called shock zone. The radius of this zone is almost two times the radius of the hole. Past the shock zone, the energy of the waves gets attenuated to some degree which causes the radial cracking of the rock mass. The gas produced as a consequence of detonation enters into these cracks and removes the rock further separated creating its fragmentation. The area in which this sensation happens is called transition zone. The radius of this zone is twenty to fifty times the radius of the hole. As an after effect of further weakening occurring in the transition zone, the waves in spite of the fact that cause era of the cracks to a lesser degree yet they are not in a position to cause the changeless deformation in the rock mass found outside the transition zone. On the off chance that these attenuated waves are not reflected from a free face, then they may cause vibrations in the rock. However in the event that a free face is accessible, the waves reflected from a free face bring on additional breakage in the rock mass affected by the dynamic tensile stress.

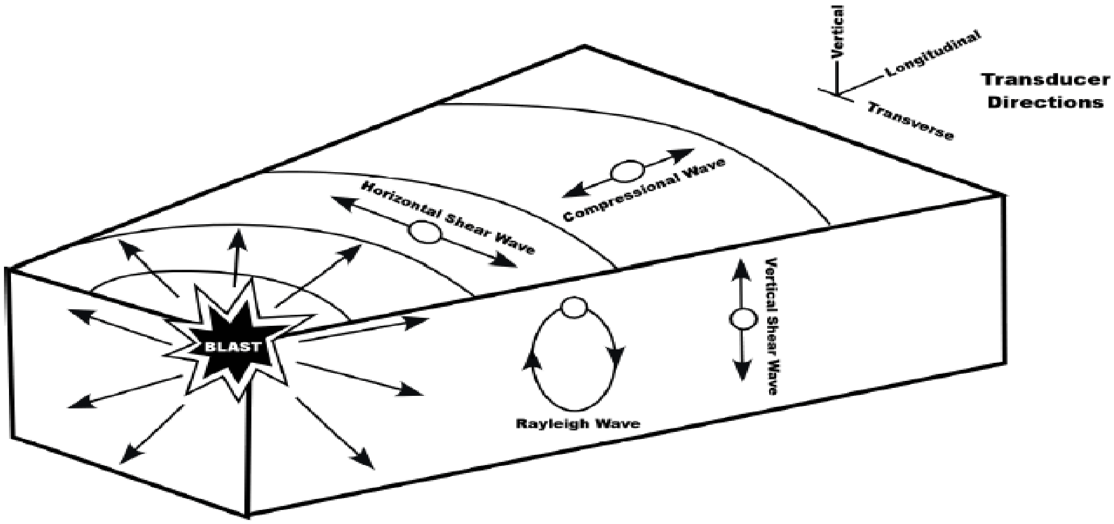


Figure No: 11: movement of particles by blast induced ground vibration

4.4 Energy balance

It is valuable to view the blasting process as an 'Energy Balance' as indicated in the outline beneath. Basically, the chemical energy of the explosives must be dispersed as fragmentation, rock development, vibration and air overpressure. Not many rate of an explosive is continuously used for breakage of rock mass i.e., something like 15 to 20% relying on the blasting technique. Rest of the most extreme energy of the explosive is waste as vibration and air overpressure i.e. around 40% in each one case.

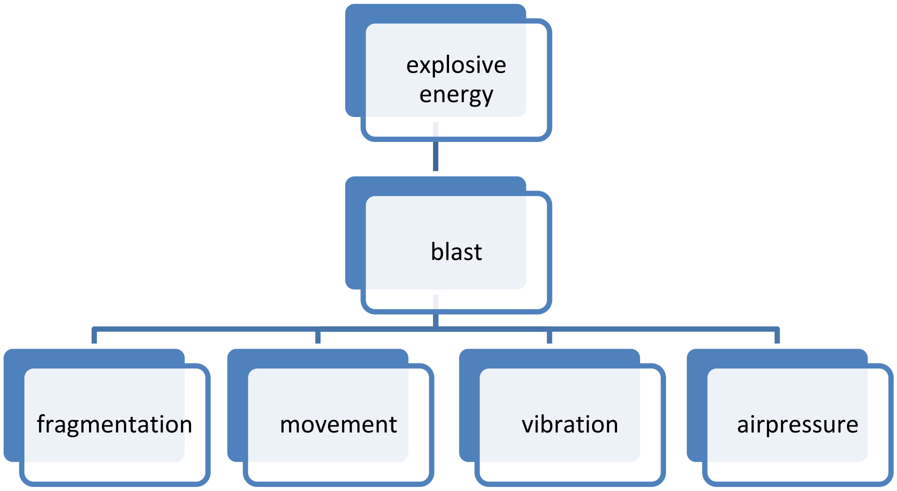


Figure No: 12: Different mode of release of energy from blasting

As the disturbance passes at a given point an individual particle of the medium is displaced from its rest position. One can 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 required therefore to measure the quantity that is most merely and generally related to damage.

4.5 Factors Taken into Account during Ground Vibration

Three factors of ground vibrations are taken in account to 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 has importance because the longer ground vibrations keep on shaking the structure, the greater the amplitude of the structural response. In addition, studies have shown that human forbearance to vibration reduces the longer the vibration continues. Generally seismographs report PPV and frequency, but duration often is ignored. Frequency is considered to be the most important of the three factors of ground vibration. When a structure is exposed to the ground vibrations near its fundamental frequency, in that case the structure enlarges the vibrations. Besides these, two more things to be taken into consideration are:

4.5.1 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). The risk of damage increases as the Ground vibrations at these frequencies amplified by the structures. When the low frequency ground vibration and natural frequency coincides with each other the structure resonance is originated.

The resonance is a state in which the structure absorbs most energy increasingly becoming deformed with time, until plastic deformation takes place. Therefore even the low peak particle velocity of ground vibrations at natural frequency of structure is more damaging to the structure. Natural frequencies of brick and concrete structure generally vary from 8- 16 Hz.

4.5.2 Structural response

Structural response is directly and linearly proportional to ground vibration amplitude. The wall material and the cracking location have an influence on the particle velocity at which cracking begins. If the complete structure is not inspected carefully, there may be chances of unfair opinion on the type of cracks. Thus it is necessary to place the transducer properly for the correct assessment of damage. When matter of mud houses is considered, numbers of cracks develop before blasting and these cracks enlarged and extended with the passage of time. As the time progresses these cracks are further widened and get extended due to blast induced ground vibrations. Concrete structures vibrate for longer period than the 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 big vibration level. Cracks in brick-structures can be detected in junction of walls, roof and at window corners. Brick walls with clay mortar and cement sand mortar act in same manner. Steel structures have more capability that can withstand more vibration level. The magnitude of the vibration on the structures is much more compared to the magnitude of the vibration on ground. Duration of vibration in structure is also longer than, that of ground vibration. Multistoried buildings are more sensitive to blast vibration than that of the single-storied buildings.

4.6 Shock wave propagation causing vibration

4.6.1 Properties of blasting waves

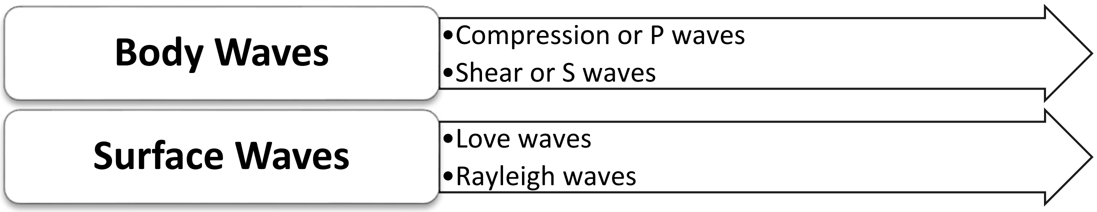
At the instant spot of an explosion the disruption takes the form of a single pulse, whose peak amplitude and duration depend on the properties of the medium and the properties and size of the explosive charge. The resulting elastic wave generally has a strong initial build-up, which is followed by an irregular series of oscillations.

4.6.2 Types of Waves Generated by the Blast

As an explosive is detonated in borehole, energy is transferred into the surrounding rock as a result of the generated shock and gas pressures. Initially it is found that the pressure of the shock wave is higher than that of the compressive strength of the rock and the rock which is present around the borehole is crushed. However the shock pressure declines quickly to the values below the compressive strength. At this stage it is noticed that the shock travels inside the rock without breaking it in compression. Rock failure is a result of tension through the tensile component of the shock wave or when the tensile wave is reflected back as a tensile wave at the media boundaries. As the distance progresses the shock waves attenuates into an elastic wave. In this case it is observed that the stresses make the particles of the rock to oscillate about their rest positions as a spring-mass system. There is no huge movement or transport of matter during the time of wave motion. The initial shock front applies a force to the rock in such a way that it will compress it and reduce its volume which is causing a wave similar to a sound wave. Its property is that which compresses and expands the rock by particle vibration along the direction of propagation.

There are two types of wave

1. Body wave
2. Surface wave



Body wave: it is the seismic wave which travels through the interior of the earth rather than across the surface of the earth. Body waves usually have smaller amplitude and shorter wavelength.

- **P wave** (Compression and Tension Waves): This wave type is basically termed compressional, dilatational, longitudinal or primary and is usually designated by the letter P (P-wave).

- **S wave**: It is another type of wave which is generated by the initial pressure pulse and the later P wave which is intermingling with discontinuities in the rock is the S-wave. Such type of wave is generated when the medium particles oscillate perpendicular to the direction of propagation. Sometimes it is referred to as shear, transverse or secondary wave.

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. Surface of the earth is considered to be the most significant boundary. There exist two basic surface waves. These waves are basically guided by the surface and are characterized by an exponential decrease in particle oscillation amplitude with the increasing distance from the boundary and by the propagation of the wave from along the boundary. Raleigh waves and the Love waves are the two fundamental surface waves.

- **Raleigh wave**: The Raleigh wave causes the surface particles to describe an elliptical counter clockwise orbit. These waves always exist in the vertical radial plane and have no transverse component
- **Q wave**: The Love wave (Q-wave) is characterized by the particle vibration of the shear type and only in the horizontal transverse direction. These waves are confined to a shallow surface zone.

