



A STUDY ON DESTRUCTIVE WAVE INTERFACE IN OPEN CAST BLASTING UTILIZING PRECISE TIMING

Soumen Chatterjee (Chattopadhyay)

Mining Engineer

M. Sc(Physics), M. Tech

Mine Manager Certificate of Competency (DGMS)

Govt.. of India.

Synopsis for Doctoral topic (submitted on

April 13,2015, IIT-ISM DHANBAD)

Madhutati, Raghunatpur, Purulia,-pin 723133

WB (India), ECL(Coal India LTD)

1.Introduction

Mining is perhaps the only industrial activity which deals with a substantially higher percentage of waste than the desired product. In a surface coal mine having 1 in 7 stripping ratio for every tonne of coal more than 15 tonne is of waste are needed to be handle. This demands a greater density of blasting which generate ground vibration. To control ground vibration various techniques of control blasting has been introduced like,

Line drilling

Cushion blasting

Smooth blasting

Pre-splitting

Delay blasting etc.

But all these technologies have certain limitations to minimize the desired ground vibration. The application of destructive wave interface by incorporating suitable delay in between consecutive blast hole can minimize the ground vibration upto the required limit in complex geomining condition. This technology of wave interference considerably minimize the reduction in ground vibration at the plane of destructive wave interface. Under this study the technology of destructive wave interference has been discussed.

The controllable parameters like

Burden

Spacing

Stemming

Hole inclination and drilling

Sub drilling

Delay interval between consecutive rows

Primer placement in the blast hole

Are broad guidelines has been introduced to reduce ground vibration.

Maximum charge per delay in a blasting round is universally accepted as the influencing parameter to quantify magnitude of vibration for any distance of concern observation has shown that for same charge per delay seismic excitation varies with total charge.

The influence of explosive weight, blast design parameters and rock geology are involves to characteristics of vibration parameters. The interference of verious seismic waves generated from a particular hole or and from different holes of a blasting round result into variation in intensity of the vibrational magnitude.

In the mechanism of rock breakage explosive gas energy released by the detonating gas accounted for about 40–50% of the energy released by the explosive. So the effect of high-energy gas produced by blasting cannot be ignored which developed differential cracks for rock fragmentation.

Explosion cracks develop along transverse cracks. In longitudinal prefabricated joints, stress waves reflect on the joint surface and create lamination cracks. Cracks always develop perpendicular to the joint surface. It may be considered that the influence of heterogeneous rock mass and joints on the blasting process, the mode of propagation of stress waves developed fractures in the composite layers of the rocks.

1.The theory of shock wave tensile failure, 2.the theory of explosion pressure failure of explosive gas, 3the theory of combined action of shock wave and explosive gas— all these three factors are involved in rock breakage mechanism. The shock wave first acts on the rock mass, causing initial fractures around the borehole—then the detonating gas rapidly wedges into the initial crack, further promoting explosion-induced crack growth. The energy released in explosion the detonating gas accounted for about 40% –50% of the energy released by the explosive. So, high energy gas produced by blasting can not be ignored in the process of cracks development.

2.Abstract

In general, whenever two waves superimposed we obtain intensity distribution which is known as interference pattern. The interference pattern produced by waves emanating from two point sources — like sound wave two interfering waves maintain a constant phase relationship.

When waves emanate from a point source in an isotropic medium all the points on the surface of sphere (whose centre is the point of source) have the same amplitude and have the same phase in a sphere. Such spherical waves front, far away from the source, are essentially a plane wave in respect to small area. Two types of waves are produced during seismic excitation for blasting vibration— body wave and surface wave. Body wave travels through earth materials and surface wave travels along the interface in between surface and earth materials. The most important surface wave is the Rayleigh wave. Body wave can be farther subdivided into compressive (compression — tension) — sound like wave and distortional or shear wave. Blast induce explosion produces predominantly body wave at small distances. These body waves propagate outward in a spherical manner until they intersect a boundary of another rock layer, soil or the ground surface. At this plane of intersection, shear waves and surface waves are produced. Rayleigh surface waves become important at larger transmission distances, typical blast vibrations, no matter the wave type, can be approximated as sinusoidally varying either with time or with distance along the radial or longitudinal line. Propagation velocity is the speed with which wave passes by the particle and the speed at which the particle move up and down while wave passes is the particle velocity. Blast induce vibration wave can also be described by their wave length, velocity of propagation and frequency in the same fashion as the water wave.

When an explosive charge inside a hole is detonated, the strain/stress wave is generated from the detonation front compressed the surrounding rock mass of the hole. If the strain wave well exceeds the compressive strength of the rock mass, an intense crushing is produced near the bore hole wall. Beyond the crashed zone, radial cracks are formed if the tangential strains exceeds the dynamic tensile strength of the rock. When the strain wave reaches a free surface, it is reflected back as two components— tensile wave and shear wave. This may produced spalling from the free face if the tensile wave is strong enough to exceed the dynamic tensile strength. After the strain wave passes, the gas pressure generated from chemical reaction of the explosive charge expands and penetrates those fractures, farther fragmenting the rock mass and finally dislodging the burden. Beyond the radial crack zone, the rock mass behaves as an elastic medium and no farther deformation is ocured. These strain/ stress waves are termed as elastic waves or seismic waves. The seismic waves travel at different velocities called wave transmission velocity or seismic wave velocity.

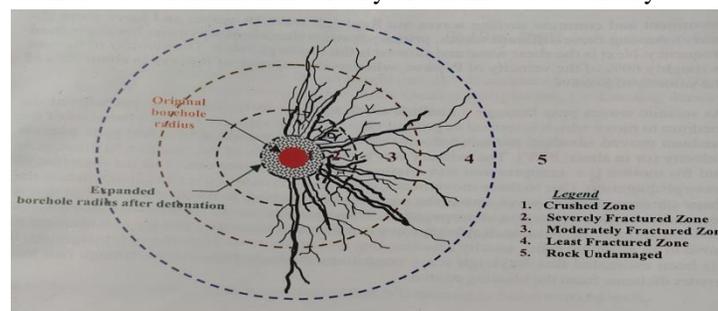


Fig.2.a:

The family of seismic waves generated from blasting source is grouped broadly into two— body wave and surface wave. The body wave consists of compressional P-wave S- shear wave. These body waves travel through the body of the materials/ medium as well as on the surface. The waves in another group are called surface waves, which travel only along the surface of a medium or material. The most prominent and common surface waves are Rayleigh wave(R-wave) and Love wave (L-wave). Among these different waves, primary wave is the fastest wave and has the highest frequency. Next is the shear wave and slowest is the Rayleigh wave. The velocity of the S-wave is roughly 60% of the velocity of P-wave whereas the velocity of R-wave is about 90% of the velocity.

3.Problem Definition

In open cast mines huge quantity of explosive is used in blasting for fragmentation of the rock mass and displacing the rock the rest energy is wasted in form of ground vibration, air blast and fly rock. Whenever blast vibration occurs it vibrates the ground with certain velocity and imparts to it certain amount of acceleration when ground vibrates in lower part of the structure and move with ground but the upper part lag behind. This results deformation in rock mass.

Ground vibration and air blast both are matter of great concern as it is causes damaged to the existing surface structure and nuisance to the resident in the closer vicinity. Ground vibration is wave motion spreading outward from the blast hole to the surrounding areas and the accurate estimation of the safety area boundary is one of the most important parameter in blasting design, specially when blasting is done adjacent to residential area. Ground vibration is affected by number of geominig parameters such as blast design, mechanical properties of the rock mass, explosive characteristics, distance from the blast face and geological disturbances. It is necessary to optimize blasting parameters to reduce ground vibration. Ground vibration is composed of two components PPV and frequency. PPV has been employed as a vibration index. It has been proven that PPV is an important indicator to determine the structural damage criteria. Solution to this problems called for and in depth study of basic parameters involves in the process of blasting to controlled. The basic features of generation and propagation of vibration is concerned with safe charge per delay and is obviously it has an important role both economic and safety point of view to control blast induce ground vibration. Simultaneously introduction of safe charge per delay and optimum blast design considerably take a part in destructive wave interference in the plane of wave interference. With utilizing precise timing we can control both ground vibration and air blast. Without changing the hole loading the PPV can be made nearly halved the reason for lower PPV values in destructive wave interference. Every predictor equation has limitations and utilities. It has already been observed that one can not predict the vibration by predictor equation to calculate the safe charge per delay. Deep -hole blasting generates ground vibrations which propagates through the ground in the state of seismic waves. These waves are of different types and propagate with different velocities in different geological environment. Each of the waves affect rock mass by characteristics particle motion pattern. The fastest P-wave characterized by radial particle motion dilates and compresses the ground materials. S-wave is characterized by transverse particle motion which can be polarized in vertical or horizontal direction. This motion results in shearing. The L-wave is a form of shear wave S but is bounded to the surface as surface wave and the R-wave is a product of P-wave and S-wave. Elliptical particle orbit generally retrograde motion and is the characteristics for the R-wave. Since all the wave travel with different velocities and number of delays varieties of duration, it may happen that all the waves intersect with each other in same time and at same space. Since R-wave is dispersive and different studies has shown numerous deviation in the dispersion curves, it is evident that atleast two or R-wave fronts of different frequencies will intersect at a certain given distance from the point of shot. This will create maxima and minima in the attenuation curve which is a expression of vibration at various scale distances.

Propagation characteristics of blast waves vary according to the characteristic properties of rock strata and angle of incident of stress wave on joint plane. The amount of energy absorbed and transmitted depends on geological parameters. At the point of incidence, the angle of incident will be equal to the angle of reflection and **ratio** between the **angle of incident** and **refracted wave** will depend upon ratio of densities and P-wave velocities of two mediums. Transmission of blast induced stress wave being a function of **Poisson's ratio**, **friction angle** and **orientation of structural plane** with respect to incidence of stress wave, the magnitudes of transmitted and reflected wave can be determined with the help of **transmission coefficient** and the **reflection coefficient** of P-wave defined by the given equation below. The pressure reduction of transmitted wave during its transmission can be determined with the help of defined equations. The velocity of P-wave and S-wave are represented by **C_p** and **C_s** in rock medium can be determined.

$$C_p = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}}$$

$$C_s = \sqrt{\frac{E}{2\rho(1+\mu)}}$$

where, E = Young's modulus; ρ = Density; and μ = Poisson ratio of rock.

Evaluation of velocity propagation and intensity of stress generated due to detonation of explosive varies with energy contained in it during the time of explosion. Velocity and intensity of wave varies with rate of energy loss due to absorption in the medium. Energy loss being proportional to energy contained, loss of energy will be more at initial period at closer distance than the far off distances where actually hole blasted. Attenuation of vibration magnitude will be faster at closer distance than that observed at far off distances. At closer distance, interference of blast waves is influenced by enhanced charge length/concentration, ratio between total charge and charge per delay and delay timing between two initiations made in same or different holes of a blasting round. Interference of blast waves from different holes result into constructive or destructive interference. Constructive interference causes amplification in magnitude and sustains for longer duration. Destructive interference, on the other hand, results into low magnitude and sustains for lesser time duration. At far off distances, where intensity and strength of measured vibration is the resultant impact of interference of blast waves generated from different delays of a blasting round.

4. Research Objective

vibrational amplitude demands to regain its shape and dimension which is self adjusted according to the geomechanical and geomining condition after absorbing seismic excitation.

The vibration and friction occurring along the surface of the rock texture enables the restoration of the surrounding blast sides because of time dependent elastic range having a natural tendency to regain the shape. Also it supplies a significant amounts of damping to the mine due to different rock layers of different properties.

Energy input during explosion to the rock mass and there is a from permanent inelastic deformation. This frequency dependent parameter to be considered.

The speed of a wave is influenced by the characteristics of the rock mass medium through which it travels. This is because a wave is essentially a disturbance that propagate through a medium. More elastic medium allows the wave to travel faster because the particle of the medium can quickly return to their equilibrium position after being displaced by the wave and allowing the disturbance to move on to the next set of particles. Therefore velocity of propagation of waves depends on the rock properties and the properties of the blast design and the given delay element between two successive holes and it depends on the density and elasticity of rock mass. A denser medium tends to slow down the wave because there are more particles that the wave has to move through.

This means that seismic wave has to do more work to displace the particle, which slows down its speed. However it has been observed that the relationship between wave speed, elasticity and density is not always straight forward. Other factors such as temperature and pressure can also effect wave speed.

Understanding of these relationships is very important for predicting and controlling seismic behaviors due to blast induced vibration for both of rock and explosive characteristics with optimum blast design

Mechanical surface waves diminishing in amplitude as they get a farther paths of journey from the surface and propagate more slowly than seismic body waves (P and S).

Thus from above study we have seen that elastic waves are physically not different from seismic, sound or ultra sound waves, other than in their respective ranges of frequencies (as per example speed of light waves travel in more speed in space rather than water or any other denser medium).

According to elastic wave theory, P-wave velocity is a maximum, Rayleigh (R-wave) velocity is a minimum, and S-wave velocity is in between them. The theoretical upper limit of crack speed in an elastic, isotropic and homogeneous materials is set the Rayleigh (R-

wave) speed. Under normal conditions, cracks rarely run beyond 50% of the Rayleigh wave speed as they scattered. This is basically proved by the measurement of crack velocity in rocks or rock materials during blasting; that is, the maximum crack velocity measured is from 8% to 30% of the P-wave velocity in each corresponding materials.

