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Velocity Of Propagation of seismic waves And it's Interaction With Surrounding Rockmass And Support System During Underground Blasting Vibration For Hard Rock Excavation (A General Study on Geophysics, Seismic Science & Rockmechanics For Underground Mining)

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Abstract

Mining induce seismicity and the related phenomenon of rock burst have become more prevalent in hard rock mining. The development have been complimented by measures in excavation design and extraction sequencing which have done much to mitigate the serious operating problems which can occur in seismically active, rock burst prone mines. In large scale open stope mining, Canadian development based on pillerless stoping, formulation of extraction sequences which promote the evaluation and uniform displacement of a regular mine stress abutment, and the extensive use of cement — stabilised backfill, has been successful in managing an acute mining challenge. Notably, these measures have been based on sound conceptual and analytical models of the relation of damaging seismicity to induce stress, geological structure potential rock displacements and strain energy released during mining. Many mining rock mechanics problem effectively depends on the evaluation of the state of stress over the time scale of the mining life of the orebody which needs to be interpreted in terms of the probable modes of the response of the host rock mass. The computational efficiency of tools for three dimensional stress analysis now permit modelling of key stages of an extraction sequence. The engineering mechanics problem posed in all structural design in the prediction of the performance of the structure under the loads imposed on it during its prescribed functional operation.

During blast induce seismicity 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 occuring along the surface of the periphery of the excavation enables the restoration Of mine structure due to time dependent elastic range without having any heavy damage. Also it supplies a significant amounts of damping to the mine Underground due to different rock layers of different Properties.

Energy input during explosion to the tunnel and protect it from permanent inelastic deformation for some time. This frequency dependent parameter to be considered.

In seismic excitation rock surrounding the excavation and existing mine pillar along the periphery of underground workings vibrates in different mode as a result of which there developed a zone of differential movement in different layers in rock take a part to damage and cracks in the existing pillars and there may be a permanent change of deformation of natural support which decrease the load bearing capacity of the overlying and underlying rock mass.

During blasting underground various seismic waves produced. Apart from this when depth of mining increases phenomenon like rock burst is very common, which is not well defined. Blasting and excavation induced seismicity can not be prevented.

Blast induce seismic excitation deformed existing rock mass near the zone of seismic excitation. In this particular situation we required to calculate dynamic load due to seismicity as well as vertical load due to high depth of cover.

While depth of mining increases the occurrence of seismic events due to depth of the mining and blast induce rock vibration increases.

In this paper a study of Geophysics, rock mechanics and behaviour of seismic science are being discussed during ground movement while blasting operation carried out. Apart from the deformation of rock during seismic excitation we have to consider the energy released from the rock burst prone zone and mechanical energy stored due to mining activities.

I. Introduction

Characterization of blast induce ground motion indicates that the shear strain and corresponding residual Excess Pore Pressure (EPPs) are associated with low frequency near — and far— field shear waves that are within the range of earthquake frequencies. Whereas the effect of high frequency P-wave are negligible. Various results show that rock joints have significant effects on the propagation characteristics of blast induce vibratio.

Rock mass is considered as elastic bodies. The explosion generated pulse in rock mass propagated parallel and perpendicular to columnar joints.

All discontinueties such as joints, faults, bedding planes and other surface of weakness exists in the surrounding of the rock excavation significantly affected by seismic excitation and it is the problem concern to the geotechnical engineering, geophysics and mining engineering.

The understanding of the interaction between rock joints and blast waves is very important as the velocities of seismic waves varies according to the geomining conditions. During rock breaking mechanism there is a outwards transmission of the strong stress wave which disturbed the existing rock texture. When dynamic stress passes through an anisotropic rock medium such as joint plans energy scattering occurs and it reflects in various direction of the bedding plans. So behaviour of interaction of seismic waves in different geomining parameters is considered.

The maximum principle stress that is transactional stress which is built up in the immediate skin of the excavation and other is, stored elastic strain energy surrounding the rock mass. Maximum principle stress remains constant but the rock strength degrades over the time due to loss of confinement and a condition of potentially unstable equilibrium situation developed in the zone of excavation. Which creates dynamic disturbance.