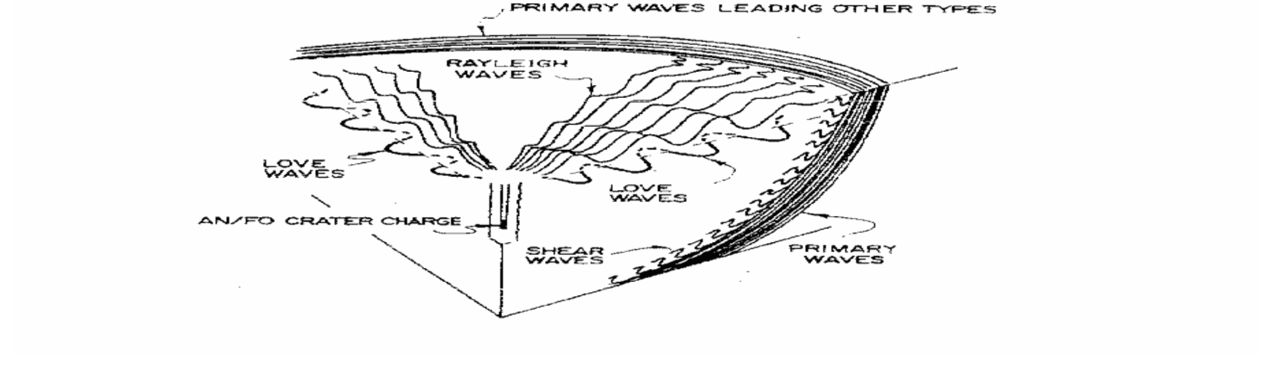


Figure No-13: Vibration waves from a cratering charge (Bauer 1981)

Above figure shows the main types of waves which are associated with blasting. These waves are generated by a hypothetical cratering charge. The P-waves are moving faster than the S-waves which are moving faster than the surface waves.

Table No-03: 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). All these waves arrive simultaneously at small distances while at greater distances they get separate and identification is possible. However in mining most blasts comprises of a series of explosions which are delayed by millisecond delays. As a result of this overlapping of the waves takes place. For complete description of the motion, three perpendicular components are necessary. The longitudinal having the direction of a horizontal radius to the blast, the transverse which is perpendicular to the longitudinal on the horizontal plane while the vertical, which is perpendicular to both the longitudinal and the transverse.

Ground vibration direction

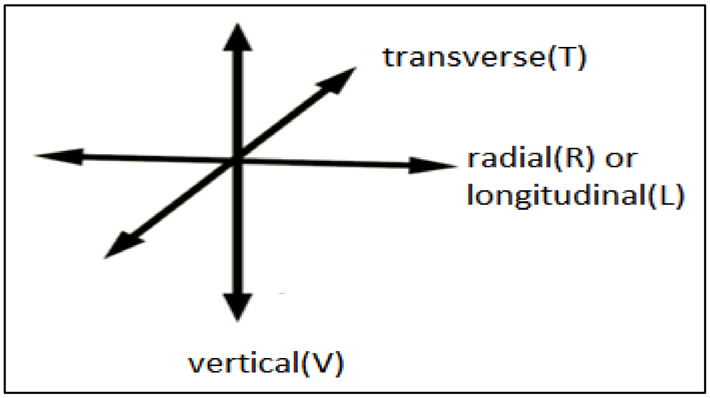
:


Figure No: 14 Vibration direction

Peak particle velocity

Movements of the particles takes place as the seismic waves travel through the rock. This is commonly termed as the vibration. Particle's motion (vibration) occurs in three dimensions which are vertical, radial and transverse. During the vibration each particle has a velocity and the maximum velocity which is referred to as the peak particle velocity (PPV). Use of a seismograph can be usually used for capturing this motion and the maximum velocities of all three directions are given. The reading of the peak particle velocity is practiced by most as the standard for measuring the intensity of the ground vibration. In the case of reporting, the maximum measurement of any of the three components is used rather than the resultant vector of all three components combined. In most of the cases the PPV is closely linked to the potential to damage structures rather than the acceleration or displacement of the rock. For measuring this peak vibration a standard unit is used which is either inches per second or millimeters per second (1.0 isp = 25.4mm/s). Peak particle velocities are also affected by the transmission and reflection of vibration waves. In the case of two equal compression waves colliding, the stresses will add and double. As they pass, they will resume their initial form and continue. In that case where two opposite waves (compression and tension) collide, then the stresses will cancel one another and continue on and resume their initial form.

4.7 Parameters influencing propagation and intensity of ground vibration

The parameters, which exhibit control on the amplitude, frequency and duration of the control vibration, are divided in two groups as follows:

A. Non-controllable parameters
B. Controllable parameters

The Non-controllable parameters are those, over which the blasting engineer does not have any control. The local geology, rock characteristic and distances of the structure from blast site is non-controllable parameters. However, the control on the ground vibrations can be established with the help of controllable parameters. The same have been reproduced below:

1. Charge weight
2. Delay interval
3. Type of explosive
4. Direction of blast progression
5. Coupling
6. confinement
7. Spatial distribution of charges
8. Burden, spacing and specification and specific charge

4.8 Reduction of ground vibration

So as to protect a structure, it is necessary to diminish the ground vibrations from the blast. The techniques which are acceptable for reduction and control of vibrations are:

A. Reduce the charge per delay; this is the most important measure for the purpose. charge per delay can be controlled by :
    I. Reducing the hole depth
    II. Using small diameter holes
    III. Delay initiation of deck charge in the blast holes
    IV. Using more numbers of delay detonators series
    V. Using sequential blasting machine

B. Reduce explosive confinement by:
    I. Reducing excessive burden and spacing
    II. Removing buffers in front of the holes
    III. Reducing stemming but not to the degree pf increasing air blast and fly rock

IV. Reducing sub-grade drilling
V. Allowing at least one free face
VI. Using decoupled charges
VII. Drilling holes parallel to bench face
VIII. Accuracy in drilling

C. Limit the explosive confinement to bedrock if the overburden can be excavated by other means.
D. Square patterns produce more vibration
E. Limit frequency of blasting
F. Time the blasts with high ambient noise levels
G. Use controlled blasting techniques
H. Use a low VOD and low density explosive

4.9 Predictor equation for ground vibration

Extensive research has been conducted to determine the mathematical relationship between vibration level, charge size and distance. The relationship is known as the Propagation Law, developed in the U.S Bureau of Mines Bulletin 656

$$\mathbf{V = H\,[D/W^{\alpha}]^{\beta}}$$

Where,

1. V = Predicted particle velocity (in/s)
2. W = Maximum explosive charge weight per delay (lbs.)
3. D = Distance from shot to sensor measured in 100's of feet (e.g. for distance of 500 feet, $D = 5$)
4. H = Particle velocity intercept
5. α = Charge weight exponent
6. β = Slope factor exponent

The values of α, β and H are determined by condition in the area, rock type, local geology, thickness of overburden and other factors. The waves emanating from the blast holes can cause damages to structures nearby to the mining areas. Thus a number of Blast Monitoring Techniques have been advised based on the number of approaches devised by researchers. Some of the approaches for the blast vibration monitoring are listed below in table

Table No 04: Predictor equations by different researchers

Approaches	**Equation for PPV**	**Description of the Approaches**
Langefors and Kihlstrom Predictor(1963)	$V = K[\sqrt{(Q_{max}/R^{2/3})}]^{B}$	This formula was based on early researcher by Langefros and Kihlstrom into blasting in hard Swedish granite.
Ambraseys-Hendron predictor (1968)	$V = K[R/(Q_{max})^{1/3}]^{B}$	The USBM investigators suggested that any linear dimension should be scaled to the cube root of the explosive charge weight for spherical geometry. An inverse power law was suggested to relate amplitude of the seismic waves and scaled distances to obtain the mentioned relationship.
Indian Standard Predictor (1973)	$V = K[(Q_{max}/R^{2/3})]^{B}$	Indian standard suggested that the blast should be scaled to the equivalent distance or the scaled distance; define as the explosive charge weight divided by the cube root of square of the real distance.
General Predictor(1964)	$V = KR^{-B}(Q_{max})^{A}$	Number of researchers (Davies et al 1964; Attewell 1964; Birch and Chaffer 1983; etc.) by considering particular charge symmetry.
Ghosh-Seamon predictor (1983)	$V = K[R/\sqrt{Q_{max}}]^{-B}e^{-\alpha R}$ $V = K[R/(Q_{max})^{1/3}]^{-B}e^{-\alpha R}$	Ghosh-Deamon predictor proposed that various inelastic effects cause energy losses during wave propagation in various medium. This inelastic effect leads to a decrease in amplitude in addition to those due to geometrical spreading. They modified the propagation relation of USMB in terms of adding inelastic attenuation factor(α)
CMRI Predictor (1993)	$V = n+k[R/\sqrt{Q_{max}}]^{-1}$	Pal Roy proposed a new predictor equation based on the data collected from different India geo-mining conditions. This equation is valid in the zone of disturbance, i.e. when $Q_{max}>0$ and $V>0$

Where,

1. V = Peak Particle Velocity (mm/sec)
2. R = Distance between blast face and monitoring point (m)
3. Q_{max} = Maximum explosive charge used per delay (kg)
4. K, A, B, α = Site constants which can be determined by multiple regression analysis
5. N = Site constant which is influenced by rock properties and geometrical discontinuities
6. k = Site constant which is related to design parameters.

Table No. 4.1 Predictor equations by different researchers

SL.No.	Approach	Equation
01	Gupta et al (1988)	$PPV= K\ [D/\sqrt{W}]^{-\beta}\ e^{-\alpha(D/W)}$
02	P pal roy 1993	$PPV = \alpha + K\ (Q^{1/2}/D)^{-1}$
03	Temrock (1995)	$PPV = K\ (Q/R^{3/2})^{0.5}$
04	Ju & Vonppaisal (1996)	$PPV = BDI*(\sigma_{cm}/4)/d.c$
05	Belgin et al	$PPV =(D/\sqrt{W})^{\alpha}\ B^{\beta}$
06	(Ali kahriman 2004)	$PPV = K*(SD)^{-\beta}$
07	Rai et al (2005)	$Q= K[PPV*R^2]^B$
08	Hossaini and sen,2004,2006	$PPV= K.R^a.Q^b$

Q= charge per delay, PPV= peak particle velocity, R, D = Distance, K,B, a, b, β = site constant

Gupta et al. [1988] suggested the following equation. Here, the expression $e^{-\alpha(D/W)}$represents the inelastic attenuation factor.

Ju and Vongpaisal (1996) suggested the following equation. Here, the BDI= blast damage indicator, σ_{cm} = the compressive strength of the rock mass, d= the mass density of the rock, c = the propagation speed of the seismic disturbance.

In Belgin et al suggested the following equation. Here, the B= burden, W= maximum charge per delay, D= distance

Ali kahriman 2004 suggested the following equation. Here, the K, β = influence of blast design and geology (). $SD= R/W_d^{0.5}$ SD= scaled distance, R distance, W_d= maximum charge per delay

CHAPTER 05

DGMS REGULATIONS

CHAPTER 05: DAMAGE CRITERIA & DGMS REGULATIONS

The damage criteria was proposed by many organizations including USBM, DGMS, Indian Standards etc. based on the Permissible PPV in mm/s and Frequency of the ground vibrations for various types of structures. The criteria based on the Permissible PPV in mm/s and Frequency of the ground vibrations for various types of structures as per DGMS (1997) as presented below in Table 05 is followed for the present investigations to estimate safe charge per delay to limit the ground vibrations within safe limit.