The important objective is minimize the ground vibration by identification or incorporating a particular delay interval that causes destructive wave interface plane after blast induce seismic excitation and a development of an empirical equation for different geomining condition varies for different rock geology has to be established as a parameter of control blasting to construct destructive wave interface at the required zone.

5. Literature Review

As the pore pressure increases due to seismic excitation, site stiffness is found to gradually decreased. During the high pore pressure site behaviour is characterized by cycle of large shear strain and very small shear stress.

Elastic waves generated whenever a transient stress imbalance is produced within or in the surface of an elastic medium. Almost any sudden deformation or movement results in seismic sources.

The elastic rebound theory is an explanation for how energy is spreading during seismic excitation. As rock on opposite sides of any geological disturbance zones are subjected to force and shift, they accumulate energy and slowly deformed until their internal strength is exceeded. At that time, a sudden movement occurs along the fault and other geological disturbances, releasing the accumulated energy and the rocks snap back to their original undeformed shape. It was considered before the development of elastic rebound theory that the ruptures of the surface were the result of strong ground shaking. In seismic excitation the accumulated strain is great enough to overcome the strength of rock. Like an elastic band, the more the rocks are strained the more elastic energy is stored and the greater potential for a rock damage. The stored energy released during seismic event partially elastic waves.

The material properties of the material concerned are known as elastic moduli like rigidity modulus, bulk modulus, poisson ratio, young modulus etc. when stress varies with time strain varies similarly and the balance between stress and strain results in seismic wave. These seismic waves travel at velocities that depend on the elastic moduli and are governed by equation of motion.

Strain is a measure of deformation that is variation of relative displacement as associated with a particular direction with the body of rock mass considered. For P-waves, the only displacement occurs in the direction of propagation. Such wave motion is termed “longitudinal”. This P-waves introduce volume change in the materials therefore they are termed as “compressional” or “dilatational”. P-waves involved shearing as well as compression. That is why P-velocity is sensitive to both the bulk and shear moduli. For S-waves the motion is perpendicular to the propagation direction. In S-wave particle motion we have seen that there are two components. The motion within a vertical plane through the propagation vector (SV waves) and the horizontal motion in the direction of perpendicular to this plane (SH waves). The motion is pure shear without any volume change. (Hence the name shear waves).

Like stress strain is decomposed into normal and shear components and seismic waves yield strains varying from 10^{-10} to 10^{-6} . And in such cases it has been proved by infinitesimal strain theory elementary strain and are its components during dilatational strain (relative volume change during deformation) shearing strain does not change the volume. In general Hooke's Law then describes the stress developed in deformed body ($F = -kx$). And mechanical work is required to deformed an elastic body is a result of elastic energy accumulated in the strain /stress field. When released this energy gives rise to seismic waves and uncompensated net force will result in acceleration as per Newton's law.

As rock is considered as “elastic continuum” so it is deformed in response to stress and there shall be two types of deformation— one is change in volume and other is change in shape. But in above study it has been cleared that” shearing strain does not change the volume “

Wave speed in a medium is primarily determined by the properties of the rock mass, specifically its elasticity.

The effect of open cast blasting deformed the rock mass at a certain depth from the surface that is load come on surface. When some amount of explosive is detonated at certain depth in single or multiple drill holes, very rapid decomposition of the charge takes place, forming gases at very high temperature and pressure. A true shock wave is formed only when the initial explosive pressure far exceeds the strength of the rock in compression, so much so that any plastic state by-passed and then it can be said to behave hydrodynamically. Such an unstable shock wave rapidly passes through the non elastic state, due to its instability and decreasing velocity, and settles into a stable quasi - elastic zone in which the oscillatory wave motion propagating at sonic velocity carries insufficient energy to permanently disturb the material in its path. This zone is known as the elastic or semi elastic wave zone (Ghosh 1983). The intensity of the shock wave attenuates very rapidly as a large amount of energy is consumed in crushing and producing cracks. Thus in elastic or semi elastic zones located away from the source, the intensity drops significantly and this produces no permanent deformation. The remaining energy goes directly into the surrounding rock as seismic waves and these waves propagate elastically. The seismic waves propagate away from its source. This remains till there is no other source of energy. The decay in the amplitude of vibration that is geometrical damping in an ideal elastic rock mass, the attenuation of amplitude for different types of waves given by Rinehart et al. 1961 as follows...

Body waves propagating along the surface, amplitude is proportional to R^{-2}

Body waves propagating through the medium, amplitude is proportional to R^{-1}

Rayleigh waves, amplitude is proportional to $R^{-0.5}$; R being the distance from the source.

The actual decay in amplitude of vibration with respect to distance is more than what has been explained due to geometrical spreading. The extra attenuation is due to inelastic nature of the rock (Bath, 1979).

In a multiple grained rock mass, the available surface area for dissipation of energy is more than that of a single crystal. Frictional forces are developed due to possible relative motion of grains during wave propagation (Walsh 1966).

The above mechanism, including dissipation due to relative motion at grain boundaries and across surfaces is termed as matrix in elasticity.

There are several causes for inelastic attenuation some of which are
 Attenuation due to fluid flow, including relaxation, because of shear motions at pore- fluid boundaries.
 Partial saturation effects such as gas pockets squeezing.
 Enhanced inter crack flow.
 Energy absorbed in a system under going phase changes.
 Large category of geophysical effects, including geological discontinuities, scattering of small pores, large irregularities and selective reflection from thin beds.
 Ghosh and Daemen (1983) reformulated the propagation equation of USBM and Ambraseys and Hendron(1968) by incorporating the inelastic attenuation factor $e^{-\alpha D}$. The modified equations are

$$V=K(D/Q^{0.5})^{-B}e^{-\alpha D}$$

and , $V=K(D/Q^{1/3})^{-B}e^{-\alpha D}$

Where K,B,and α are empirical constants, α is called the inelastic attenuation factor.

The effect of the inelastic attenuation factor of the Langefors et al. (1958) and Indian Standard (1973) equations has been reported in the work of Pal Roy (1991).

To the standardize the values of site constants for various rock masses and to assess the validity of a particular empirical model, the blasting research group of the CSIR -CIMFR , India conducted investigations on different types of exposed rock masses, which included lime stone (fissured and highly jointed), granite (hard and fresh), iron ore, coal, dolomite, basalt, sandstone (weathered) and sandstone - alluvium (Pal Roy,1991).

It is important that if no assumptions are made about the joint distribution of the concerned random variables, the validity of the prediction and of the estimate of the site constants can not be judged.

In the case of normal distribution,the square of the coefficient will determine the strength of the regression equation. If there are more than one independent variables in the model as in above equations then in the calculation of correlation coefficient between two variables, there will be an effect of the third variable. This effects can be avoided if the partial correlation coefficient are considered. The partial correlation coefficient measure only the effect of the specified variables while ignoring the influence of the other variables. There may be possibility for a positive simple correlation coefficient to be transformed into a negative partial correlation coefficient.

Inelastic attenuation of elastic waves is a characteristic that could be applied for the study of the geotechnical properties of rocks and to predict the change in the shape of a plane stress wave while passing through a rock mass.

CSIR -CIMFR India predictor equation model assuming special significance because of its simplified form and the consideration of the zone of disturbance due to blasting (Pal Roy, 93). The equation is valid only in the zone of disturbance. At the boundary of this zone and outside this boundary, V is obviously zero everywhere. This equation considers two distinct categories of parameters n and K, where n is related to the category of parameters that are influenced by rock properties and geometrical discontinuities and K is related to design parameters including charge weight, distance from the source, charge diameter, burden spacing, sub- grade drilling, stemming length and delay interval. The equation is

$$V= n+K(D/Q^{0.5})^{-1}$$

As n is categories as a damping parameter that is influenced by rock properties and geometrical discontinuities, in practical solutions the value is always negative. Thus from this equation we can reach in a conclusion how open cast blasting disturbed the underground rock mass.

Using the concept of rock breakage and the theory of reflection of seismic waves at a free surface CSIR-CIMFR has developed a mixed analytical - empirical model for the prediction of blast induce ground vibration (Pal Roy and Dhar, 1992). The model accounts for the characteristics of the explosive, rock mass properties and charge loading parameters. The equations are

$$V_v= \{2K_1PD r_1 2l(r_1+r_2)^{-\tau\alpha}\}/\rho_1 c_1 (l_2+x_2)^{3/2}$$

$$K_1=VD\rho_2/\rho_1 c_1$$

$$PD= \frac{1}{2} \sigma_t [10^3(Q/K^3)^{1/3}]^2 / (k_2 r_2)^2$$

Above equations are dimensionally balance. When the blast hole contains more than one explosive then VD and ρ_2 may be taken as the simple average of their respective values.

V_v = peak particle velocity (mm/s)

$K_1 = (\text{characteristic impedance of explosive}) / (\text{characteristic impedance of rock})$

$\rho_1 = \text{density of rock (gm/cm}^3\text{)}$

$c_1 = \text{P-wave velocity in rock (m/s)}$

$\rho_2 = \text{density of explosive (g/cm}^3\text{)}$

$VD = \text{velocity of detonation of explosive (m/s)}$

$PD = \text{peak charge pressure (MPa)}$

$r_1 = \text{radius of the charge (mm)}$

$l = \text{depth of centre of explosive column from the surface (m)}$

$x = \text{distance of the measuring transducer from the blast hole (m)}$

$Q = \text{weight of explosive in blast hole (kg)}$

$\sigma_1 = \text{tensile strength of rock (MPa)}$

$K_2 = \text{proportionality constant} = 1.0 \text{ for most rock}$

$K_3 = \text{factor relating to the lifting of one m}^3 \text{ rock mass by } 0.8 \text{ kg/m}^3 \text{ explosive (for most rock)}$

$\tau = \text{charge symmetry parameter (2 for cylindrical charge and 3 for spherical charge)}$

$\alpha = \text{an explosive constant of parametric value lying between 1.2 and 1.5.}$

In 1934 Rockwell stated that vibration energy cause by blasting was proportional to frequency and amplitude. Field studies from 1935 to 1940 by the USBM in the frequency range 4-40Hz and amplitude range 0.0025-12 mm related damage to acceleration have been fulfilled.

Jimeno et al (1995) suggested for staggered drilling pattern: $S = 1.15B$ for vartical holes and $S = 1.15B \cos \theta$ for included hole where θ is the angle of inclination with respect to the vartical. $S =$ spacing in m, $B =$ burden in m, $S < B$ is used in cast blasting, smooth blasting and cushion blasting and in places where the specified requirements is to get bigger size of boulder with clean wall cut rather smaller fragmentation of burst rock. Very small spacing may caused excessive crushing between charges. Large block in front of the blast hole create toe problem and can not be overruled. In 1995 Pal Roy (CSIR -CIMFR) given a equation for calculation of optimum values of spacing in m.

$$S = 1.30 * B - 4.0 * (L/C) * 1/RQD$$

$L =$ loading density of explosive (kg/m)

$C =$ charge factor (kg/m³)

$RQD =$ rock quality designation

For Burden Rustan(1990) given $B = 18.1 * D^{0.689}$ (+52% maxi expected value — 37% min value)

$B =$ practical burden in m

$D =$ diameter of the blast hole

In 1995 Pal Roy given $B = H * D_e / D_h * 5.93 / RQD + 0.037 * (L/C)^{0.5}$

$H =$ hole depth in m

$D_e =$ diameter of explosive (mm)

$D_h =$ diameter of the blast hole (mm)

Therefore, if burden is very little air blast level will be high and too much burden will produce severe back break and shuttering on the back wall and this enhance the ground vibration.

Extensive research has been conducted to determine the mathematical relationship between vibration level, charge size and distance. This propagation law is developed by USBM

$$V = H * (D/W^\alpha)^\beta$$

$V =$ predicted particle velocity (in/s)

$W =$ maximum explosive charge weight per delay (lbs)

$D =$ distance from the shot to sensor measured in 100's of feet

$H =$ particle velocity intercept

$\alpha =$ charge weight exponent

$\beta =$ slope factor exponent

The values of α, β and H are determined by geomining condition of the area — rock type, local geology, thickness of overburden and other factors. The wave emanating from the blast holes can cause damages to structures nearby to the mine areas. Thus a number of

blast monitoring techniques have been advised based on the number of approaches advised by the researchers. Some of the approaches for the blast vibration monitoring predictor equation are given below

1. Langefors and Kihlstrom (1963)

$$V=K[\sqrt{(Q_{\max}/R^{2/3})}]^B$$

2. Ambraseys— Hendron (1968)

$$V=K[R/(Q_{\max})^{1/3}]^B$$

3. Indian standard (1973)

$$V=K[(Q_{\max}/R^{2/3})]^B$$

4. General predictor (Davies 1964)

$$V=KR^{-B}(Q_{\max})^A$$

5. Ghosh - Demon(1983)

$$V=K[R/\sqrt{Q_{\max}}]^{-B}e^{-\alpha R}$$

$$V=K[R/(Q_{\max})^{1/2}]^{-B}e^{-\alpha R}$$

6. CMRI(1993)

$$V=n+k[R/\sqrt{Q_{\max}}]^{-1}$$

7. Gupta et al (1988)

$$PPV=K[D/\sqrt{W}]^{-\beta}e^{-\alpha(D/W)}$$

8. Pal Roy(1993)

$$PPV=\alpha+K(Q^{1/2}/D)^{-1}$$

9. Temrock(1995)

$$PPV=K(Q/R^{3/2})^{0.5}$$

10. Hossaini & 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 constants



6. Science of Wave Interference

Destructive interference occurs when waves come together so that they completely cancel out each other. When two waves destructively interfere, they must have the same amplitude in opposite direction. To comprehend the destructive wave interference we must examine on the basis of the combination of waves that is principle of superposition. If two or more waves are traveling in a medium, the resulting wave function is the algebraic total of individual wave function. When the waves of identical frequency and equivalent amplitude super imposed then interference takes place. The path difference between destructive interference of odd multiple. For destructive interference $(2n+1)\lambda/2$. The equation for destructive interference

1. The phase difference between two waves is an odd multiple of π ,

$$(2n-1)\pi$$

2. Difference between the paths of two waves is $\lambda/2$

$$\Delta=(2n-1)\lambda/2$$

3. The time interval among the two waves is an odd multiple of $T/2$

$$\theta=(2n-1)T/2$$

The result and amplitude is equivalent to the difference between the amplitudes of individual waves.