Rock burst may release large amount of seismic energy instantaneously because there is a relaxation of elastic strain stored in a large volume in a highly stressed rock surroundings. During excavation these destructive forces acting on the nature pillar and this highly stressed conditions existing load do not give to regain the original shape of the concerned rock mass when both seismic waves excitation and strata movement withdrawn.

Acoustic properties of rocks relate alternating stresses of varying frequencies and elastic strain. In hard rock blasting there are longitudinal and transversal waves propagation of which is described by the simple wave equation through the study of seismic science and Geophysics. Propagation velocities of elastic waves in rocks decrease with increasing temperature and increase with increasing pressure.

So describing the behaviour of mode of vibration the inner friction in rocks which in turn depends on temperature, pressure, porosity and pore saturation shall be studied. Rocks possess elastic intrinsic and extrinsic anisotropies. Therefore anisotropy behaviour of elastic waves shall be considered during extraction of minerals. The characteristics impedance of a rock ,which is defined as a product of the sonic velocity and the density of the rock is a comprehensive physical property for an intact rock and it is closely related with strengths, fracture toughness, young modulus and poison ratio. Characteristics impedance for a given rock mass either increases markedly with increasing depth. So behaviours of geomechanical disturbances shall be considered during underground mining operations during seismic excitation. Rock quality designation (RQD), rock mass index (RMI), rock mass rating (RMR) and protodyakonov index and other geological parameters which are significantly variable rock to rock are needed for proper dimension of the mine environment. Characteristics impedance of intact rock affects the proneness of rock burst.

When a wave travels in a absorbing medium it losses energy as it propagates through the medium. It has been found experimentally the amplitude of the wave decays by a constant fraction of its value when the wave progresses through a certain distance. This means that the amplitude falls exponentially with distance and we can write the amplitude at a distance x which respect to the origin at x=0 as,

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$A(x)=A_0e^{-\alpha x}$

where A_o is the amplitude at x=0 . The constant α is called the attenuation constant. From above equation we find that

$$\alpha= - 1/A(x)*dA(x)/dx$$

Thus α is the decrease in amplitude per unit amplitude per unit length. Therefore α is the fractional amplitude attenuation of amplitude A(x) per unit length. So during construction of shock wave absorber support system above equation must be considered.

In an elastic meterials at last two types of waves can be propagated— pressure waves and shear waves. Whereas in an acoustic meterials only pressure waves are propagating. Both shear waves and pressure waves are governed with the same equation. The elastic wave equation described the propagation of elastic disturbances produced by seismic waves in blasting. The acoustic wave equation governes the propagation of sound.

Using the stress and strain theory we can solve the seismic wave equation for elastic wave propagation. The equation of wave propagation in elastic solids are described by using Hooke's law and Newton's second law of motion. Solid bodies such as rock mass are capable of propagating forces that acting upon them.

Seismic wave velocities p-wave(V⍰) for unconsolidated materials 1.5—2 km/s, for sedimentary rock bed it is 2—6 km/s, for igneous rocks 5.5—8.5 km/s, for steel it is 6.1 km/s.

II. Literature Review:

In method of minerals extraction natural support of hard rock excavation in mining is important because during blasting in hard rock various seismic waves of various amplitude and strength are produced according to different geomechanical and geomining parameters which may dislodge or decrease the efficiency of the existing static support. When natural frequency and the frequency of seismic waves co-inside the phenomenon like resonance damage the natural mine environmental support system exponentially in day-to-day blasting. In this case, such mine pillars do not withstand the vibration and dynamic load come in contact in the peripheral body of the excavation. The various passive energies and elastic potential energies stored in the surrounding zones of the excavation play an active role for rock collapse. Due to geothermic gradient heat developes in deep mines and thermal conductivity of the rock therein distribute heat and seismic energies.

When seismic waves propagate through a rock mass, they encounter an increasing volume of rock mass, causing decrease in energy density. Such geometrical damping diminishing energy and seismic waves simultaneously affected by numerous inelastic effects that also cause energy loss during wave propagation.

In such situations amplitude is decreased. Although generally seismic waves do not have sufficient energy much beyond the zone of disturbance due to intrinsic attenuation.