Table No.05: DGMS Damage criteria

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

Table No-06: 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 No. 07: Ground vibration limits

Sl.No.	**Distance**	**Scaled Distance**
1.	0-300m	50
2.	301-5000m	55
3.	Over 5000	65

Table No.08: 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

5.1 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).
- Eological, 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.

CHAPTER 06

BLASTING SEISMOGRAPHS

CHAPTER 06: BLASTING SEISMOGRAPHS

6.1 Blasting seismographs :

Blasting seismograph consist of a transducer (generally a geophone, although an accelometer may be used) connected to a processor to collect any analyze the signals. The tri-axial geophone contains three mutually perpendicular transducers, each consisting of a spring-loaded moving mass system located within a moving coil. The system moves in a magnetic field created by a permanent magnet, when the ground vibration caused the coil to move within the magnetic field an electric current signal is induced with a magnitude proportional to the velocity of the coil. The signals are conducted to the processor by cable as indicated in figure 7.

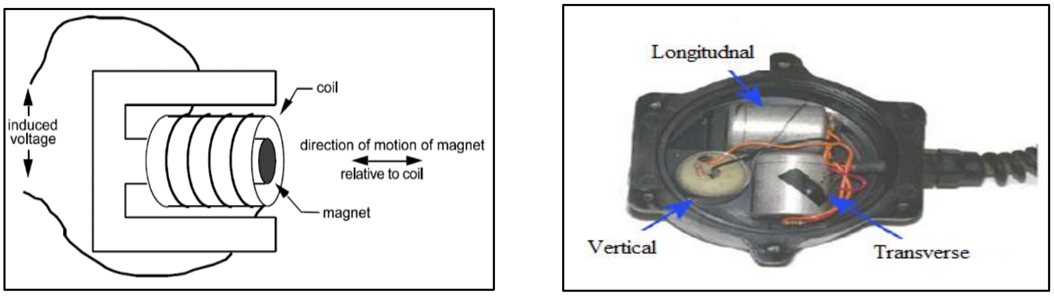


Figure No-15: (a) Geophone sensor operation (b) A tri-axial geophone

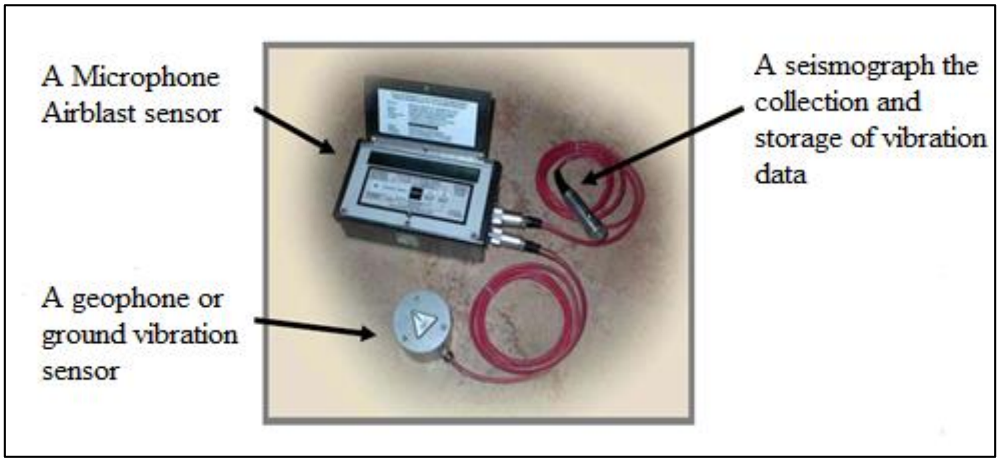


Figure No-16 Parts of a seismograph

Some of the commonly used equipment’s for measuring ground vibration due to blasting are as follows: Micro- Innovations: - PVM A6/Sinco ETNA 8., Blastronics: - µ MX, Instanel: - [Blastmate DS 677, Minimate Pro6, Minimate Pro4 , Minimate Plus ,Minimate Blaster, Blastmate III] , Datamaster: - Dynamaster Blast Monitoring System,Terrock: - Vibpak/CJ4/VIB Vibration Monitoring System

6.2 Specifications of Minimate Blaster

Currently in this mine, ground vibration monitoring is conducted with the help of the equipment Minimate Blaster of Instantel. The monitor incorporates an eight-key tactile keypad and on-board LCD, with a clearly structured, menu-driven interface. Specification of the equipment is listed below in the Table IV.

Table No 09: Specification of the vibration monitoring equipment - Minimate Blaster

General Specifications	**Minimate Blaster**
Channels	Microphone and Tri-axial Geophone
Vibration Monitoring	
Range	Up to 254 mm/s (10 in/s)
Resolution	0.127 mm/s (0.005 in/s) or 0.0159 mm/s (0.000625 in/s) with built-in preamp
Accuracy	+/- 5% or 0.5 mm/s (0.02 in/s), whichever is larger, between 4 and 125 Hz
Transducer Density	2.13 g/cc (133 lbs/ft3)
Frequency Range	2 to 250 Hz, within zero to -3 dB of an ideal flat response
Air Overpressure Monitoring	
Weighing Scale	Linear
Range	88 to 148 dB (500 Pa (0.072 PSI) Peak)
Resolution	0.25 Pa (0.0000363 PSI)
Accuracy	+/- 10% or +/- 1 dB, whichever is larger, between 4 and 125 Hz
Frequency Range	2 to 250 Hz between -3 dB roll off points

Event monitoring measures both ground vibrations and air pressure. The monitor measures transverse, vertical and longitudinal ground vibrations. Transverse ground vibrations agitate particle in a side to side motion. Vertical ground vibration agitate particle in an up and down motion progressing motion. Longitudinal ground vibration agitates particles in a forward and back motion progressing outwards from the event site. Events also affect the air pressure by creating what is commonly referred to as “air blast”. By measuring air pressure, we can determine the effect of air blast energy on structures

Figure No-17: Minimate blaster

6.3 Procedure for Monitoring

1.Install the Minimate Blaster

Unpack the Minimate Blaster then attach the spikes to transducer and then place the transducer pointing in the direction of the event. Connect the microphone.

2.Turn the Minimate Blaster On

Press and hold the enter key, located on the Minimate Blaster face panel, until you hear an audible beep.

3.Check your installation

We can check our installation by pressing the Test key. This executes the sensor check program and tests the transducer and microphone.

4.Review Setups

Before we begin, we can review the current Minimate Blaster setups. To review the setups, press the option key and the Test key together.

5.Change the Minimate Blaster Setups

We can change the record mode, choose the trigger source, set the trigger level and choose a recording stop mode from various options available in the system of Minimate Blaster.

6.Record Events

Now we can record the events, for this just press the Start Monitor key to begin monitoring.

7.View the Events

We can view the events we have just recorded. From the main window, press the Up Arrow key to display the view event window.

8.Turn the Minimate Blaster OFF

We are finished with the Minimate Blaster functioning, so we can turn it off, Just press cancel key to return to main window and then press hold the Enter key until the display disappears.

CHAPTER 07

CASE STUDY

CHAPTER 07: CASE STUDY

7.1 BLAST VIBRATION STUDY AT OPEN CAST IRON MINE – A CASE STUDY

7.1.1 Geology of the iron ore area

The iron ore deposits of the region belong to iron ore series of Dharwar age. The main rock types of this series are shaley quartzite, banded hematite jasper and iron ore. Laterite occurs at places as capping on the ore body and on shales. The stratigraphic succession on the areas is mentioned below:-

- Newer dolerite dyke & sills
- Ultra basic igneous intrusion
- Granite rocks
- Shales with epidiorite & volcanic ash beds
- BHJ with iron ore bodies
- Shales with thin calcerous and sandstone bands
- Limestone at places
- Purple sandstone with basal conglomerate
- Hornblend Mica Schists and Quartzites

Upper Shale, Tuffaceous ferruginious shale usually with fine lamination; contains a few manganiferrous shale band. Banded Hematite Jasper,with thin intercalations of tuffaceous shale and with supergene enrichment to Iron ore bodies. Lower Shale, which is tuffaceous along the Eastern flank and slaty in the west Mafic Lavas (local).

The iron ore bodies generally occupy the top portion of the hills and are elongated in the north-south direction. Structurally the area appears to be the eastern limb of an overturned syncline whose western limb is overturned and falls outside the lease area. Eastern limb has a strike variation between NE-SW to NNE-SSW and dip inclination varying between 16^0- 50^0 due northwest to west. Lateritisation is also more towards eastern flank than the eastern flank. Because of the structural features, ore seems to be concentrating more and more towards west in depth. Minor structural features such as folds, joints and fissures are also present.

7.1.2 Description of the formation

The Iron ore body in the lease area can be considered to be having two ore zones, one to the west of Bonaikora and another to the east. The western ore zone is mainly composed of laminated soft ore with isolated patches of hard ore. The eastern ore zone has scattered float soft ore with isolated patches of hard ore. The eastern ore zone has scattered float ore over a considerable portion with patchy out crops of hard ore at the cliff sections.

The general agreement for the origin of iron ore is that it was formed due to continuous leaching and replacement of BHJ and shale by the action of meteoric water which has percolated through joint and fissures. The principal types of ores and waste found in this area are classified into following names:-

- Lateritic ore/Soft ore
- Hard Ore
- Friable & laky Ore
- Blue dust and Powdery Ore (High concentration of Fe, but more friable)
- BHJ and Shale
- Laterite

Hard Ore: - It is a steel grey coloured, fine grained massive and homogeneous variety of iron ore. The ore is bedded in nature having parallel and alternate bands of primary and secondary hematite. The general range of variation of quality of hard ore is:-

Fe% - 64.50-68.50

SiO_2% - 0.50-2.00

Al_2O_3 - 0.50-3.00

Soft Ore: - This type of ore is soft, spongy and laminated, often porous, due to which it has undergone intense lateritisation within weaker zones. All the enriched laterities and geothites belong to this category.