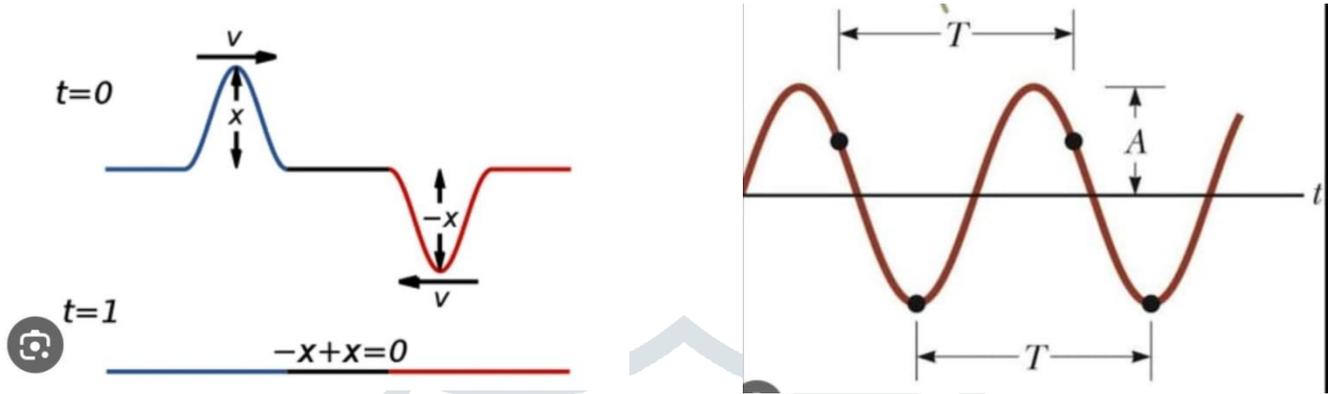


Fig.6a

Fig.6b:

The period T of a wave is the time interval required for the element to complete one cycle of its oscillation and for the wave to travel one wave length

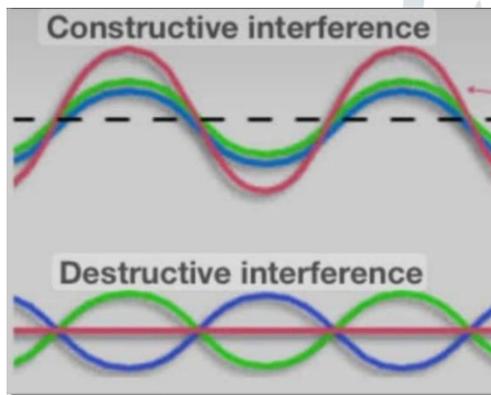


Fig.6c:

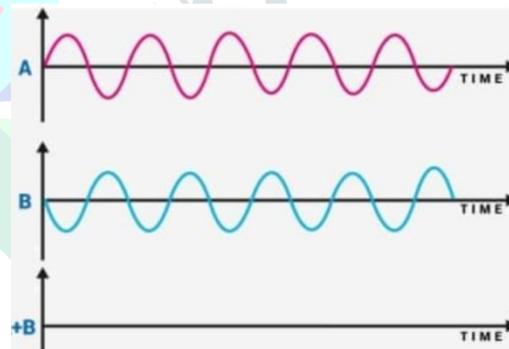
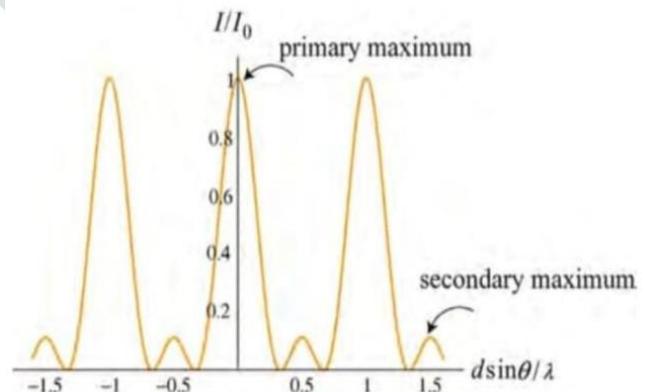


Fig.6d:



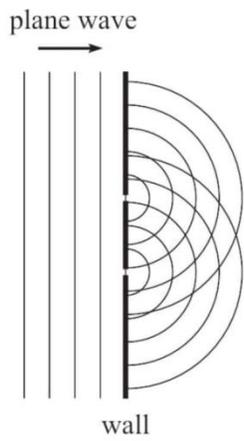


Fig.6e

Fig.6f:

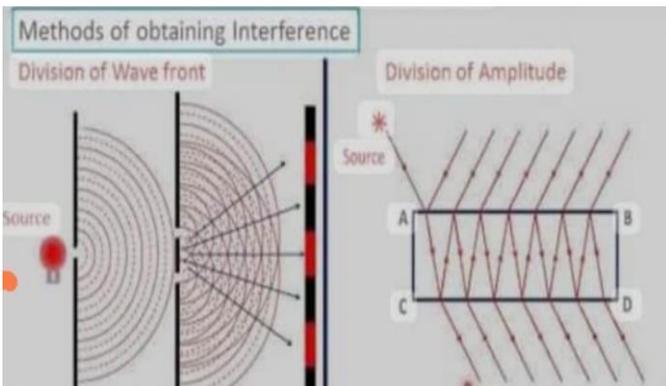


Fig.6g:

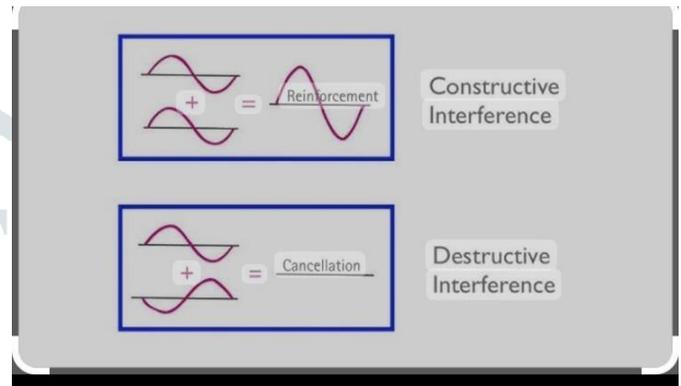


Fig.6h:

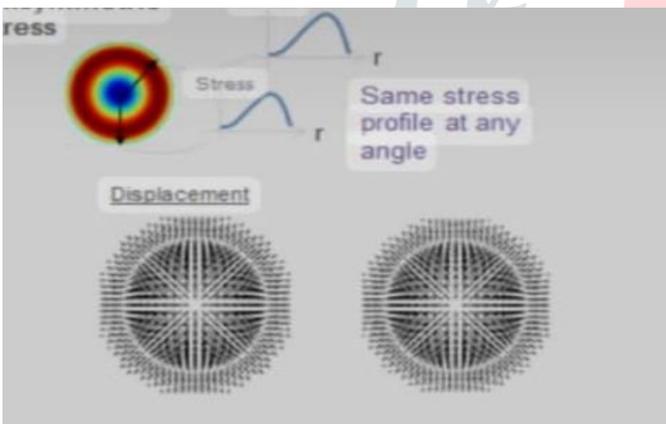


Fig.6i

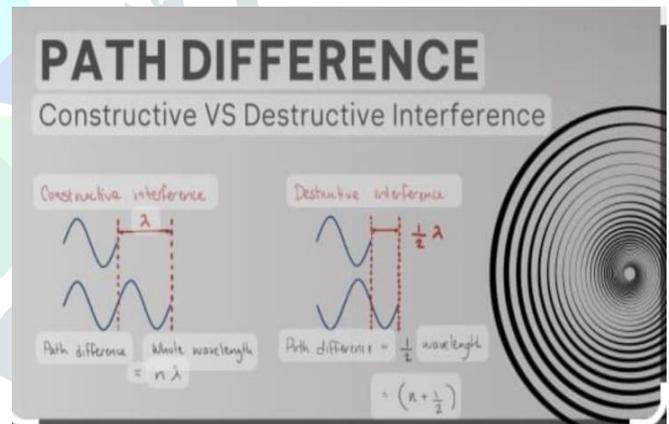


Fig.6j:

Let us consider the superposition of two wave trains of same wavelength (or frequency) but differing in phase in a homogeneous medium. If a_1 and a_2 are the amplitudes of the two waves, the displacement due to one wave at any instant is represented as

$$y_1 = a_1 \sin \omega t$$

The displacement due to another wave at the same instant t is represented as

$$y_2 = a_2 \sin(\omega t + \delta)$$

Where δ is the phase difference between two waves at instant t . The resultant displacement y of the two waves is given by Principle of superposition (as stated above) i.e.

$$y = y_1 + y_2 = a_1 \sin \omega t + a_2 \sin(\omega t + \delta)$$

$$\text{or } y = (a_1 + a_2 \cos \delta) \sin \omega t + (a_2 \sin \delta) \cos \omega t$$

Putting $R \cos \phi = a_1 + a_2 \cos \delta$

$$R \sin \phi = a_2 \sin \delta$$

Where R and ϕ are new constant. We get from equation

$$y = R\cos\phi\sin\omega t + R\sin\phi\cos\omega t$$

$$\text{Or } y = R\sin(\omega t + \phi)$$

This is the equation of resultant wave with R as amplitude and ϕ , phase difference. We can get the values of R and ϕ from the equations as

$$R^2 = (a_1 + a_2 \cos\delta)^2 + (a_2 \sin\delta)^2$$

$$\text{or } R^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\delta$$

$$\text{And } \tan\phi = a_2 \sin\delta / a_1 + a_2 \cos\delta$$

The intensity is proportional to square of the amplitude *i. e.* I is proportional to R^2 , and in arbitrary units

$$I = R^2 = a_1^2 + a_2^2 + 2a_1 a_2 \cos\delta$$

As a_1 and a_2 are constants, the intensity I will be maximum or minimum depending upon the value of δ .

i. For the maximum intensity : When $\cos\delta = 1$, the intensity is maximum and given by

$$I_{\max} = a_1^2 + a_2^2 + 2a_1 a_2 = (a_1 + a_2)^2$$

Here the corresponding phase difference

$\delta = 0, 2\pi, 4\pi, \dots = 2n\pi$ ($n = 0, 1, 2, 3, \dots$) and the path difference for brightness is

$$\begin{aligned} \text{Path difference} &= \lambda/2\pi \cdot \text{Phase difference} \\ &= \lambda/2\pi \cdot 2n\pi = n\lambda = 2n \cdot \lambda/2 \end{aligned}$$

thus for maximum intensity the phase difference is even multiple of π or the path difference is even multiple of half wavelength ($\lambda/2$).

ii. For minimum intensity : When $\cos\delta = -1$ the intensity is minimum and given by

$$I_{\min} = a_1^2 + a_2^2 - 2a_1 a_2 = (a_1 - a_2)^2$$

The phase difference $\delta = \pi, 3\pi, 5\pi, \dots = (2n+1)\pi$, ($n = 1, 2, 3, \dots$) and the corresponding path difference for darkness is

$$\text{Path difference} = \lambda/2\pi \cdot (2n+1)\pi = (2n+1) \cdot (\lambda/2).$$

Thus for minimum intensity, the phase difference is odd multiple of π or path difference is odd multiple of half wavelength ($\lambda/2$).

iii. Average intensity: The average intensity \bar{I} is given by

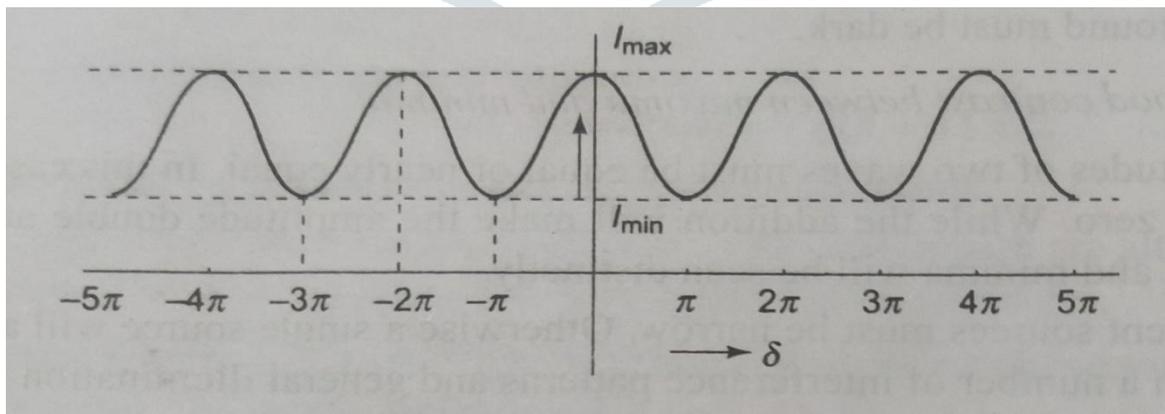


Fig.6k:

$$\bar{I} = \int_0^{2\pi} I d\delta / \int_0^{2\pi} d\delta = \int_0^{2\pi} (a_1^2 + a_2^2 + 2a_1 a_2 \cos\delta) d\delta / \int_0^{2\pi} d\delta$$

$$\bar{I} = (a_1^2 + a_2^2) 2\pi / 2\pi = a_1^2 + a_2^2 = I_1 + I_2$$

Hence the average intensity is equal to the sum of the intensities of individual waves. This means that in interference pattern the energy $2a_1 a_2$ is simply transferred from minima to maxima *i. e. interference is based on conservation of energy*. The intensity versus phase difference curve is shown in the above Fig.