Amplitude (A) of particle displacement due to blast induce vibration is proportional to the square root of the weight of the explosive charge(Q) and inversely proportional to the distance (D) from the blast. That is:

$A=KQ^{0\cdot5}/D$

:Morris (1950):

So during calculation of amplitude of seismic waves both should be considered, distance and weight of explosive charge. So the explosive used and associated with blasting has a major importancy.

Generally two groups of seismic waves activated by detonation of explosive charge. Body waves travel within rock mass and surface waves travel along free interfaces. At the moment of blasting rock near the hole shows a hydrodynamic behaviour.

This shock waves instantaneously moved from non-elastic state to quasi elastic zone in which the oscillatory wave motion propagated in sonic velocity and carries insufficient energy which is not destructive for surrounding rock mass.

The amount of energy transferred to a given rock mass is linear function of the product of the density and the rate of detonation, termed as characteristics impedance of explosive. Explosive which has the larger characteristics impedance or close to the characteristics impedance of rock, transfers more energy to the rock mass. So this is the most important variable. For observation of intensity and strength of seismic waves.

Body waves consist of two discrete components— compressional (P-wave) and shear (S-wave). S-wave have two components— S-horizontal and S-vertical.

Two types of surface waves generated in mine blasting— Rayleigh (R-wave) and Love(L-wave). P-wave are faster than S-wave. Velocity of the Love waves remains less than the shear waves velocity. R-wave propagated at a velocity less than S-wave.

But most explosive are detonated as a series of smaller explosion which are delayed by milliseconds and differences in travel paths and delay times result in overlapping arrival of both wave fronts and wave types. (Pal Roy, 1995)

So we have to consider the overlapping waves phenomenon in seismic excitation.

The shock energy transmitted to the rock depends on detonation pressure of the explosive and the detonation pressure is a function of explosive density.

Concern explosive science is being given because —

The most commonly used equation for the detonation pressure

$P(d)(N/m^2) = [V_e^2(m/s) * d_e(kg/m^3)]/3.8$

P (d)= detonation pressure

V_e= detonation velocity of the explosive

d_e= detonation density of the explosive.

As detonation pressure is maximum in the direction of shock waves. So velocity of shock waves depends on the above factors and taking a part during construction of seismic excitation phenomenon. All these parameters are taken to be consideration in calculating to choose the appropriate dimension of the natural support system which enable to absorb the shock.

III. A Study on Geophysics and Rock Mechanics and Seismic Science during blasting

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 (both of rock mass and its support structure). 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 materials of its support structure that is it depends on density and elasticity. Density is a measure of how much mass contain in a given volume. 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 these relationships is very important for predicting and controlling seismic behaviours both of rock, surrounding the mine excavation and its support meterials.

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 ulta 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 meterials 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.

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 there internal strength is exceed. 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 shap. 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 an rock burst or rock

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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, poison 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 sensetive 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 by stress field. When released this energy gives rise to seismic waves and uncompensated net force will result in acceleration as per Newton's law.(Reading — Telford et al, section 4.2, Introduction to seismology, Peter M Shearer, Institute of Geophysics and Planetary Physics, University of California).

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 "

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

The effect of open cast blasting deformed the underground rock mass that is load come from 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 parmanent 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 accross surfaces is termed as matrix in elasticity.

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In this concern the study of Dr. Pijush Pal Roy ,Scientist CSIR- CIMFR ,India,1991 has given a potential observation in which different parameters may be a strong tool to give a real model to construct the shock absorber support system the hypothesis made in this paper. In the study of the Dr. Pal Roy it has been found describes below —

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 catagory of geometrical effects, including geological discontinueties, 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 $$V=K(D/Q^{1}/3)-Be-\alpha D$$

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 negetive 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 considered 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 discontinueties 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

$$V= n+K(D/Q^{0}.^{5})$$

As n is categories as a damping parameter that is influenced by rock properties and geometrical discontinueties, 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

$$Vv= \{2K1PDr12l(r1+r2)^{-}\tau\alpha\}/\rho1c1(l2+x2)3/2$$

$$K1=VD\rho_2/\rho_1c_1$$

$$PD= \tfrac{1}{2}\,\sigma t[10^3(Q/K3)^{1/3}]^2/(k2r2)^2$$

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.