Fe% - 59.00-65.00

SiO_2% - 1.70-5.00

Al_2O_3% - 2.50-7.00

Friable and Flaky Ore:- It is brownish to steel grey coloured ore enclosing flakes or hematite containing sufficient secondary goethite as cementing material along bedding planes in addition to kaolinious and shaly material safely preserving the original texture of parent BHJ. Most of friable ore bands can easily be dug from a fresh working face because of its friable nature. The general range of variation of quality of Flaky ore is:-

Fe% - 62.50 – 65.00

SiO_2% - 0.80 – 4.00

Al_2O_3% - 0.70 – 4.00

Blue Dust: - It occurs as natural fines, often underlying Flaky and Friable ore containing powdery hematite. It occurs at lower horizons of ore body. The general range of variation of quality of Blue dust is:-

Fe% - 64.50 – 68.00

SiO_2% - 1.00 – 3.50

Al_2O_3% - 0.80 – 3.00

Laterite: - Laterite occurs as a capping of iron ore and it is product of lateritisation of iron ore. It is porous and spongy in nature and constitutes mainly of goethite (iron hydroxide). The laterite capping varies in thickness from 2 – 20 m. The general variation of quality is:-

Fe% - 26.00 – 50.00

SiO_2% - 2.00 – 37.00

Al_2O_3% - 7.00 – 33.00

BHJ and Shale: - It shows an even parallel arrangement of alternative hematite and Jasper bands which taper lenticular along the bedding plane and often grade into friable flaky ore or blue dust.

Unbanded variety of BHJ also exists in nature which is very hard compact massive and fine grained and contains only Jasper with disseminated hematite. This variety often grade laterally into shaly type. Shales of various colours are also found in the area, but are usually confined to lower levels of the eastern and southern escarpment, this form the base of the ore whose profile is undulating.

7.1.3 Surface Blast Design

The primary objectives in rock blasting are to optimize blast performance and to ensure the safety of everyone by implementing safe practices in and around the blast site. And the secondary objectives include maintaining the stability of high walls so that men and equipment working on and under them are safe, Fragmenting rock masses to reduce their downstream hauling and crushing cost and to move rock masses to facilitate their load-out by site specific equipment.

A proper blast design will yield adequate fragmentation, which will lower downstream costs related to hauling, equipment maintenance and crushing. The shape and location of the muck pile is an important element of shot design. Requirements range from a need for extreme throw. Controlled blasting techniques are used to efficiently distribute explosive charges in rock mas, thereby minimizing the fracturing of rock beyond the crest-line of the high wall or designed boundary of main excavation areas. Such fracturing is basically called as over break. Here in mines over break is not a big problem and it varies from face to face depending upon the explosive used and bench configuration. Some of the methods used for preventing over break are namely- Presplitting, Smoot blasting, Line drilling and Cushion blasting.

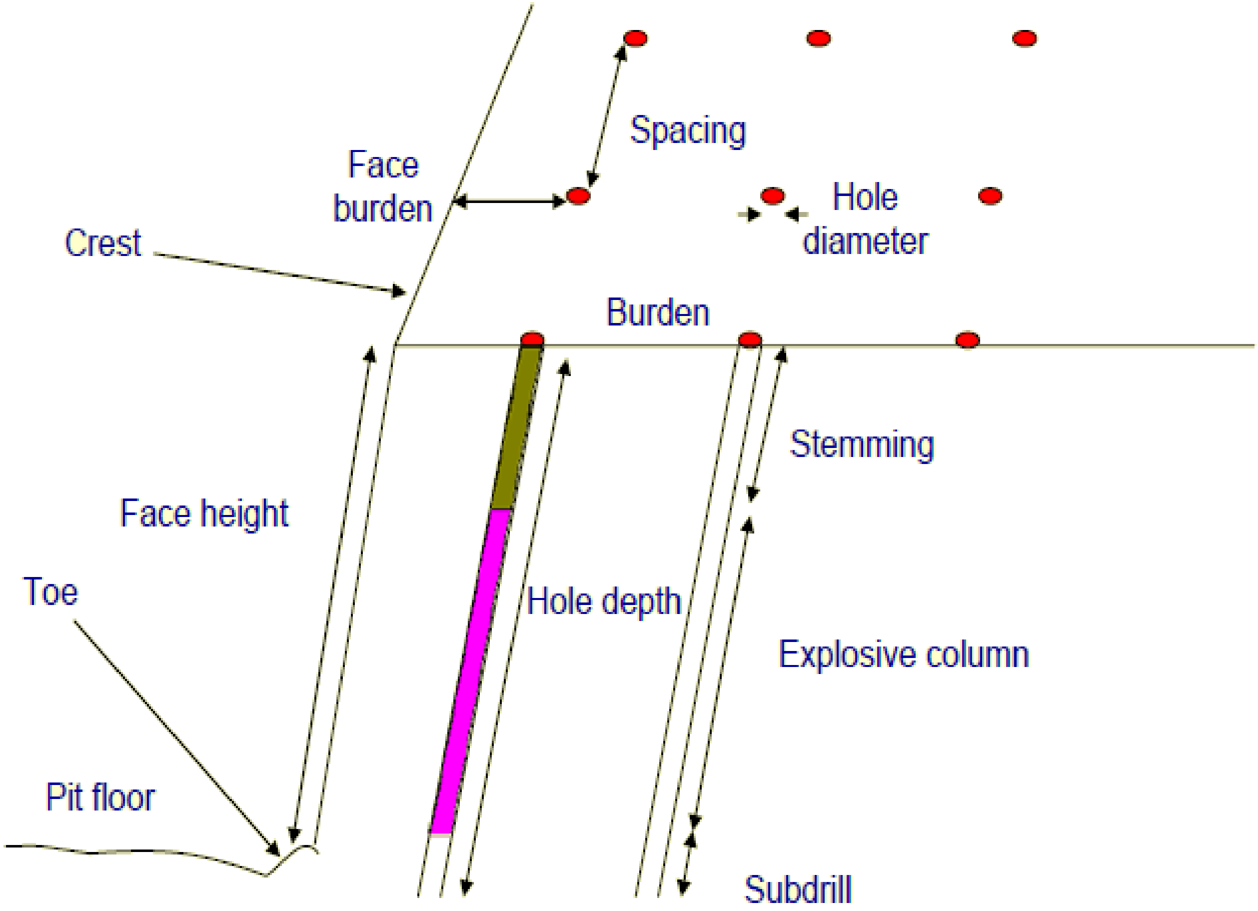


Figure No-18: Blast design pattern

7.1.4 Observations and calculation of blast vibration of iron ore mine

Values are recorded for different blasting site in which peak particle velocity, frequency is measured through monitoring device and distance of the monitoring site form the blasting site is also recorded. Accordingly charge per delay (Q_{max}) is calculated and for the various observations:

Table No-10: observation of blast vibration for iron ore

Sl. No.	Peak Vector Sum (mm/sec)	Frequency (Hz)	Holes (Nos)	Qmax (charge/delay)	Distance (m)	√Qmax	[D/√Q]	Ln[D/√Q]	Ln PPV
1	**1.10mm/s at 0.034sec**	13	76	242	215	15.5563	13.82	2.626	0.0953
2	**3.30mm/s at 3.162sec**	7	40	176	177	13.2665	13.34	2.5907	1.1939
3	**3.14mm/s at 0.545sec**	9	33	244	208	15.62049	13.36	2.5922	1.1442
4	**0.651mm/s at0.006sec**	8	42	165	212	12.84523	16.50	2.8033	-0.4292
5	**1.33mm/s at 0.748sec**	9	42	193	179	13.89244	12.88	2.5556	0.2851
6	**0.603mm/s at 0.001sec**	13	47	188	225	13.71130	16.40	2.7972	-0.5058
7	**1.62mm/ at 1.929sec**	10	36	239	226	15.45962	14.62	2.6823	0.4824
8	**4.49mm/s at 0.731sec**	4	63	171	178	13.07669	13.61	2.6108	1.5018
9	**5.91mm/s at 0.458sec**	7	48	166	196	12.88409	15.21	2.7219	1.7766
10	**1.11mm/sec at 0.960sec**	7	55	192	211	13.85640	15.23	2.7232	0.1043
11	**1.44mm/s at 0.739sec**	13	30	235	226	15.32971	14.74	2.6905	0.3646
12	**2.59mm/s at 0.552 sec**	8	27	156	176	12.48999	14.09	2.6454	0.9516
13	**2.11mm/s at 0.581 sec**	9	23	159	178	12.60952	14.12	2.6475	0.7466
14	**3.24mm/s at 0.535 sec**	7	40	223	229	14.93318	16.11	2.7794	1.17557
15	**1.10mm/s at 0.319 sec**	9	42	202	203	14.21267	14.28	2.6588	0.0953
16	**1.24mm/s at 0.339 sec**	8	58	250	213	15.81138	13.47	2.6004	0.2151
17	**4.45mm/s at 0.339 sec**	12	37	268	189	16.37071	11.54	2.4458	1.4929
18	**1.6mm/s at 1.002 sec**	12	40	265	175	16.27882	10.75	2.3749	0.4700
19	**1.06 mm/s at 0.551 sec**	11	42	243	219	15.58845	14.04	2.6419	0.05826
20	**2.13 mm/s at 0.757 sec**	13	121	191	205	13.82027	14.83	2.6966	0.7561
21	**3.43 mm/s at 0.240 sec**	7	38	233	199	15.26433	13.04	2.568	1.2325
22	**1.71 mm/s at 0.420 sec**	11	50	187	212	13.67479	15.50	2.7408	0.5364
23	**4.18 mm/s at 0.850 sec**	8	140	247	187	15.71623	11.90	2.4765	1.4303
24	**3.71 mm/s at 0.320 sec**	5	69	158	206	12.56981	16.39	2.7966	1.3110
25	**3.10 mm/s at 0.631 sec**	13	131	249	203	15.77973	12.86	2.5541	1.1314

In the present study analysis of the blast vibration data recorded for various blasts has been done in order to find out the most suitable mathematical model that represent the given mine condition, so that to predict the impact of future blasting operations on the nearby structures. The fundamental equation used in the present study is produced below: -

$$\mathbf{Vm = k\,[D/\sqrt{Qmax}]^{\alpha}}$$

Figure No. 19 mine bench face after blasting operation

So this X-Y relation for the straight line is solved via Regression Analysis method and the values of the slope and constant (intercept on the Y axis) is find out and which eventually will give us the values of the site constants.