7. Related Seismic Science

The blasting vibration effect is a seismic phenomenon in a certain range around the explosive, which causes the vibration. As the vibration propagates in a medium, the vibration amplitude is usually decreased due to wave-front expansion and the energy dissipation in the medium.

A safe and economical blasting should not only achieve the expected blast fragmentation, but also effectively control blasting vibration without exceeding the control standard. That is why a quantitative and reasonable blasting design is required. The premise of the design is to comprehensively and rationally analyze the vibration attenuation law and to evaluate the vibration attenuation parameters.

The attenuation law of blasting vibration is very complicated, which involves the knowledge of explosion mechanics, wave dynamics, rock mechanics and geological engineering. At present, there are no accurate theoretical methods for prediction. An effective and feasible method is to establish an empirical equation for the generation and attenuation of blasting vibration through regression analysis of a large number of measured data. Usually, the peak particle velocity (PPV) is selected as the vibration variable.

The classical Rayleigh surface rotational wave in terms of its theoretical notation and, resulting from this, properties associated with the induced seismic phenomena in mines are being discussed because of good understanding of the seismic excitation due to blasting induce vibration. This kind of seismic wave was analyzed in-depth from the point of view of the parameters governing the form of its mathematical notation based on the similarity to the records obtained during the induced seismicity in near-blasting zone. It is possible to relate the amount of the emitted seismic energy to the expected highest amplitude of rotational vibrations in the entire field of their impact on the rock mass. As a result, this made it possible to impose the completely defined R wave to the numerical models of given objects. when dynamic load induced by the rotational wave, would be an objective of consideration. Values of seismic rotations were evaluated concerning the energy and the distance of the seismic event's source. It was found that the results of the calculations matched with a satisfying degree with the field seismic measurements of the rotational ground motion induced by propagating the seismic wave due to open cast blasting. Seismic activity is one of the deadliest and destructive source of hazards affecting both the local society and the environment. Natural earthquakes occur due to a sudden release of energy accumulated in Earth's crust, usually when the masses of rock are acting mutually against one another, which causes sudden fracture and slip along the fault lines. Regardless of the type of seismic event, the additional dynamic load may generate a significant damage to structures located near the seismicity source. This is particularly visible in the regions of mining-induced seismicity. In most of the seismic cases the seismic load is defined as a clear translational ground motion, which describes the characteristic of Primary (P) and Secondary (S) body wave propagations through the ground. At the same time, the rotational load, generated mostly by Rayleigh (R) and Love (L) surface waves, as well as with body wave interactions with the ground surface are neglected, mainly due to the lack of rotational measurements of the ground motion. Whenever the seismic acceleration is higher than the slope critical acceleration causing collapse, then permanent displacements occur. Thus, the rotational seismic movements related mostly to the surface wave propagations are neglected. The Rayleigh wave characteristics has been separated from the velocity records using the method of time–frequency decomposition.

In order to separate surface waves from the overall ground motion, the qualitative methodology of the time–frequency decomposition is used. The Rayleigh wave velocity is generally about 10% lower than the velocity of the S-wave.

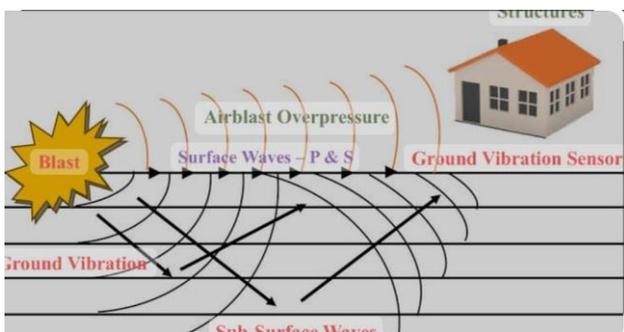


Fig.7(a): Assesment of ground vibration

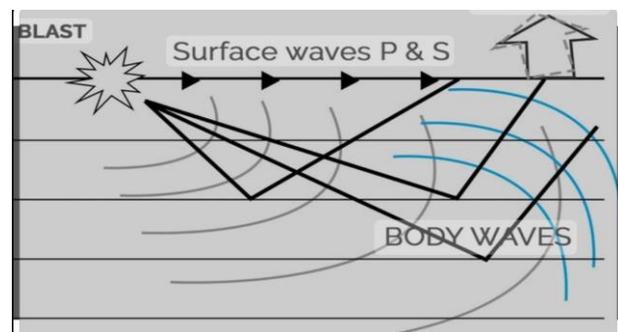


Fig.7(b): Wave reflection

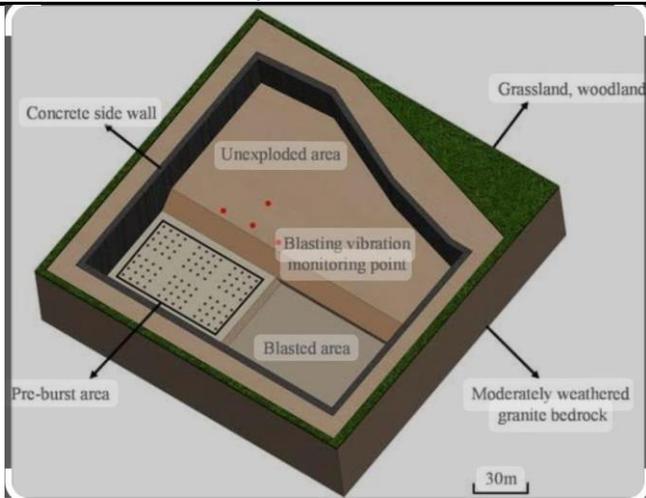


Fig.7(c): Different zones of vibration

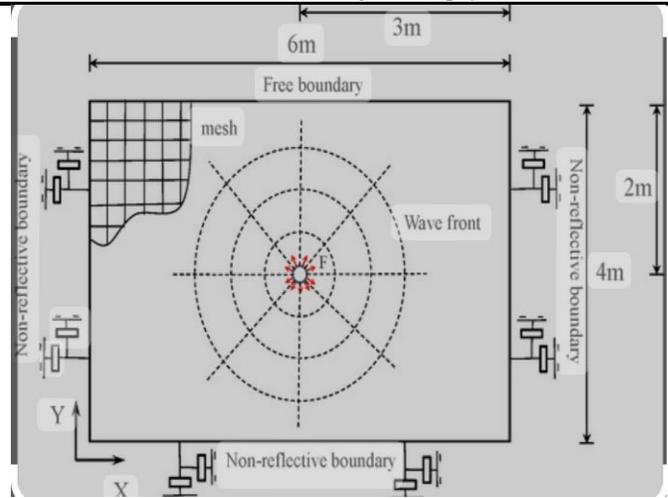


Fig.7(d): Study on surface vibration

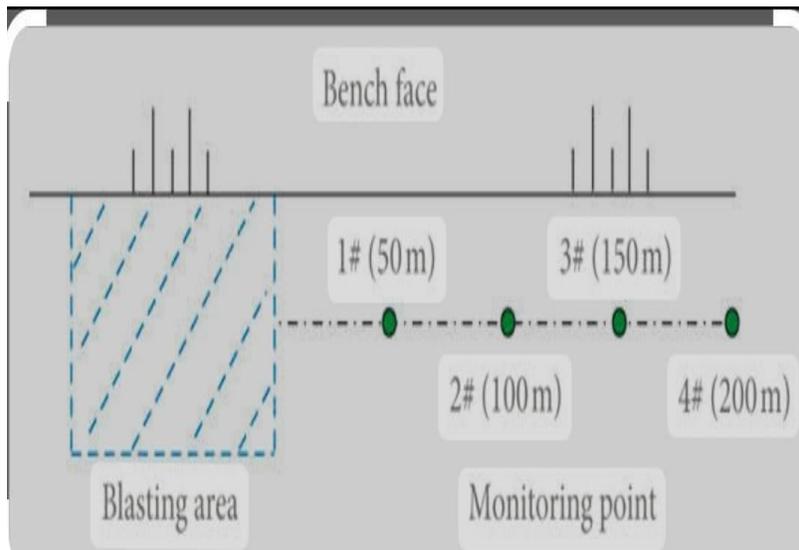
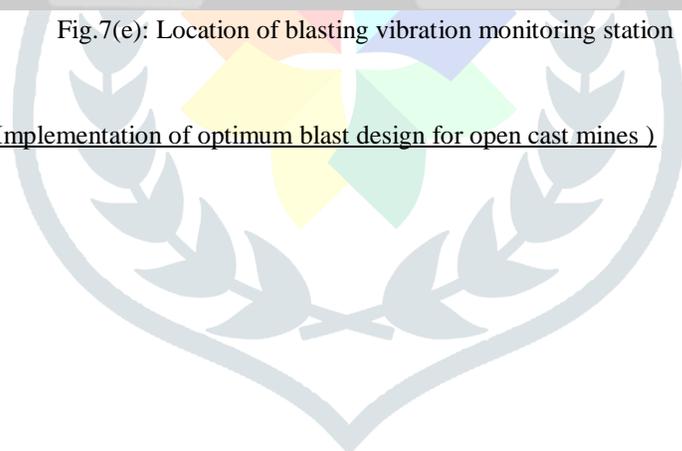


Fig.7(e): Location of blasting vibration monitoring station

8. Methodology and work plan (Implementation of optimum blast design for open cast mines)



Site characterisation

Definition of hydromechanical properties of the host rock mass for mining

Mine model formulation

Conceptualisation of site characterisation data

Design analysis

Selection and application of mathematical and computational schemes for study of mining layout and strategies

Rock performance monitoring

Measurement of the operational response to mining of the host rock mass

Retrospective analysis

Quantification of in-situ rock mass properties and identification of dominant modes of response of mine structure