VV= peak particle velocity (mm/s)

K1=(characteristic impedance of explosive)/(characteristics impedance of rock)

ρ_1= density of rock (gm/cm³)

c_1= P-wave velocity in rock (m/s)

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ρ_2= density of explosive (g/cm³)
VD = velocity of detonation of explosive (m/s)
PD = peak charge pressure (MPa)
r_1= radius of the charge (mm)
l= depth of centre of explosive column from the surface (m)
x= distance of the measuring transducer from the blast hole (m)
Q= weight of explosive in blast hole (kg)
σ_1= tensile strength of rock (MPa)
K_2= proportionality constant=1.0 for most rock
K_3= factor relating to the lifting of one m³ rock mass by 0.8kg/m³ explosive (for most rock)
τ= charge symmetry parameter (2 for cylindrical charge and 3 for spherical charge)
α= an explosive constant of parametric value lying between 1.2 and 1.5.

Excessively high ground vibration from underground production blasting alone or coupled with the increase stress due to openings created by extraction of minerals or coal may cause damage to the roof rock and may affect the stability of roof bolts and mine supports and cause ventilation stoppage. The area of underground workings affected by such vibration needs to be assessed and proper supports ensured. Based on the studies conducted by CSIR -CIMFR in conventional methods of blasting in mining and construction projects, a peak particle velocity (PPV) of 100 mm/s was found safe for the stability of coal mine roof and pillars from underground blasting. Thus the area of underground workings experiencing a vibration of 100 mm/s or more should be treated as a zone of disturbance. Blasting vibration may induce substantial dynamic loading on mine openings, which is difficult to assess and generalize in respect of the effect on the over stability of workings. General observation of Siskind(2000) shown there can be an effective guidance to prevent roof collapse and pillar failure and it has been seen from his studies that there is a strong influence of geotechnical properties on the velocity and frequency content in the wave motions. Therefore, there is a need with specific attention for determining the damage threshold values on underground working.

Apart from seismic load on mine pillar the mechanics of vartical loading on pillar due to depth of cover and other geological parameters is very complex to give a exact mathematical analysis. In order to compute the pressure acting on the pillar the following assumptions are made

Any element of the ground at a depth d below the surface is subjected to a pressure P_0, which depends on the weight of the superincumbent rock so that P_0=W*d (w= weight per unit volume of the superincumbent rock.

Each pillar support the volume of the rock over an area which is the sum of the cross sectional area of the pillar plus a portion of the bord area, the latter being equally shared by all the pillars. The load is vertical only and is uniformly distributed over the cross sectional area of the pillar. Then Pressure (P) can be written as P= P_0*1/1-R.(R= percentage of extraction).

The determination of load on rock pillars is difficult. The strength of coal (or sedimentary rock like coal)pillars S was found to have as S=R*K*$W^{0.46}$/ $h^{0.66}$ ld/in²(CSIR -CIMFR, Sheorey et al , 1982, after Salamon and Munro, 1967).

Here, S= strength of pillar in ld/in²
K= a constant= 1320 ld/in², which is the strength of one ft³ of coal.
W= width of pillar
h= height of the pillar

Load bearing capacity of rock mass has a function is to limit the convergence so that the roof fractures are low enough to have no adverse effects on mining activity. Certain amount of convergence is unavoidable and is desirable upto some extend as the value being different roof situation or the geomechanical parameters. Thus the desired load bearing capacity after mine excavation may be defined as that which will not permit the convergence to be in excess of the threshold value at which roof deterioration accelerates. It should be noted that no universal formula can be given which will be applicable to all situations. Every situation will need detailed study and analysis of the lithology of the nature of the rock mass.

(Reading— Rock Mechanics for underground mining by B. H. G. Brady and E. T. Brown, 3rd edition, Kluwer Academic Publishers, New York)

All these parameters have a strong influence to categorised the strength of the seismic excitation during open cast blasting which in turn results the underground rock movement.

IV. Stress and strain behaviour (Reading;Shearer. P,Telford et. al)

By combining classical dynamics of Newton's , the acceleration of Simple Harmonic Motion (SHM), and Hooke's Law, we can derive the equation relating the angular frequency (ω) to the mass(m) and the spring constant (k). As per convention acceleration is denoted by “a”.