Where,

1. Vm = Peak Particle Velocity
2. k, α = Site constants
3. D = Distance from the monitoring site to the blasting site

4. Qmax = Charge per delay in kg.
5. $(D/\sqrt{Qmax})$ = Scaled distance

For the fundamental equation taking log both side, we get:-

$$\text{Ln} (Vm) = \text{Ln}\ k+\alpha*\text{Ln} (D/\sqrt{Qmax})$$

Now comparing the equation with the fundamental equation of a straight line, we get

$$\mathbf{Y = m*X + c}$$

Where,

1. $Y =$ $\text{Ln} (Vm)$
2. $X =$ $\text{Ln} (D/\sqrt{Qmax})$
3. $c =$ $\text{Ln}\ k$
4. $m =$ α

Thus the equation for the measured blasting data’s obtained via regression analysis is found out to be:-

$$\mathbf{Y = 5.4399 - 1.7931X}$$

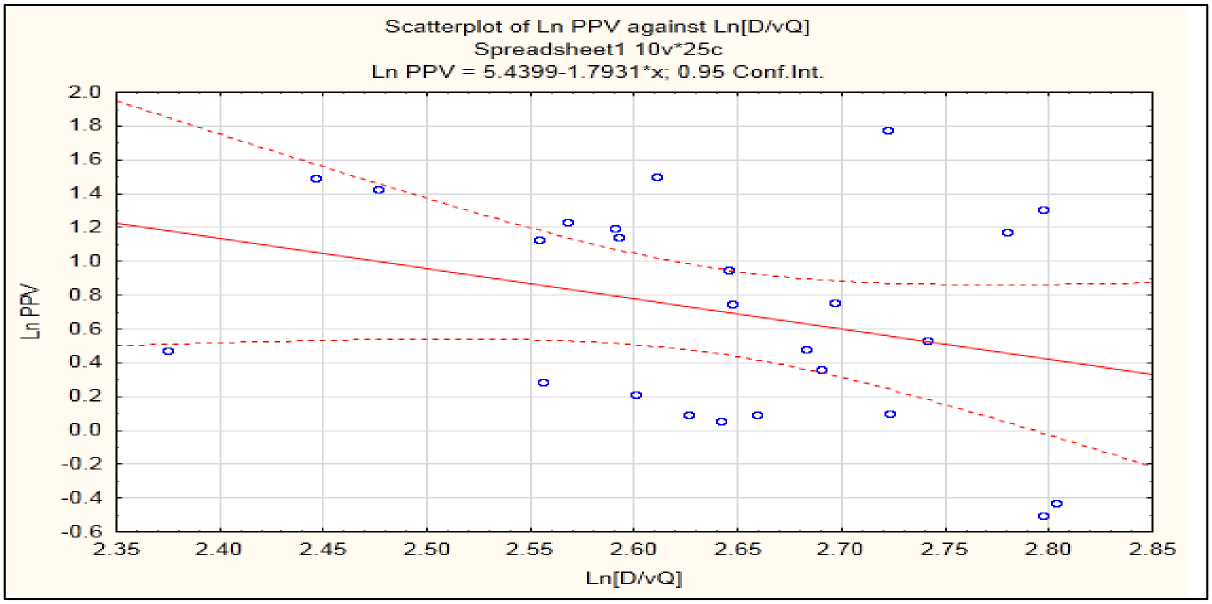
Now comparing the equation with the general predictor equation then,

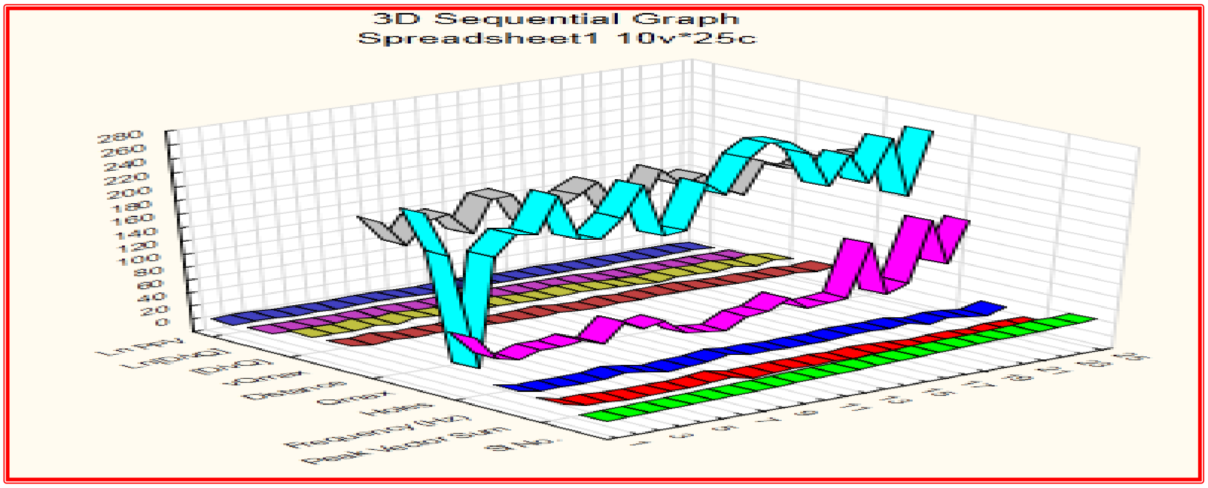
Ln k = 5.4399 ; k = Antilog (5.4399)

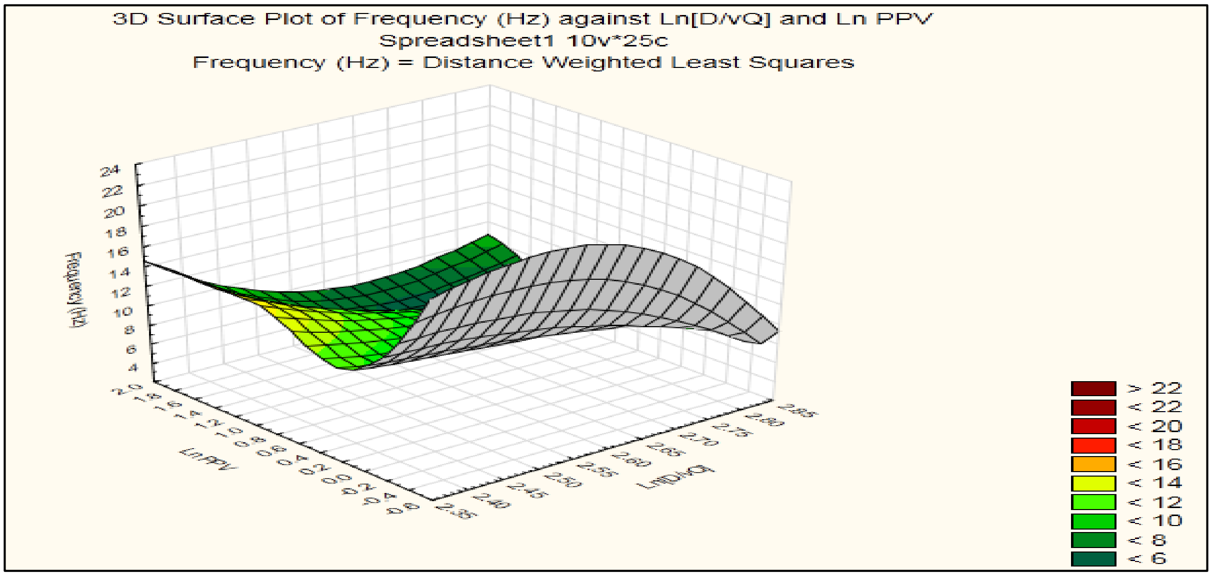
$$\mathbf{k = 230.419140 \ ; \ m = (- 1.7931)}$$

So the predictor equation becomes:-

$$\mathbf{Vm = 230.4191[D/\sqrt{Qmax}]^{-1.7931}}$$


Scatterplot of Ln PPV against Ln[D/vQ]
Spreadsheet1 10v*25c
Ln PPV = 5.4399-1.7931*x; 0.95 Conf.Int.
Ln PPV
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
2.35
2.40
2.45
2.50
2.55
2.60
2.65
2.70
2.75
2.80
2.85
Ln[D/vQ]


3D Sequential Graph
Spreadsheet1 10v*25c
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Ln PPV
Ln[D/vQ]
[D/vQ]
vQmax
Distance
Qmax
Holes
Frequency (Hz)
Peak Vector Sum
Sl No.


3D Surface Plot of Frequency (Hz) against Ln[D/vQ] and Ln PPV
Spreadsheet1 10v*25c
Frequency (Hz) = Distance Weighted Least Squares
Frequency (Hz)
24
22
20
18
16
14
12
10
8
6
4
Ln PPV
Ln[D/vQ]
2.35
2.40
2.45
2.50
2.55
2.60
2.65
2.70
2.75
2.80
2.85
> 22
< 22
< 20
< 18
< 16
< 14
< 12
< 10
< 8
< 6

7.2 BLAST VIBRATION STUDY AT OPEN CAST COAL MINE – A CASE STUDY

7.2.1 Geology of coal area

Singrauli coalfield which is covering an area of 2202 Sq Km and is mainly located in the Singrauli district of Madhya Pradesh except for 80 Sq Km which falls in the Sonebhadra district of Uttar Pradesh. The Kachni River divides the coalfield into two parts viz. the major western and southern part. The north-eastern part covers an area of 312 Sq Km and contains thick quarriable coal seams making it the highest potential area of the coalfield and at present the entire coal production of Singrauli Coalfield of around 58 Mt. is being mined out from this area.

7.2.2 Regional Geology

About 96% of the Singrauli coalfield occurs in the state of Madhya Pradesh, in the Sidhi/Singrauli districts. The remainder (4%) of the coal field comes under Sonebhadra District, Uttar Pradesh. The coalfield is aligned in East-West direction and is elongated in shape. The length is around 102 Km and maximum width is about 45 Km in the central part of the coalfield.