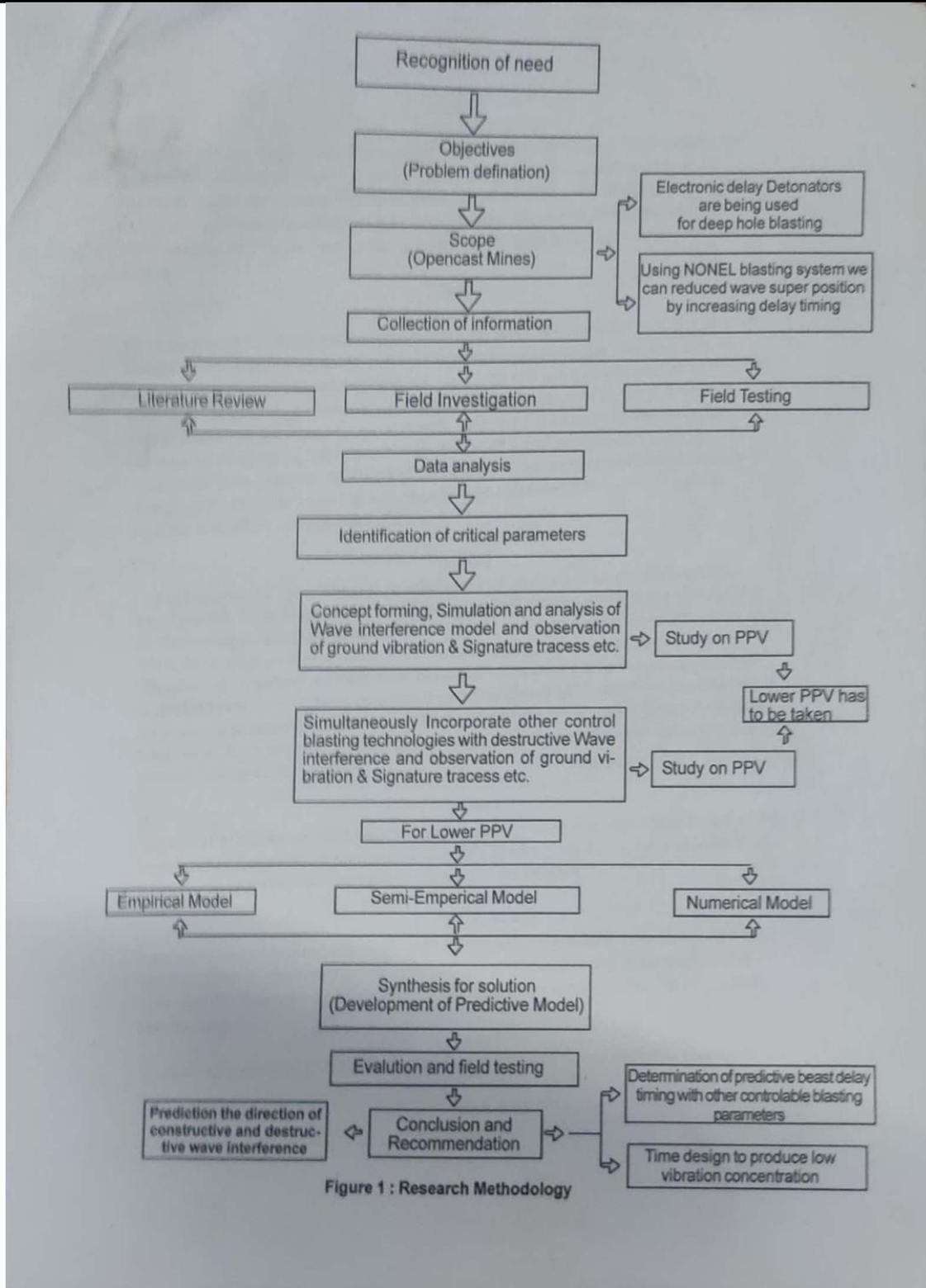


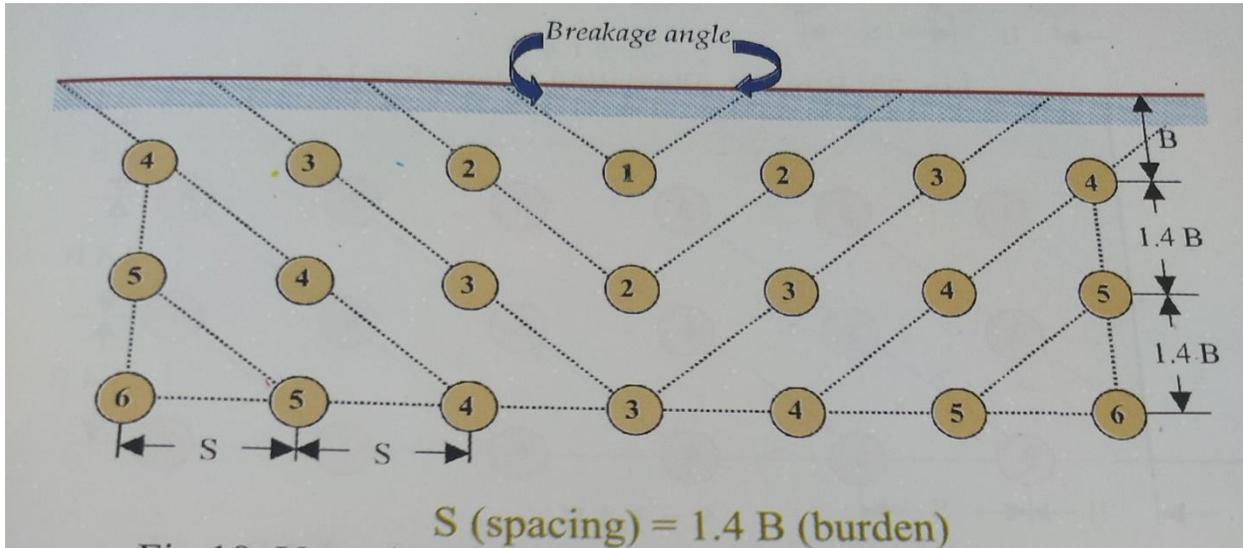
Figure 1 : Research Methodology

Flow chart of Research Methodology

1.Open cast mines→2. Geological data collection → 3. Field investigations →4. Collection of information →5. Data analysis →6. Identification of critical parameters →7. Concept forming →8. Analysis and observation of web interface model →9. Ground vibration and signature testing (study on PPV)→10. Lower PPV has to be taken →11. Empirical model→12. Semi empirical model →13. Numerical model →14. Synthesis of solution for development of predictive model →15. Evaluation and field testing →16. Conclusion and recommendations →17. Prediction of the direction of constructive and destructive wave interface →18. Determination of predictive best delay timing with other controllible blasting parameters →19. Time design to produce low vibration concentration

Electronic delay detonator used for deep -hole blasting and using nonel blasting system we can reduce wave superposition by increasing delay timing.

Time design to produce low vibration concentration.



S(spacing) = 1.4B(burden)
Fig.8a: V-cut (square corner) progressive delays

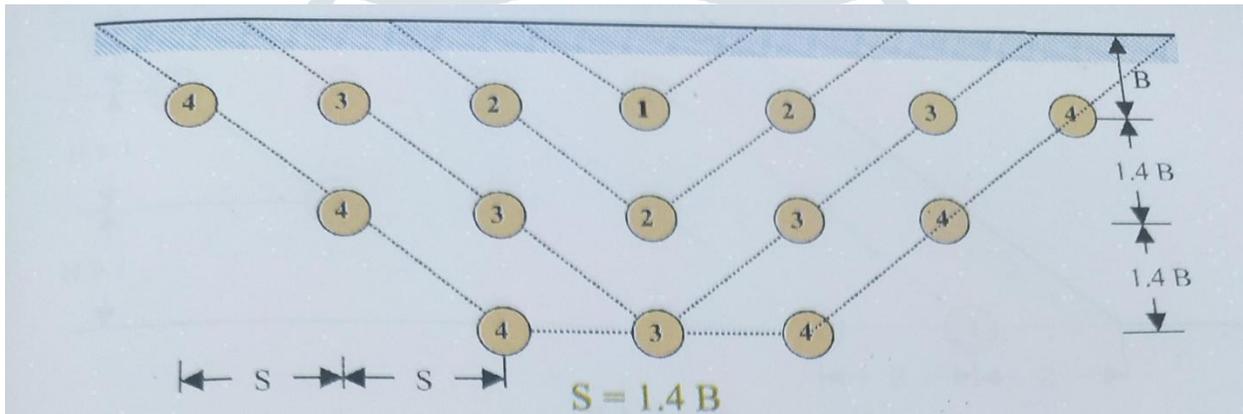


Fig.8b: V-cut (angle corner), progressive delays, S=1.4B

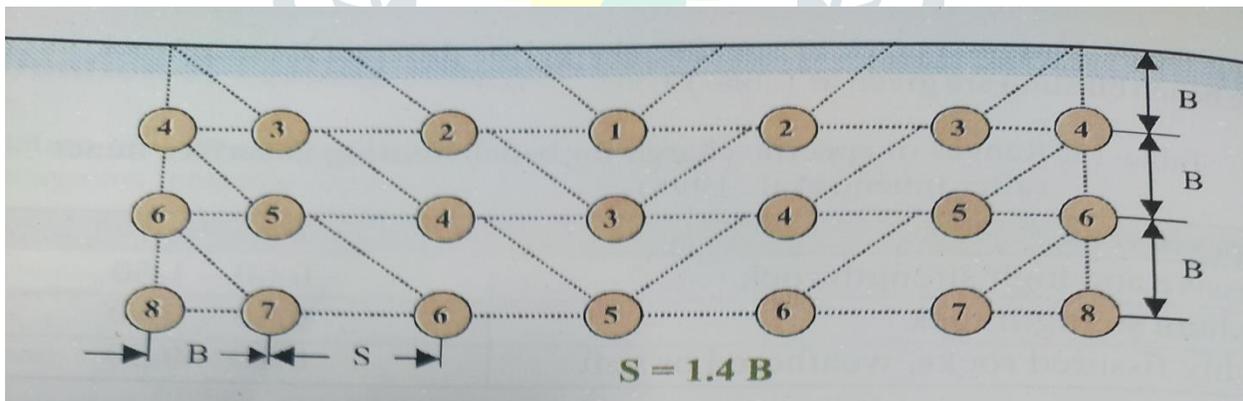


Fig.8c: Box-cut progressive delays, S=1.4B

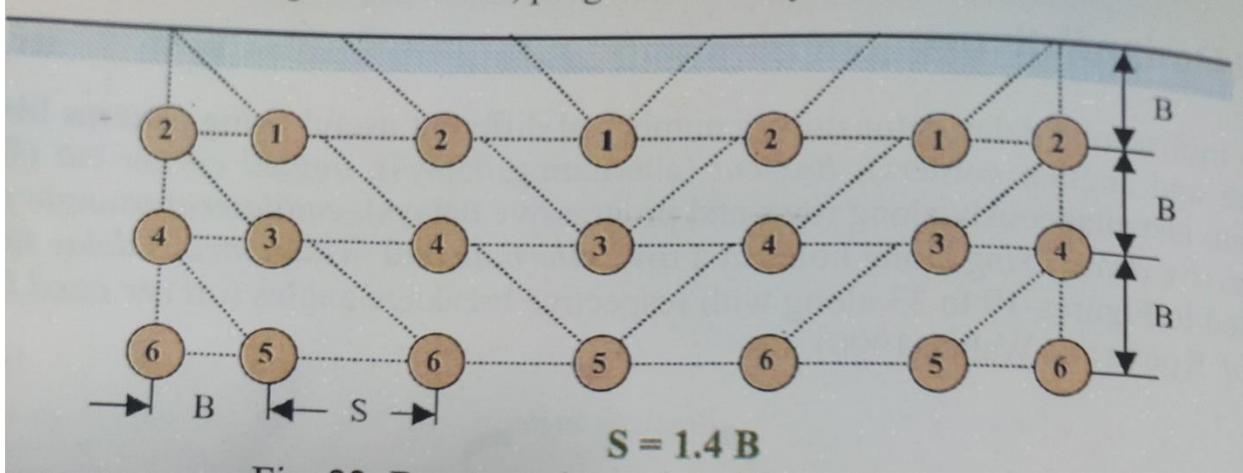


Fig.8d: Box-cut alternating delays, $S=1.4B$

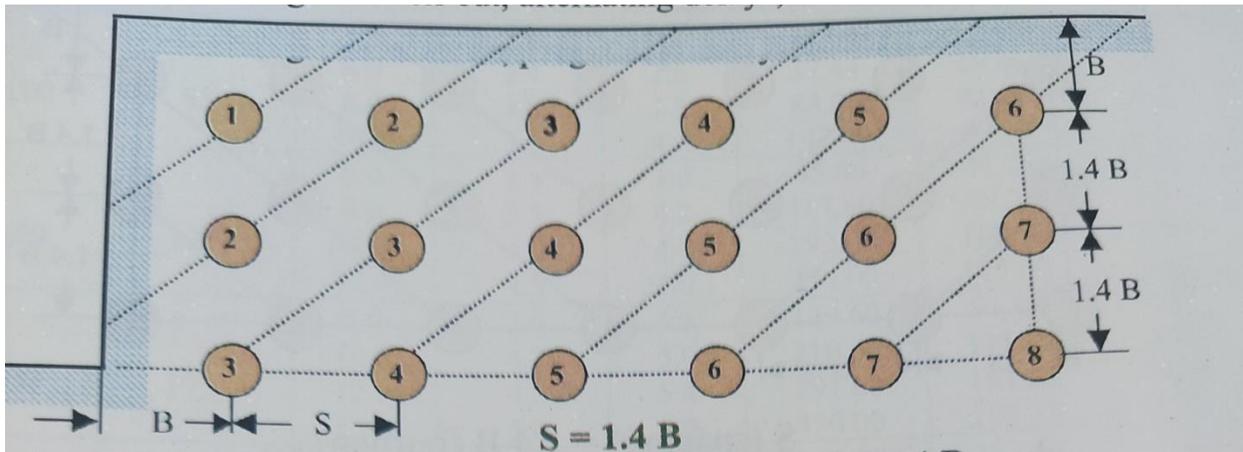


Fig.8e: Corner-cut fired on echelon, $S=1.4B$

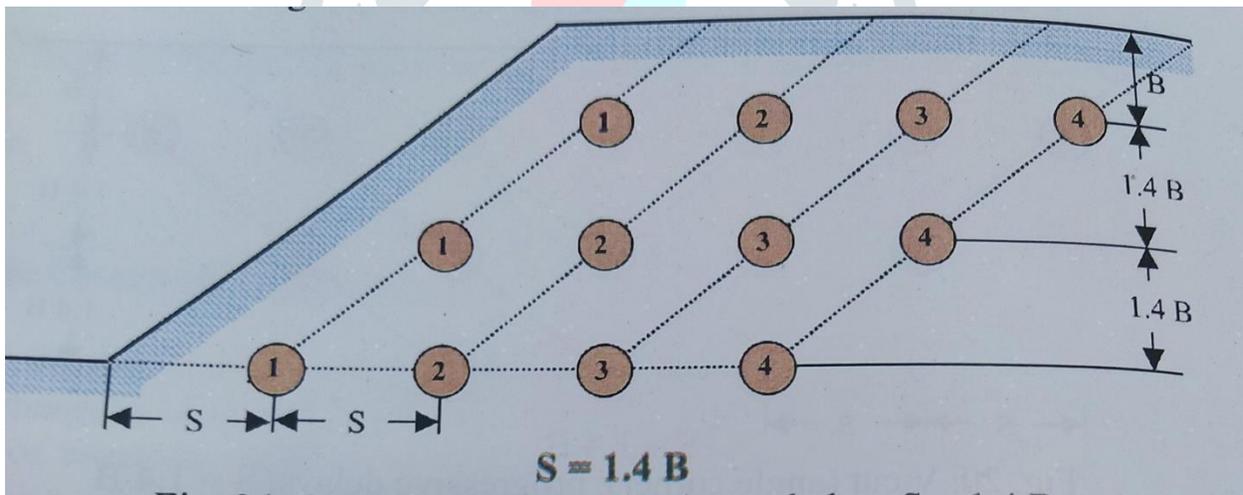


Fig.8f: Angled corner cut, fired on echelon, $S=1.4B$

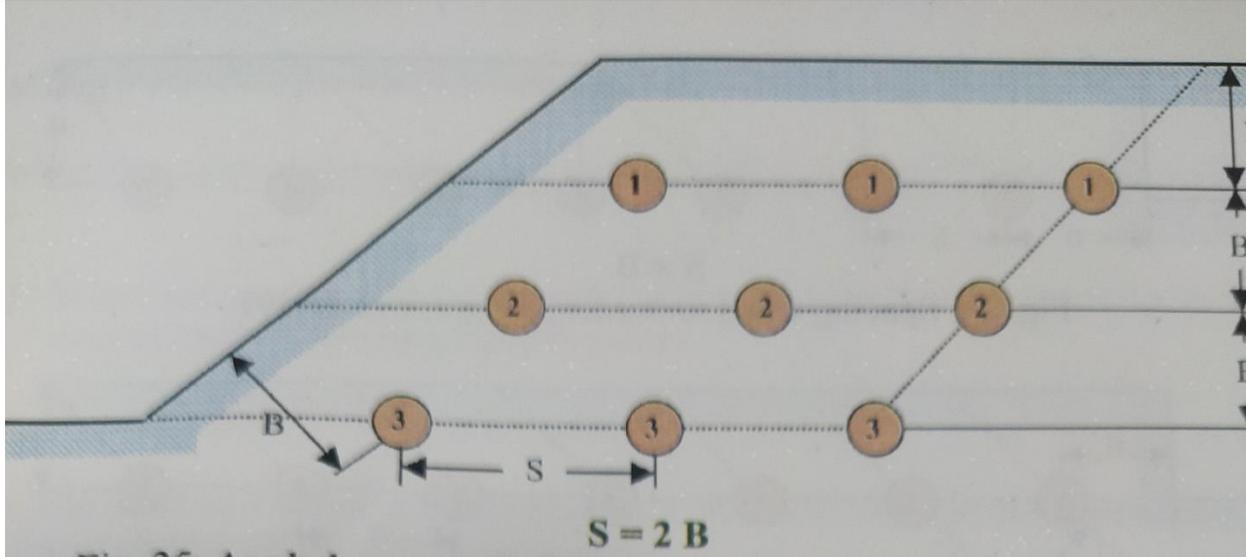


Fig.8g: Angled corner cut, fired instantaneously along rows, $S=2B$

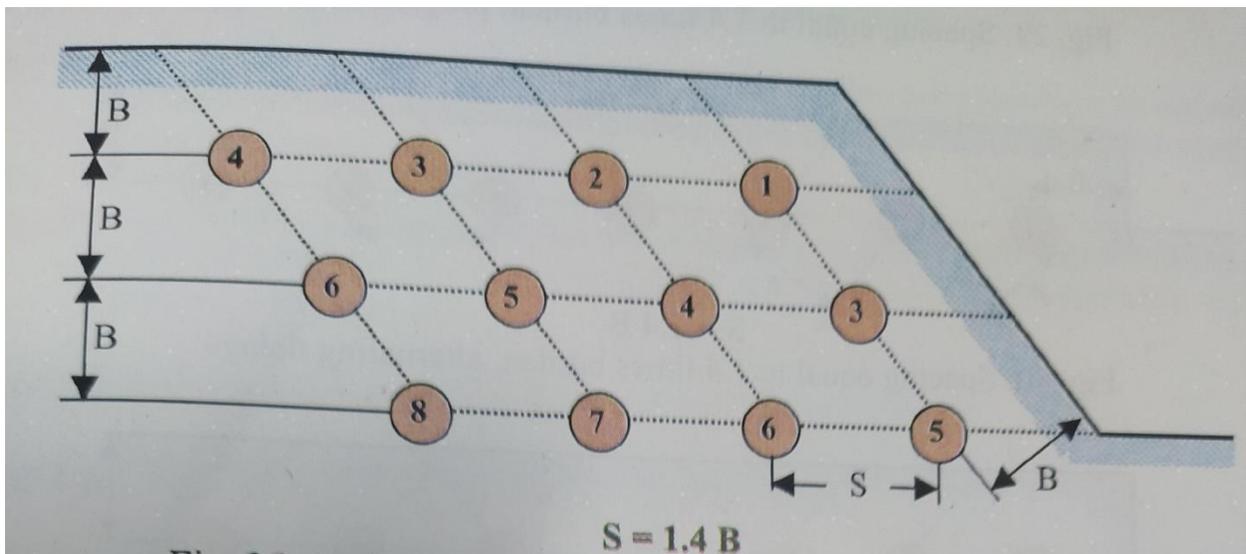


Fig.8h: Angled corner cut fired on progressive delays, $S= 1.4B$

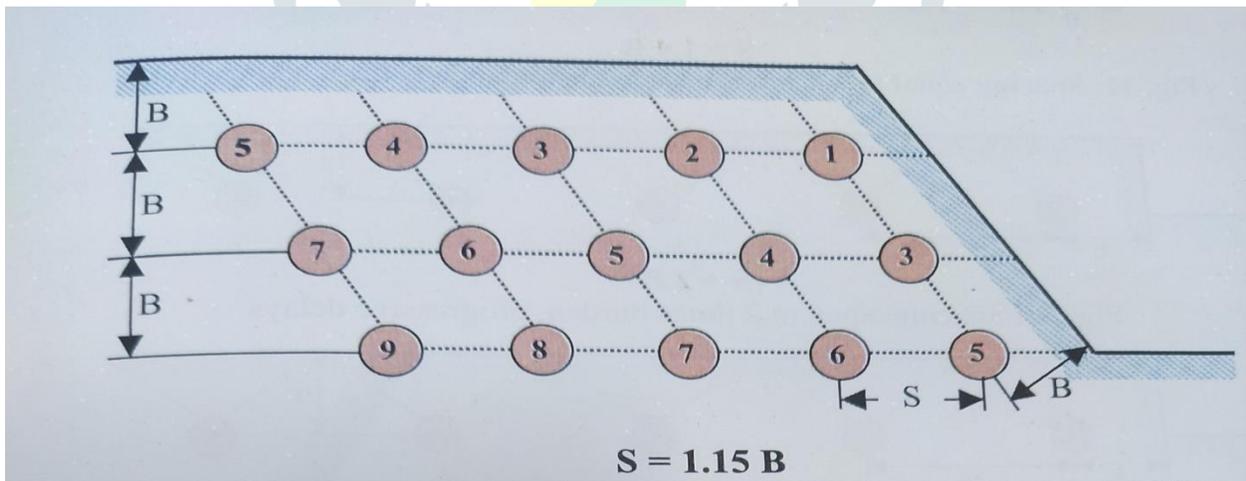


Fig.8i: Equilateral triangle pattern for low benches, $S=1.15B$

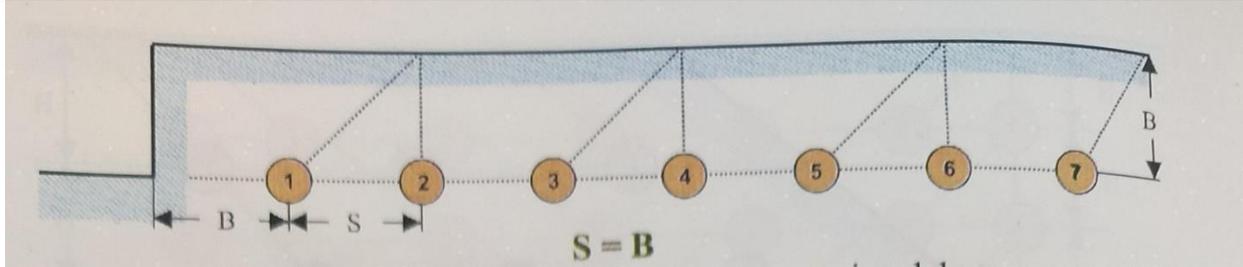


Fig.8j: Spacing equal to burden, progressive delays

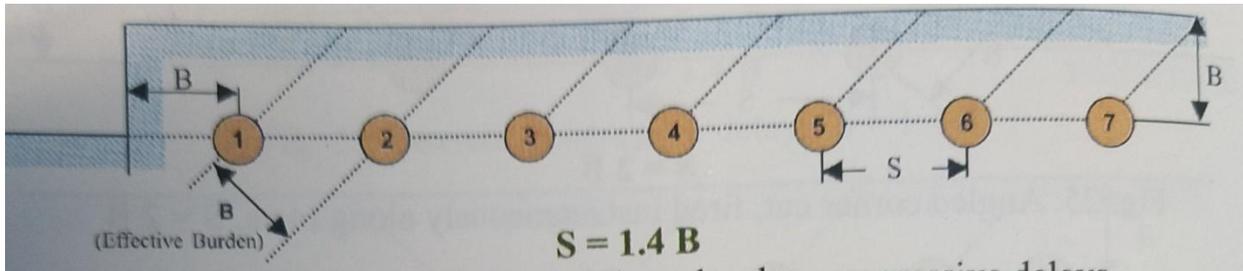


Fig.8k: Spacing equal to 1.4 times burden, progressive delays

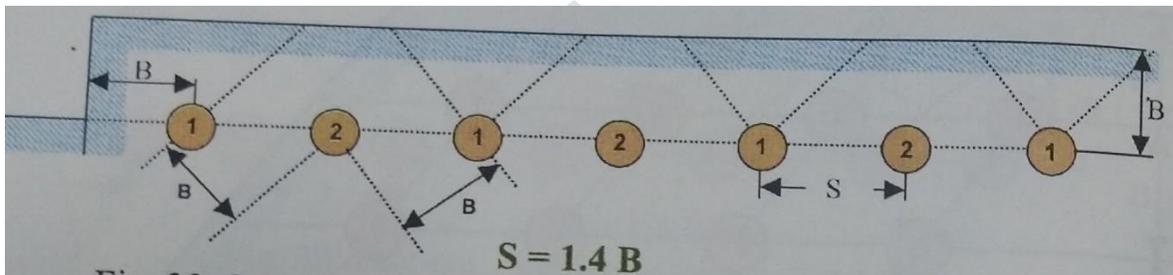


Fig.8l: Spacing equal to 1.4 times burden, alternating delays

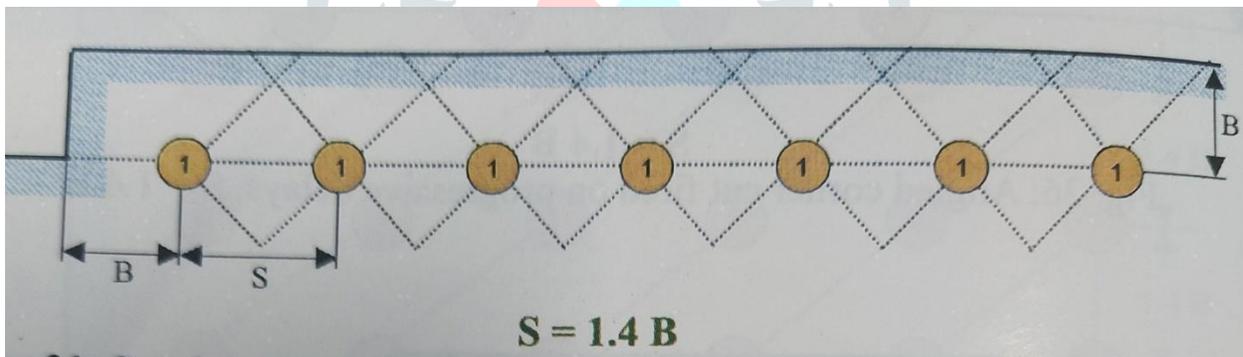


Fig.8m: Spacing equal to 1.4 times burden, instantaneous firing along row

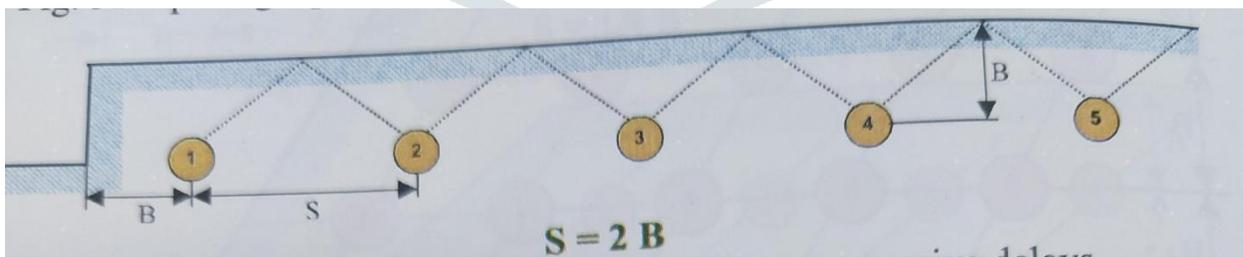


Fig.8n: Spacing equal to 2 times burden, progressive delays

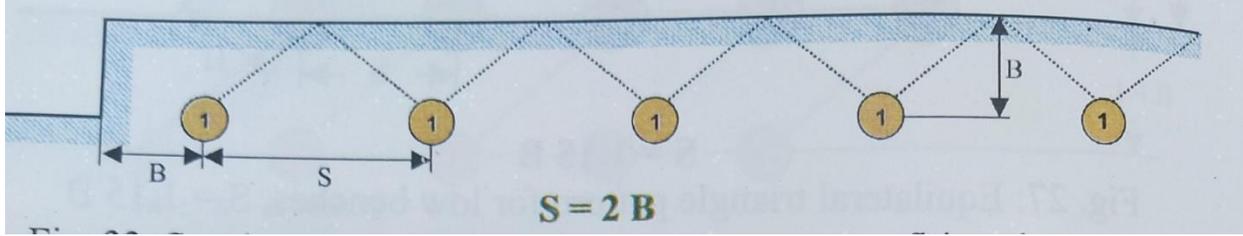


Fig.8o: Spacing equal to 2 times burden, instantaneous firing along row

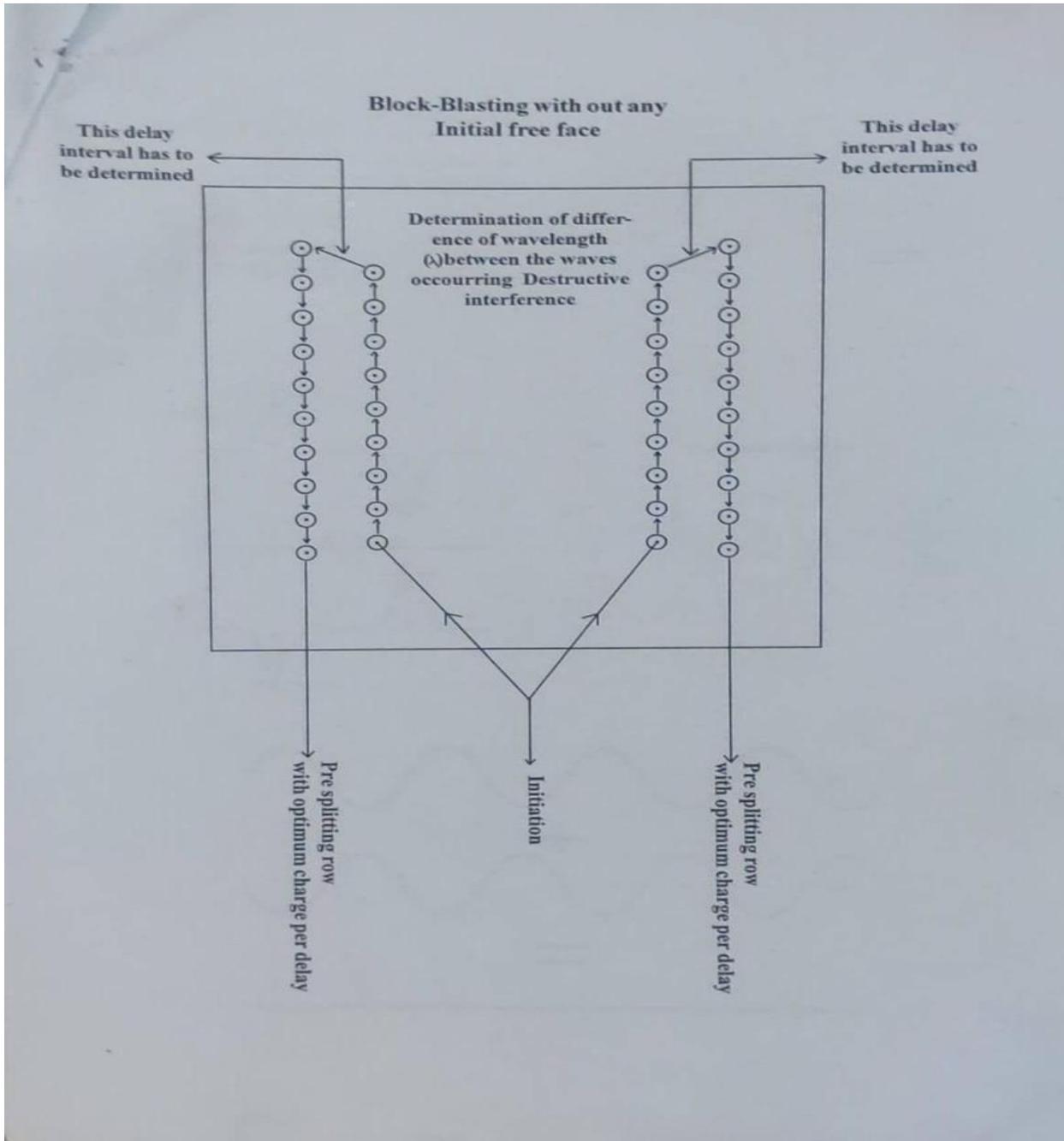


Fig.8p:

Initiation with different types of detonators.

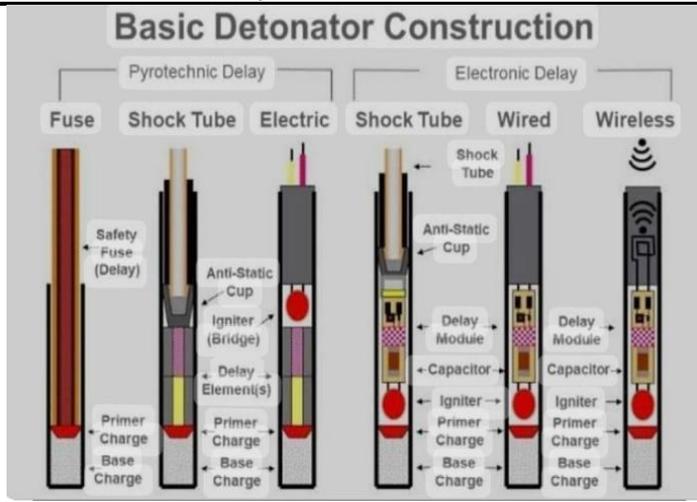