A total of 6 series of formation have been recognized on broad lithic characteristics within the Gondowna rocks of Singrauli Coalfield (after GSI). In ascending order they are Talchirs, Barakar, Barren Measure, Raniganj, Panchet and Mahadeva. The coalfield is broadly divided in two parts, the eastern most part of the coalfield and the western part. The beds have an almost north-south strike in the east as well as in the west which gradually swings to east–west strike in the southern part revealing a half basin whose northern part is cut by a prominent E-W trending boundary fault. The Talchirs occupy the lower plains and the Barakars stand out as high plateau with steep escarpment. The Barren Measures and Raniganj Formations occur as crescent shaped outcrops around Jhingurdah Project in the north. The Precambrian basement on which the Gondowna sediments rest with a profound unconformity, comprises Gneisses and Schists in the south, while Phyllites and Quartzites are also observed on the north. The oldest sediments of Gondowna group are the Talchirs, which unconformably lies over the basement and a large part of it is submerged under Rihand Reservoir. The Barakar sediments cover a large tract in the eastern part of the coalfield and define prominent landmarks because of the hard and compact nature of the strata. The Barakar sequence mainly consists of medium to coarse grained sandstones with a number of coal horizons and thin bands of shale and clay. Fine grained sandstones are also observed but their proportion is much less than coarse grained sandstone. The generalized stratigraphic sequence of Sigrauli Coalfield is as follows in below table:

Table No-11: Generalized stratigraphic sequence of Sigrauli Coalfield

Age	Group	Formation	Lithology	Thickness(m)
Cretaceous		Intrusive	Dolerite dykes and sills.	**Not Estimated.**
Upper Triassic	Upper Gondwana	Mahadeva	Coarse grained, ferruginous sandstone with bands of shale, clay and conglomerate.	**Not Estimated.**
Lower Triassic	Lower Gondwana	Panchet	White, greenish white and pink micaceous, medium to coarse grained sandstone with red beds, greenish brown silty shales and conglomerates.	**Not Estimated.**
Upper Permian		Raniganj	Fine grained sandstone and shales with coal seams.	**215-403**
Middle Permian		Barren Measures	Very coarse grained to ferruginous sandstones, green clay and shales	**125-300**
Lower Permian		Barakars	Medium to coarse grained sandstone, shales, clays and coal seams	**325-600**
Upper Carboniferous		Talchir	Tillite, Sandstones, Siltstones, needle shales.	**75-130**
Unconformity				
Precambrians			**Phyllites, Quartzites, Schists and Gneisses**	

7.2.3 Geological Structure

In the present mining block consisting of two blocks Block I and Block II, the southern part which mainly comes in Block II is structurally distributed whereas the northern part of the Block I is free from geological disturbances. There are altogether 11 faults in the southern part of which six have continued from adjoining Block III. The beds have an almost E-W strike in the eastern part which swings NW-SE in the southern part and gradually becomes almost N-S in the northern part. The synclinal axis passes roughly in NE-SW direction. The dips are northerly, north-easterly and easterly in relation to swings in strike. The undisturbed northern property has gentle dips of about 2° to 3°. In the southern part the gradient in general is steeper than northern part. In the remaining part of the southern property the gradient generally varies from 3° to 5°

7.2.4 Observation and calculation:-

Table No-12: observation of blasting data in coal mine

BLAST NO.	1	2	3	4	5	6	7	8	9
Parameters									
Location of blast	490	385	COAL	O/S	385	370	370	450	385
Spacing (mts)	10	11	7	5.5	11	9	9	10	10
Burden (mtrs)	9	9	6	4.5	9	8	8.5	9	9
Average Depth (mtrs)	16	23	10	6	23	15	16	23	16
Average Depth (mtrs) Excluding subgrade	14.40	20.70	9.00	5.40	20.70	13.50	14.40	20.70	14.40
Total no. of holes (nos.)	184	32	100	136	56	124	32	67	113
Dia. of hole (mm)	259	259	259	159	259	259	159	259	259
Name of SME	Shakti-Bulk101	Shakti-Bulk101	Shakti-Bulk101	Shakti-Bulk101	Shakti-Bulk101	Shakti-Bulk101	Shakti-Bulk101	Shakti-Bulk102	Shakti-Bulk101
Total quantity of SME (kgs)	111,590	30,240	11,990	8,100	53,200	55,640	15,570	55,590	68,310
Total cast booster (kgs)	172.5	56.3	25.0	34.0	84.3	93.0	24.0	84.5	125.0
Total quantityof Explosive (kgs)	111,763	30,296	12,015	8,134	53,284	55,733	15,594	55,675	68,435
Decks/hole	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total quantity of D/F (mtrs)	9100	2500	3200	2500	2750	5200	1700	3300	5350
Total quantityof E.D. (nos.)	1	1	1	1	1	1	1	1	1
Total quantity of C/R (nos.)	43	38	20	40	24	126	46	48	100
Charge/ hole (kgs)	606.47	945.00	119.90	59.56	950.00	448.71	486.56	829.70	604.51

Length of explosive Charge Column(mtrs)		37.80	4.80	2.38	38.00	17.95	19.46	33.19	24.18
Length of Stemming Column(mtrs)	16.00	-14.80	5.20	3.62	-15.00	-2.95	-3.46	-10.19	-8.18
Total Volume Blasted(Cum)	238,464	65,578	37,800	18,176	114,761	120,528	35,251	124,821	146,448
P.F.(cum/kg)	2.13	2.16	3.15	2.23	2.15	2.16	2.26	2.24	2.14

Figure No.20 after blasting size of coal

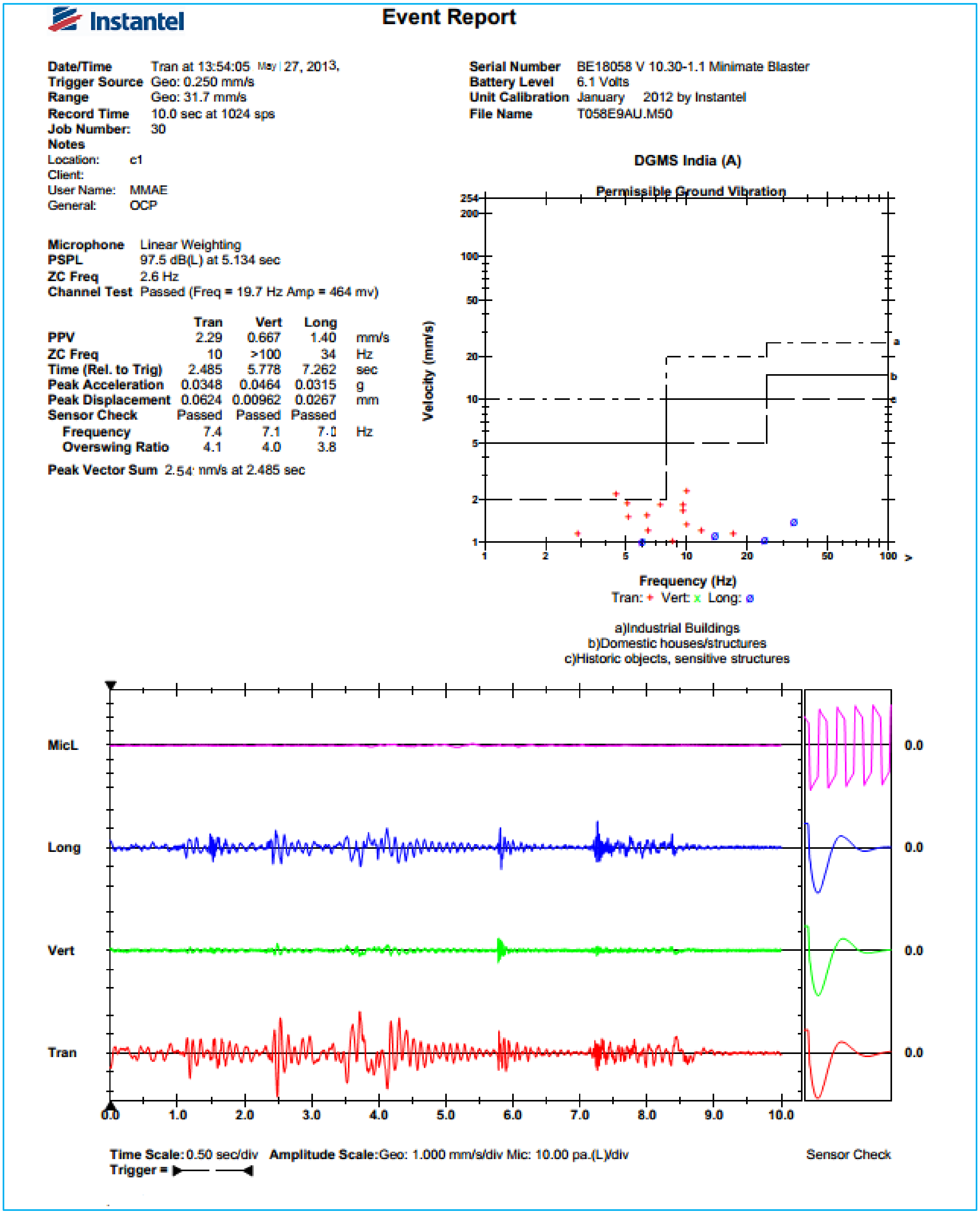
Table No-13: Observation of blast vibration for coal

Distance	**Charge/Delay(Q)**	**Velocity(PPV)**	**LN(v)**	**LN (d)**	**LN(q)**
331	944	1.778	0.575489	5.802118	6.850126
367	501	1.143	0.133656	5.905362	6.216606
367	915	1.524	0.421338	5.905362	6.818924
420	863	1.143	0.133656	6.040255	6.760415
450	616	1.59	0.463734	6.109248	6.423247
450	885	1.778	0.575489	6.109248	6.785588
500	1139	5.67	1.735189	6.214608	7.037906
560	950	1.33	0.285179	6.327937	6.856462
600	434	0.254	-1.37042	6.39693	6.073137
600	625	0.587	-0.53273	6.39693	6.437752
600	625	0.651	-0.42925	6.39693	6.437752
600	715	0.873	-0.13582	6.39693	6.572283
600	860	2.32	0.841567	6.39693	6.756932
600	1085	3.11	1.134623	6.39693	6.989335
600	1121	3.24	1.175573	6.39693	7.021976
650	1305	1.03	0.029559	6.476972	7.173958
700	220	0.317	-1.14885	6.55108	5.393628
700	575	0.476	-0.74234	6.55108	6.35437
700	600	0.952	-0.04919	6.55108	6.39693
700	625	1.43	0.357674	6.55108	6.437752

Multiple regression analysis has been develop to find the best fit prediction for the equation. **Value of X axis** correspond to observe /actual value. (Use of Statistica software trial version)

Value of Y-axis correspond to predicted charge per delay according to equation with highest regression coefficient.

So perform the multiple regression analysis, find the site constant and correlation coefficient from different predictor equation mention below table 14 & 16.