Fig.8q:

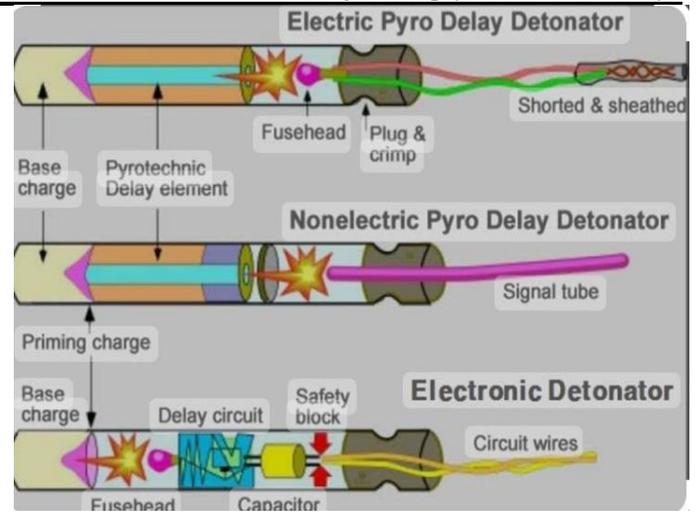


Fig.8r:

Three types of detonators

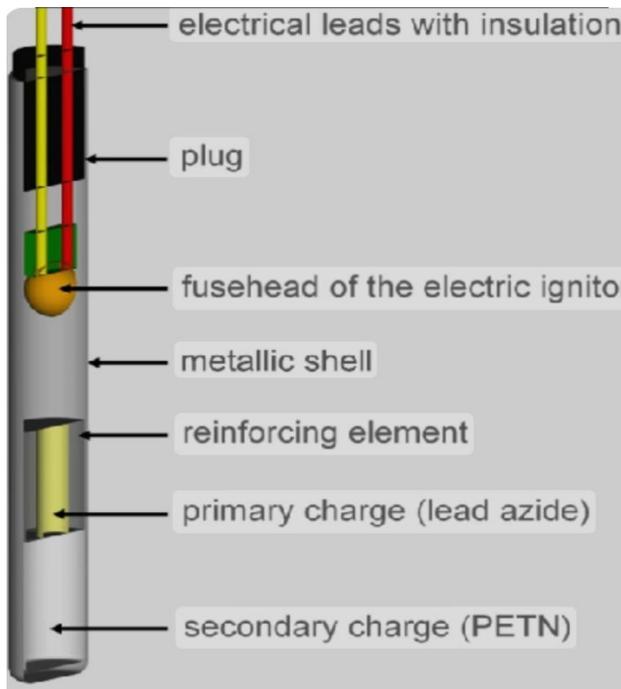


Fig.8s



Fig.8t:

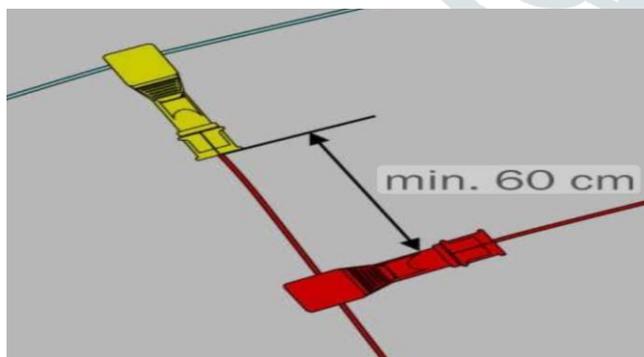


Fig.8u:

Non electric initiation system

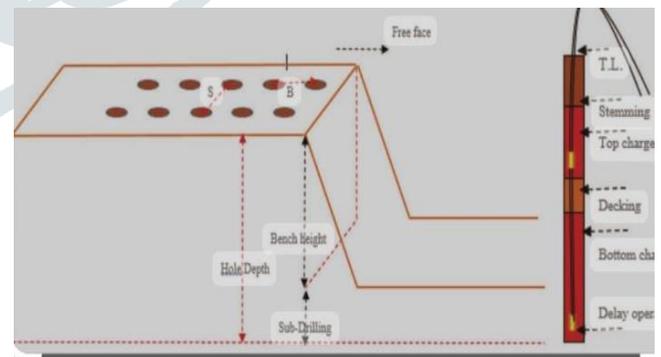


Fig.8v:

Thumb rules for open bit blast pattern

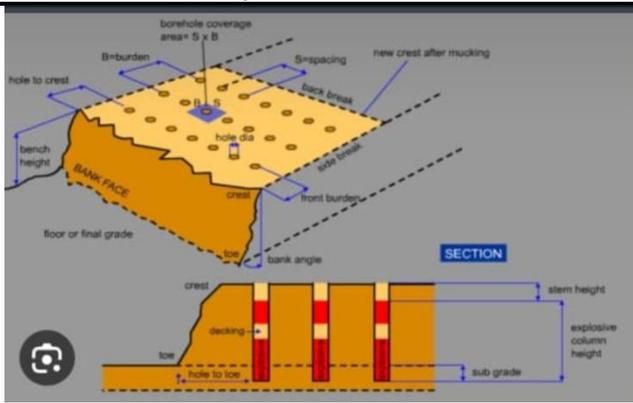
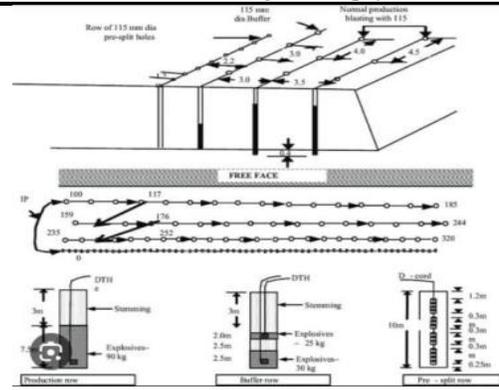


Fig.8w:



Bench model

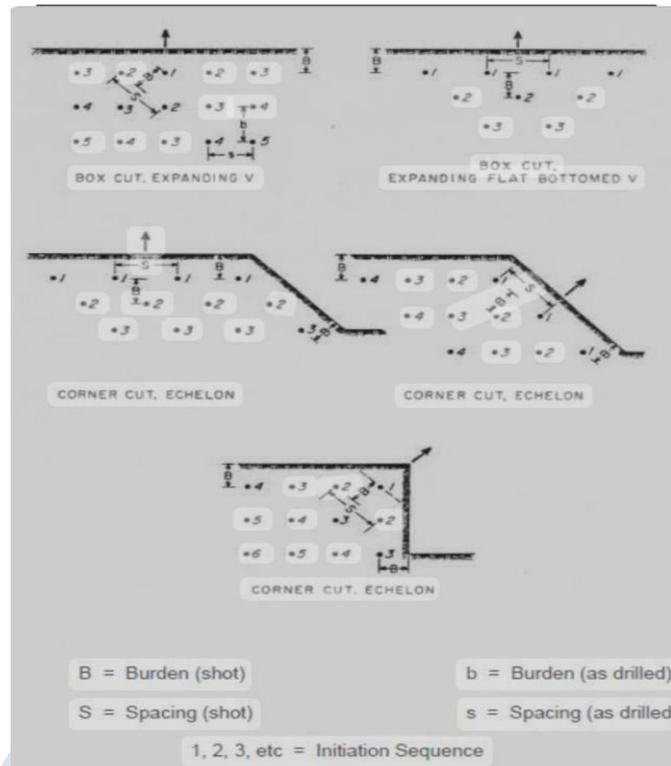


Fig.8.1.a:
Optimum blast design for pit slope stability

Using milliseconds delay detonators, a number of useful firing pattern has been shown on the above figures. Apart from as seismic waves pass through a rock medium they cause particles of the medium to move which is termed as ground vibration. The velocity at which particles of the medium moved is called particle velocity and its maximum value is called PPV. The primary wave causes particle of the medium to move in too and fro motion that is (compression and dilation) with particle movement in the direction of wave propagation. Due to this movement volume of the medium is changing whereas the shape remain same. S-wave causes the particles of a medium to move in a direction that is perpendicular to its direction of propagation. These particle movement change shape of the medium not the volume. Rayleigh wave causes particles on the surface of a medium to move in a elliptical orbit, usually a motion that is contrary to its direction of propagation and it has been estimated that Rayleigh wave constitutes the highest potential damage risk at greater distance from the blasting source.