Event Report

Date/Time Tran at 13:54:05 May 27, 2013,
Trigger Source Geo: 0.250 mm/s
Range Geo: 31.7 mm/s
Record Time 10.0 sec at 1024 sps
Job Number: 30
Notes
Location: c1
Client:
User Name: MMAE
General: OCP

Microphone Linear Weighting
PSPL 97.5 dB(L) at 5.134 sec
ZC Freq 2.6 Hz
Channel Test Passed (Freq = 19.7 Hz Amp = 464 mv)

	Tran	**Vert**	**Long**	
PPV	2.29	0.667	1.40	mm/s
ZC Freq	10	>100	34	Hz
Time (Rel. to Trig)	2.485	5.778	7.262	sec
Peak Acceleration	0.0348	0.0464	0.0315	g
Peak Displacement	0.0624	0.00962	0.0267	mm
Sensor Check	Passed	Passed	Passed	
Frequency	7.4	7.1	7.0	Hz
Overswing Ratio	4.1	4.0	3.8	

Peak Vector Sum 2.54 mm/s at 2.485 sec

Serial Number BE18058 V 10.30-1.1 Minimate Blaster
Battery Level 6.1 Volts
Unit Calibration January 2012 by Instantel
File Name T058E9AU.M50

DGMS India (A)

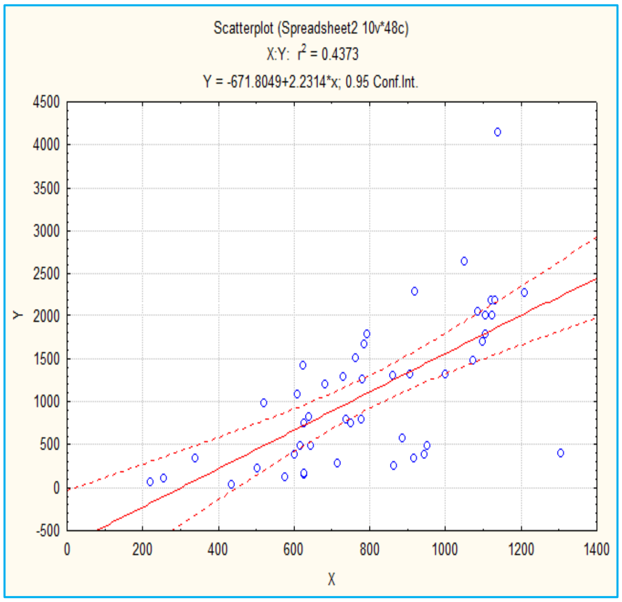
Time Scale: 0.50 sec/div **Amplitude Scale:** Geo: 1.000 mm/s/div Mic: 10.00 pa.(L)/div
Trigger = ▶— —◀

Figure No: 21; a typical blast vibration data related to the blast

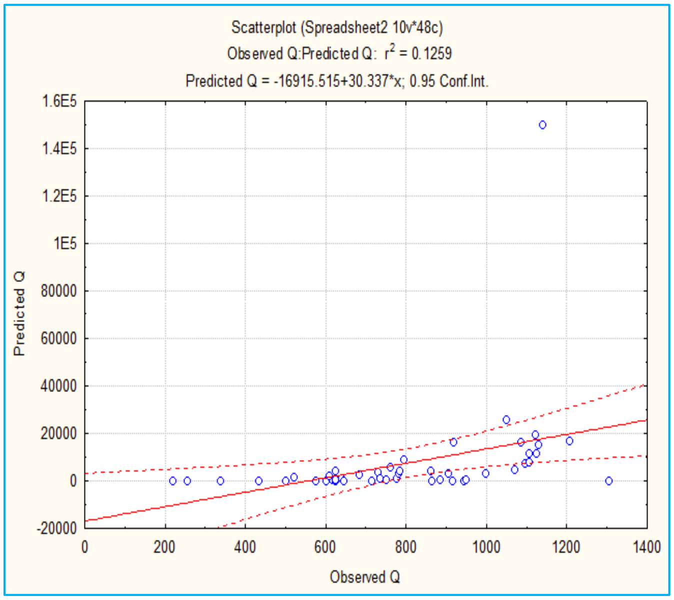
Table No-14: Site constants and correlation coefficient from different predictor equations (coal)

Equations	k	B	A	n	R(correlation coefficient)
Langefors and Kihlstrom Predictor(1963)	5.51	1.273	-	-	0.67
Ambraseys- Hendron predictor (1968)	24.26	-0.6485	-	-	0.35
Indian Standard Predictor (1973)	0.152	0.994	-	-	0.69
General Predictor(1964)	0.779	0.058	0.779	-	0.63
CMRI Predictor (1993)	20.65	-	-	0.85	0.58

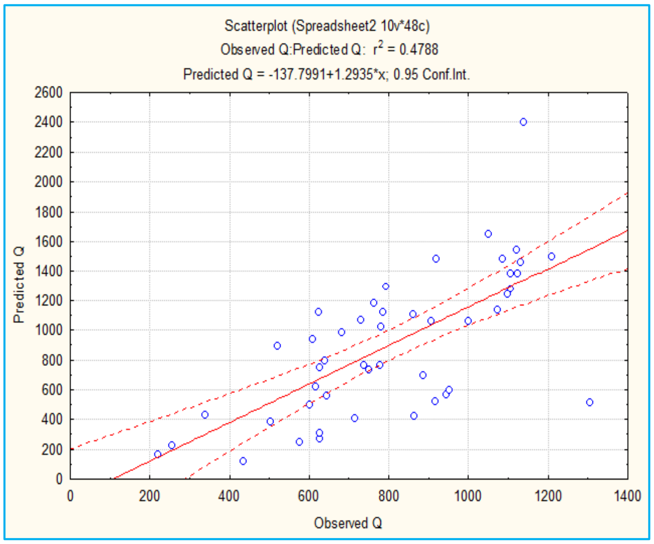
Langefors and Kihlstrom Predictor (1963)



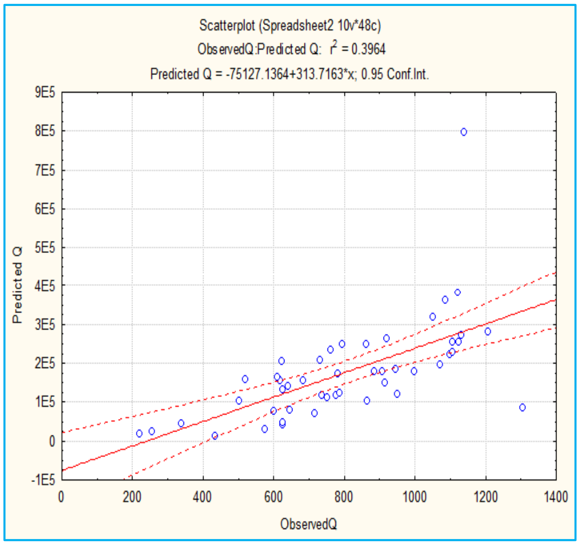
Ambraseys- Hendron predictor (1968)



Indian Standard Predictor (1973)



General Predictor (1964)



CMRI Predictor (1993)