9. Instrumentation

In seismic excitation due to blast induce ground vibration in open cast mines transmitted through the ground creating a dynamic response in structures. The type and characteristics of the vibration and duration of seismic pulse frequency of propagating waves transmit energy. For measurement of such vibration within certain frequency ranges geophones are being used. This is typically an electromagnetic transducer which emits an electric current which is proportional to the velocity of the vibrating particle. The electric signal is generated by a moving coil within the field of a stationary magnet.

It is designed to measure vibrations within certain frequency ranges. Vibration is measured in terms of peak particle velocity (PPV). The frequency of the ground vibration is estimated from the wave form recorded by seismographs. Vibration monitoring is continued for each site until the test structure become damaged or severely cracked.

10. Conclusion

1. Rock parameters

- a. P-wave velocity (m/s)
- b. Density (g/cc)
- c. Joint spacing (m)
- d. Dip/Azimuth (degree)
- e. Compressive st.(MPa)
- f. Tensile st.(MPa)

2. Explosive parameters

- a. Explosive brand and type
- b. Density (g/cc)
- c. RWS/RBS
- d. Explosive amount (kg)
- e. charge diameter (mm)
- f. VOD(m/s)

3. Design parameters

- a. Burden (m)
- b. Spacing (m)
- c. Hole depth (m)
- d. Hole diameter (mm)
- e. Charge diameter (mm)
- f. Number of rows
- g. Initiation pattern
- h. Delay sequence
- I. Delay interval (ms)

To make the plane of destructive wave interface all the above parameters are equally significant in reduction of ground vibration.

Now blast stability can be defined as the blasting characteristics of the rock mass subjected to a specified blast geometry geological site parameters and explosive characteristics. Blast stability indicates how safely blasting operation can be done under restrictions. The most important physical and mechanical rock properties for safe blasting include—

1. Acoustic impedence
2. Rock structure
3. Frictional properties of the geological discontinuities

In 1989 Ashby given empirical relationship to describe the powder factor required for safe and adequate blasting based on the fracture frequency and friction angle.

$$\text{Powder factor} = 1.4 \cdot \tan(\varphi+i) / \sqrt{(\text{fracture/metre})^{1/3}} \text{ kg/m}^3$$

Where fracture/metre represent the fracture frequency.

φ = friction angle

i= roughness angle

Apart from all these factors the shock pressure pulse (when shock wave is transmitted through water and moves as a pressure discontinuety then we have to considere energy in the pressure pulse which is given by the equation

$$E_s = (12.5 \cdot R^2) / (D_0 \cdot C_0 \cdot W)^{1/3} \int P^2(t) dt$$

R= distance between shot and the transducer (m)

W= charge weight (kg)

D₀= density of water (g/cc)

C₀= velocity of sound in water (m/s)

$P(t)$ = pressure as a function of time

τ = time constant of the falling pressure pulse (s)

t_i is calculated by dividing peak pressure by $e = 2.718$ because upto one time constant pressure falls exponentially.

The integral term can be calculated from the pressure -time profile recorded by the transducer. E_s determines the value of shock energy away from the charge. Close to the charge there is some loss of shock energy. The loss of shock energy depends on velocity of detonation (VOD) and density of the explosive.

During Implementation of a technique to optimize the ground vibration using precise delay it shall be remembered that the other parameters related to control blasting shall be controlled for blast induce seismic excitation. In this concern a blasting method conceptually developed by Livingston (1956) where the blast holes are drilled perpendicular to the surface being blasted and the holes are charged with a concentrated charge (length of charge < 6 times the blast hole diameter). He determined that a relationship existed between the critical depth D_c , from which the first signs of external action in the form of cracks and fractures are noted and the weight of the explosive Q in agreement with the following empirical equation (Jimeno et al, 1995)—

$$D_c = E_t * Q^{1/3}$$

In this strain energy equation E_t = strain energy factor and is a characteristic constant in each rock - explosive combination. Also there is a factor called decoupling which is denoted by $D_c = R_h/R_e$,

R_e = radius of explosive (mm)

R_h = radius of hole (mm), has a significant role to minimize the ground vibration.

Another parameters Hoop strain cause changes in circumferential stresses (Downing 1985). Such strain occurs when Compressive or shear waves propagate perpendicularly along the axis of the hole.

To reduce the blast-induced ground vibrations, here a different technology now being used which quite different from conventional methods and do not take into account the mechanics of seismic waves. Contrary to conventional methods, the proposed technique does not consider any blast-parameters such as explosive types and amounts, blast-geometry, blast-hole design, hole-depth,diameter, etc., except appropriate time-delays to construct a destructive wave interface in the zone of disturbance. The technique employed the most suitable time-delays among blast-hole groupings to minimize destructive interference of the surface waves at the location of blast-induced vibrations.The crucial point of the proposed technique can significantly reduce over break, air over pressure apart from reduction in ground vibration.

11. Applicability

By introducing appropriate delay actually we construct a destructive wave interface to optimize the ground vibration and over break air pressure apart from reduction in ground vibration. That is it is a part of control blasting through which we can maintain pit slope stability, proper dimension of bench, gradient of haul road etc.

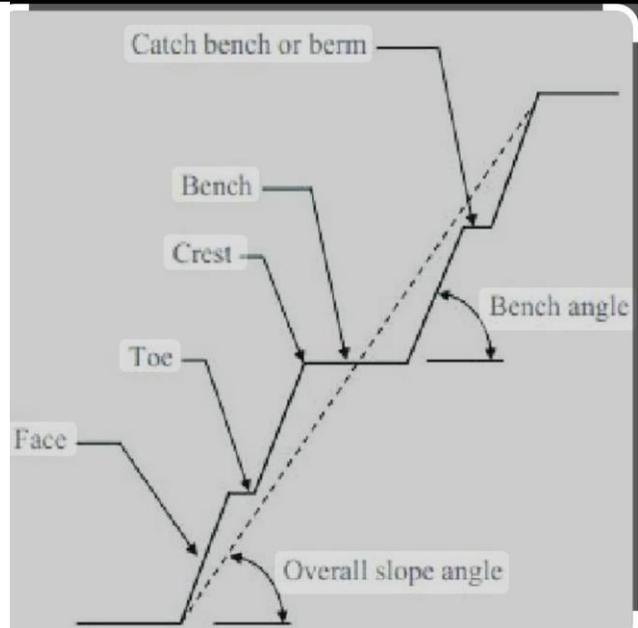


Fig.11.a: Mine geometry

Fig.11.b: Open pit bench slope

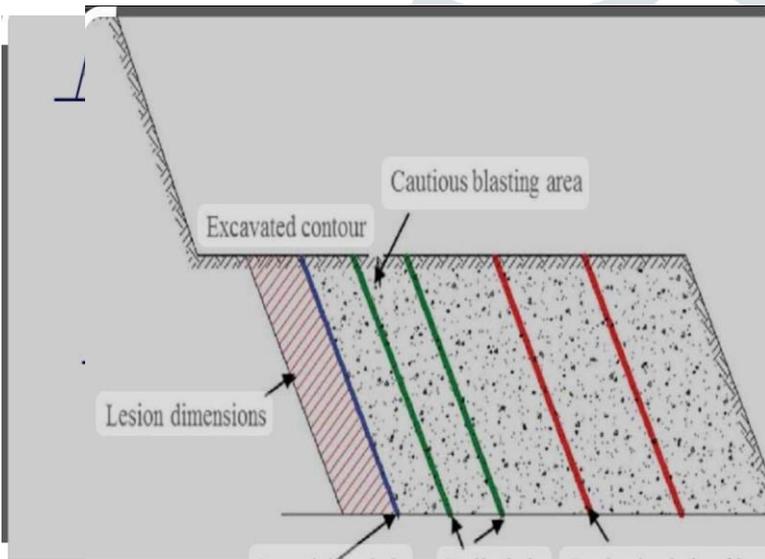


Fig.11.c: Maintenance of slope angle

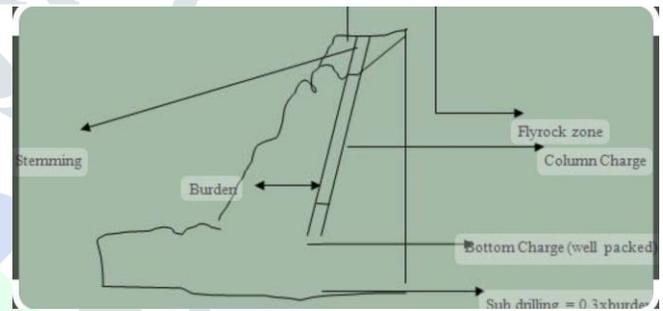


Fig.11.d: Optimization of smooth blasting

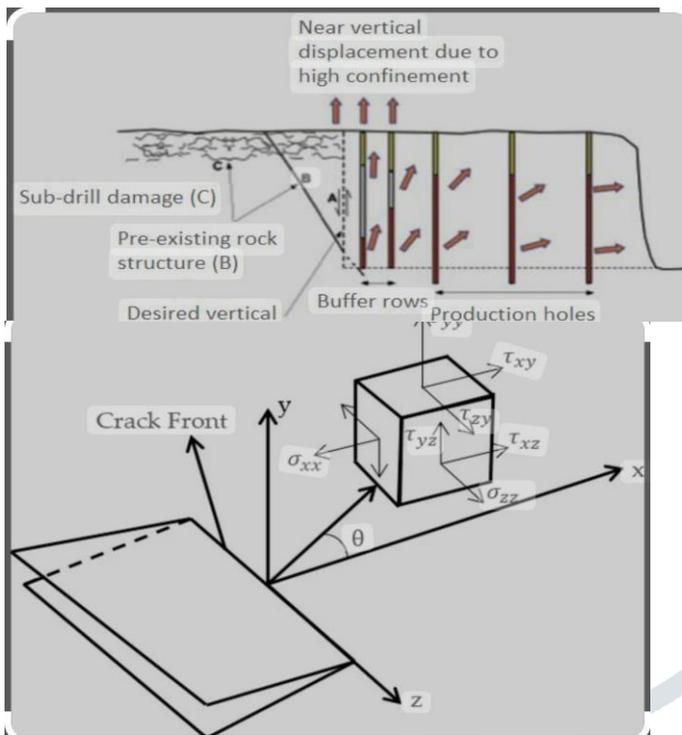


Fig.11.g: Stress intensity distribution

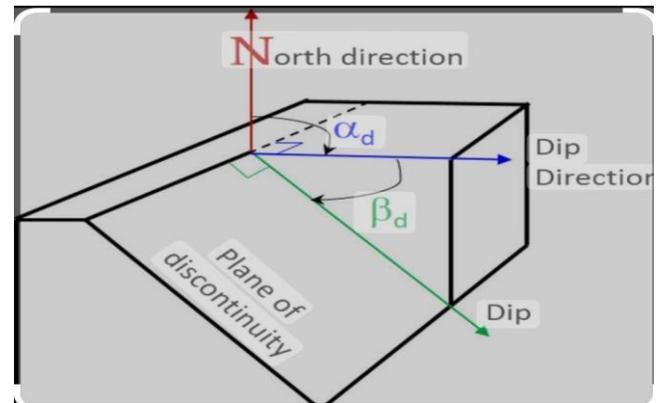
Fig.11.e: Master plan of blasting
Fig.11.f: Fly rock control

Fig.11.h: Prevent farther deformation of geological disturbances

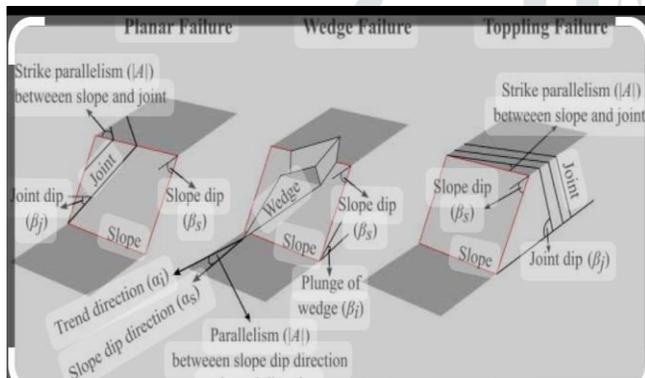


Fig.11.i: Gives a good slope mass rating

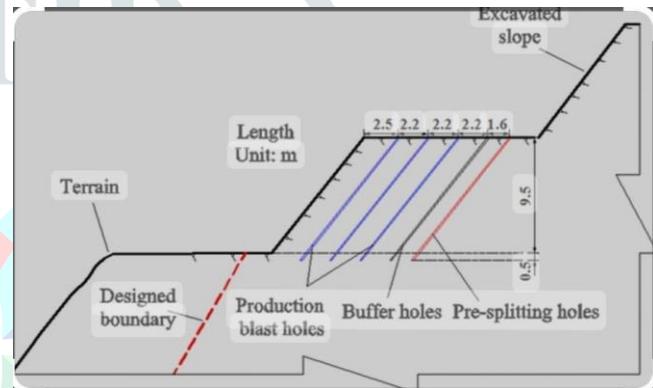


Fig.11.j: Without pre-splitting we get the advantage of pre-splitting

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