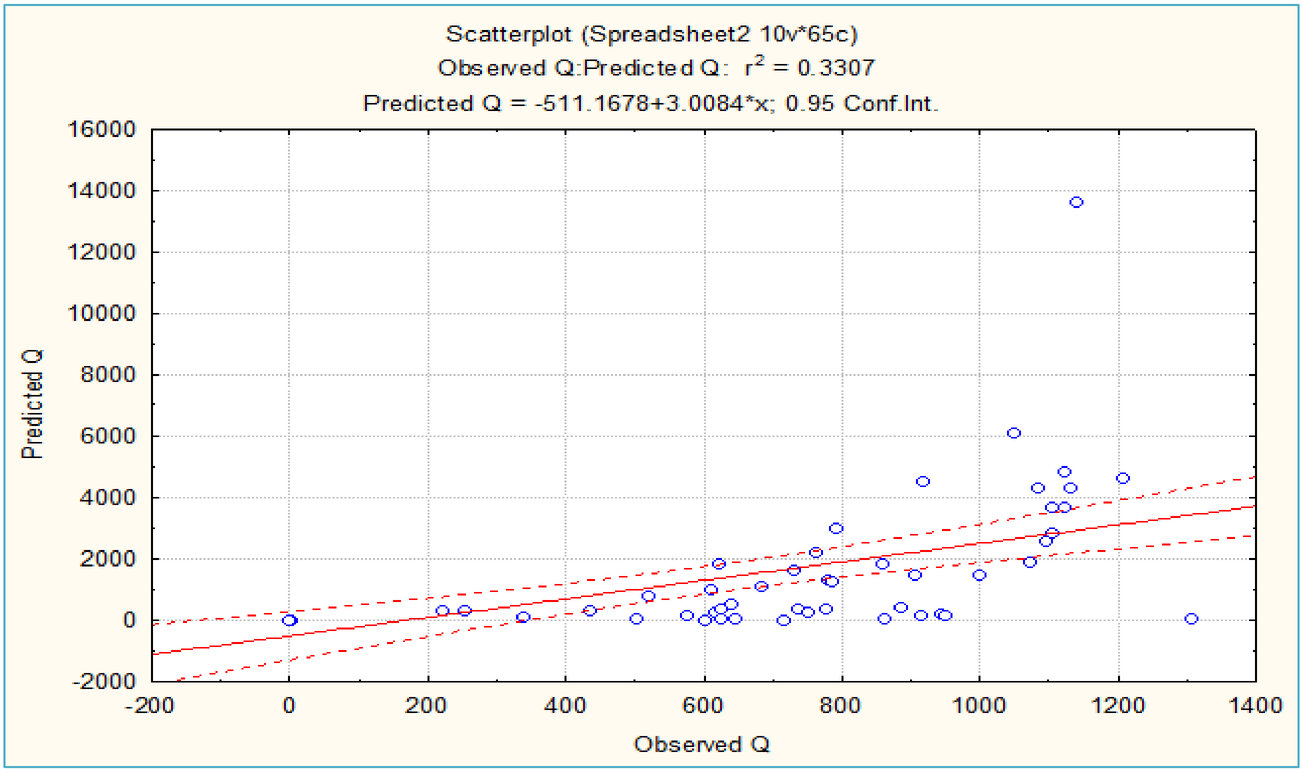


Table No-15: Observation of Blast vibration for overburden

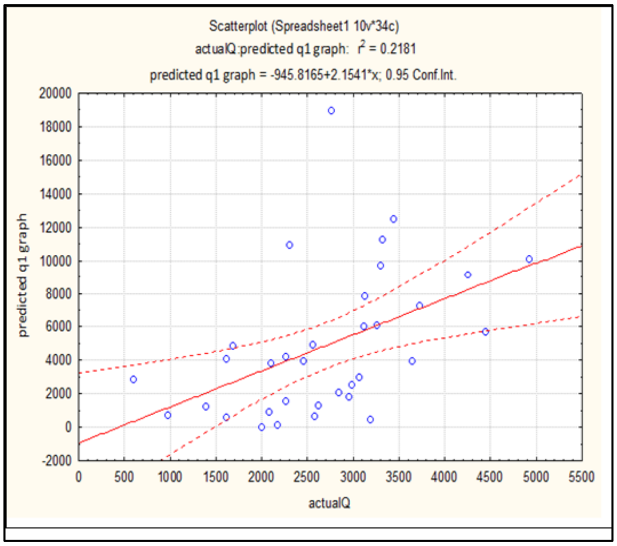
Distance(D)	Charge/Delay(Q)	Velocity(PPV)	lnV	lnQ	lnD
500	2620	2.13	0.756122	7.87093	6.214608
500	3066	2.71	0.996949	8.028129	6.214608
500	4253	3.73	1.316408	8.355453	6.214608
500	4923	3.84	1.345472	8.501673	6.214608
560	1615	1.62	0.482426	7.38709	6.327937
600	975	1.71	0.536493	6.882437	6.39693
600	2840	2.29	0.828552	7.951559	6.39693
600	3644	2.75	1.011601	8.200837	6.39693
600	4445	3.05	1.115142	8.399535	6.39693
650	1391	1.9	0.641854	7.237778	6.476972
700	2004	0.254	-1.37042	7.6029	6.55108
700	2080	1.7	0.530628	7.640123	6.55108
700	2100	2.57	0.943906	7.649693	6.55108
700	2260	2.64	0.970779	7.72312	6.55108
700	3120	2.92	1.071584	8.045588	6.55108
700	3720	3.08	1.12493	8.221479	6.55108
750	1613	2.54	0.932164	7.385851	6.620073
750	1680	2.67	0.982078	7.426549	6.620073
750	3259	2.85	1.047319	8.089176	6.620073
800	2170	0.937	-0.06507	7.682482	6.684612
800	2580	1.46	0.378436	7.855545	6.684612
800	2954	1.97	0.678034	7.990915	6.684612
800	2980	2.16	0.770108	7.999679	6.684612
850	2459	2.41	0.879627	7.80751	6.745236
850	3320	3.24	1.175573	8.10772	6.745236
875	600	2.17	0.774727	6.39693	6.774224
875	2305	3.18	1.156881	7.742836	6.774224
900	3125	2.86	1.050822	8.04719	6.802395
980	2765	3.56	1.269761	7.924796	6.887553
1000	2268	1.73	0.548121	7.726654	6.907755
1000	2555	2.41	0.879627	7.845808	6.907755
1000	3300	2.92	1.071584	8.101678	6.907755
1210	3445	2.92	1.071584	8.144534	7.098376
1265	3185	1.14	0.131028	8.066208	7.142827

Figure No-22: After blasting size of overburden

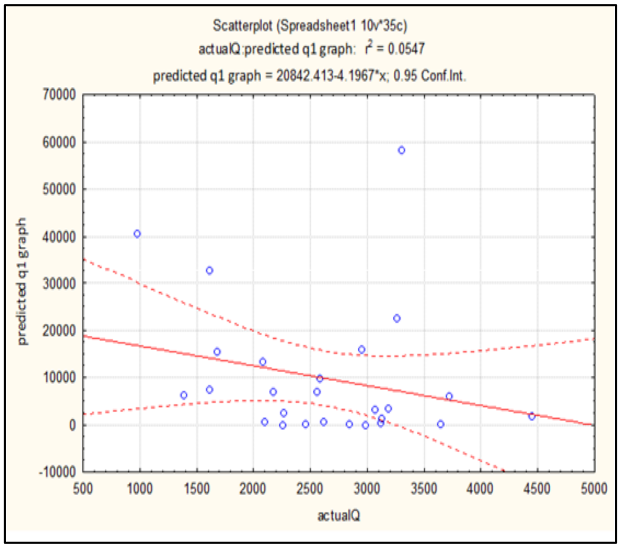
Table No-16: Site constants and correlation coefficient from different predictor equations (o/b)

Equations	k	B	A	n	R(correlation coefficient)
Langefors and Kihlstrom Predictor(1963)	2.635	0.349	-	-	0.47
Ambraseys- Hendron predictor (1968)	11.66	-0.4148	-	-	0.23
Indian Standard Predictor (1973)	0.632	0.367	-	-	0.36
General Predictor(1964)	1.217	0.08	0.178	-	0.64
CMRI Predictor (1993)	20.65	-	-	0.85	0.37

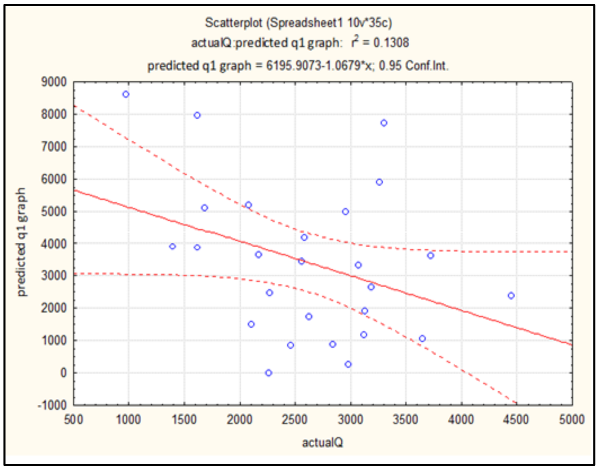
Langefors and Kihlstrom Predictor(1963)



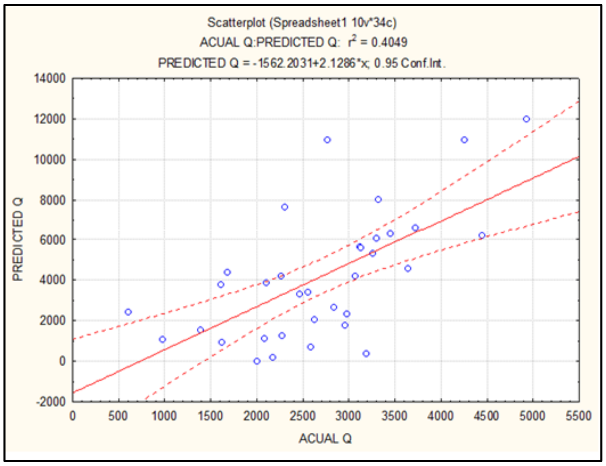
Ambraseys- Hendron predictor (1968)



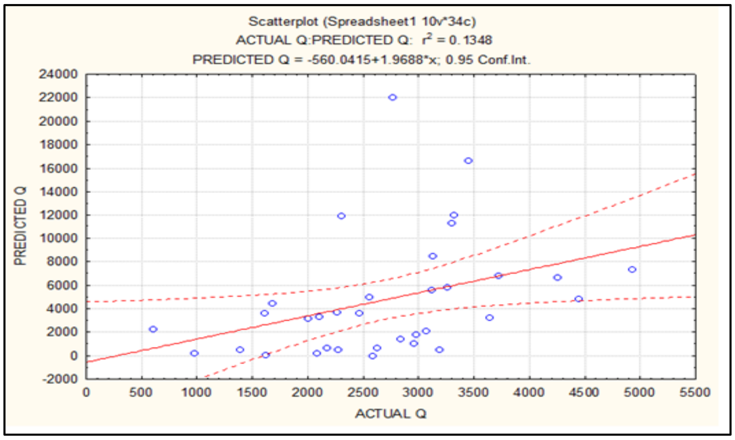
Indian Standard Predictor (1973)



General Predictor (1964)



CMRI Predictor (1993)



CHAPTER 08

CONCLUSION

CHAPTER 08: CONCLUSION

8.1 Conclusion:

Analysis of the blast vibration data of the Peak Particle Velocities (PPVs) for various blasts was recorded. It was found that for the different blast PPV varies and it is related to that of the charge per delay. In most of the blasting operation PPV is found to be within the limits. It is possible because of the use of different amounts of charge per delay for each blast. In this project, vibrations generating from the blasting practices and how it will affect the nearby structure is studied. According to the DGMS circulars the safe PPV for industrial buildings under the frequency range of 8 to 25 Hz is 20mm/sec. In the present study the measured PPV and frequency matches this configurations, in which industrial building such as Plant and crusher will have no adverse impacts. A safe charge per delay is determined in accordance with the regulations issued by the regulatory authority DGMS (Director General of Mine Safety), Government of India.

So determination of specific amounts of charge per delay should be done for a blast hole to keep PPV within the limits as stated by the DGMS when an explosive is detonated.

The vibration levels were found to be less than 5 mm/sec which is within the limits, when following equations were used for finding safe charge during blasting.

The Equation is –

Case study 1: For Iron ore mine:

$$\mathbf{PPV = 230.4191[D/\sqrt{Q_{max}}]^{-1.7931}}$$

Case study 02: For coal mine:

The mine overburden comprises of sandstone, lime, etc. and below it lies coal. So two equation are predicted separately. Now equation with highest correlation coefficient from the table 13 & 15, for coal & overburden can be stated as:

For coal:

$$\mathbf{PPV = 0.152[Q/D^{(2/3)}]^{0.994} \quad with\ r^2 = 0.69}$$

For overburden:

$$\mathbf{PPV = 1.217*D^{0.08} *Q^{0.178} \quad with\ r^2 = 0.64}$$

However, we can conclude that when specific amount of charge per delay is decided so as to keep the PPV within the limits as stated by the DGMS during the blasting, with this we have other advantages like maximum safety with optimum fragmentation and higher blasting Efficiency causing lower ground vibration.

8.2 REFERNCES

1. ISRM. 1992, Suggested method for blast vibration monitoring. Int J Rock Mech Min Sci Geomech Abstr; 29(2):145–6.
2. http://www.vulcanhammer.net/svinkin/prediction.php
3. http://terrock.com.au/vibration/blasting.html
4. Khandelwal Manoj, Singh T N, 2007, PhD thesis, Evaluation and prediction of blast induced ground vibration and frequency for surface mine- a neural network approach, pp- 1-30
5. Langefors U, Kihlstrom B, Westerberg H., 1958, Ground vibrations in blasting. Water Power, 400p
6. Singh B, PalRoy P., 1993, Generation, propagation & prediction of ground vibration from opencast blasting, Blasting in ground excavation & mines, pp- 21-35.
7. Singh P K, 2006, Standardisation of blast vibration damage threshold for the safety of residential structures in mining areas.
8. Pal B.K and Brahma K.C. Department Of Mining Engineering , National Institute Of Techonology , Rourkela ,odisha-769008 , An Application of Regression Model for Evaluation of Blast Vibration in an Opencast Coal Mine – a Case Analysis , Canadian Journal on Computing in Mathematics, Natural Sciences, Engineering & Medicine Vol. 1, No. 3, April 2010.
9. Jayanthu S. and Naveen Ch. , Rao G V, B R V Kumar Susheel Kumar , ground vibrations in opencast mine blast onstructures vis-à-vis a local environmental effect and its mitigation through mining technology.
10. Minimate Blaster Instantel ISO 9001 user manual.

11. Statistica and Minitab software trial version.

12. Misra G.B, (1979) Surface Mining, Dhanbad Publishers, Dhanbad, Explosives, pp.337-392, Blasting, pp.393-448

13. Deshmukh D.J., (2011)Element of Mining Technology , Vol.-1 , Denett & co. Nagpur , Explosives, Accessories And Blasting Practices ,pp.8.1-8.69

14. Kalu L.C., (1994) D.G.M.S. Circulars, Lovely Prakashan, Dhanbad, Explosives and Shot firing, pp.397-444.