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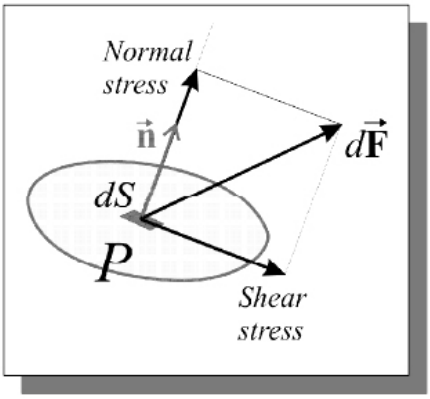
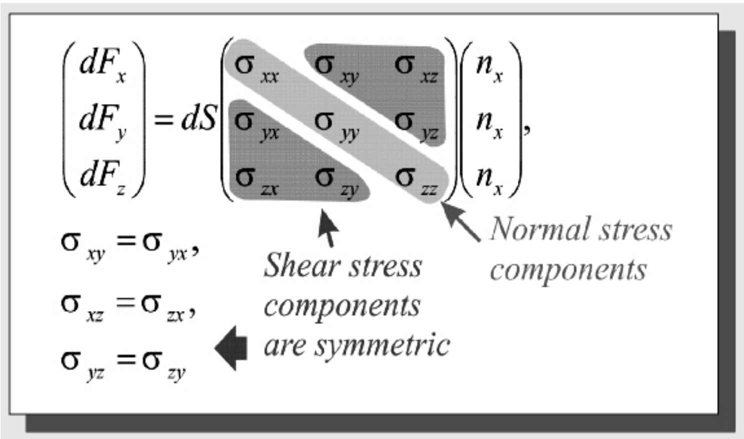
Newton's second law: F=m*a
Simple Harmonic Motion:$\alpha=-\omega^{2x}$
Hooke's Law: F=-kx
$F=-m\omega^2x=-kx$
$k=m\omega^2$
$\omega=\sqrt{(k/m)}$
We can then find the period (T) associated with this oscillating mass-spring (as shown in figure) by the definitions of period and angular frequency. We shall use "f" to indicate the frequency (not the angular frequency, they're different)
T=1/f
$\omega=2\pi f$
so $T=2\pi/\omega= 2\pi\sqrt{(m/k)}$
Simple Harmonic Motion is periodic motion, motion that repeats itself over consistent intervals, that is assumed to ignore damping in anisotropic rock mass.
The spring constant (k) is a quality of the spring that describes how "strong" the spring is.
Spring with a higher spring constant are more difficult to compress and extend than springs with a lower spring constant.



Consider the interior of a deformed body :-
At Point P, force dF acds o n any infinitesimal area ds stress, with respect to direction n is a vector lim (dF/ds)(as ds-0)

Stress is measured in [Newton /m^2]
dF can be decomposed in to components relative to n
i)Parallel (normal stress)
ii)Tangentinal (Shear Stress)

Stress in general , is a tensure : It is describe in terms of 3 force components acting across each of 3 mutually arthogonal surfaces. 6 dependent parameters. Force dF/ds depends on the orientation n, but stress does not. Stress is best described by a matrix.



In a continous medium , stress depends on (x,y,z,t) and thus it is field.

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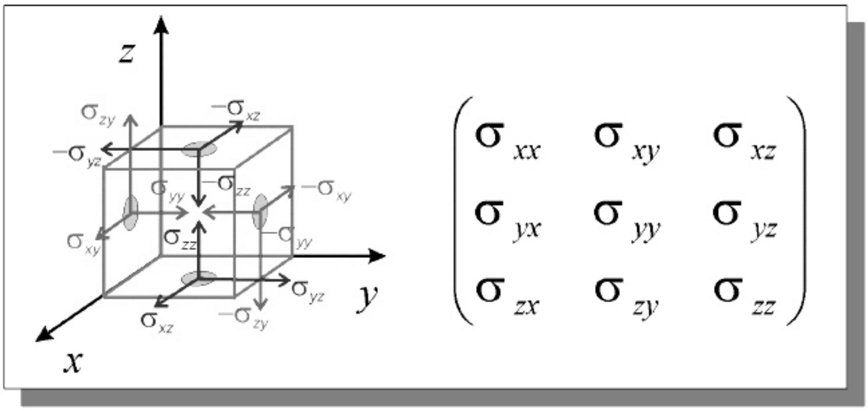
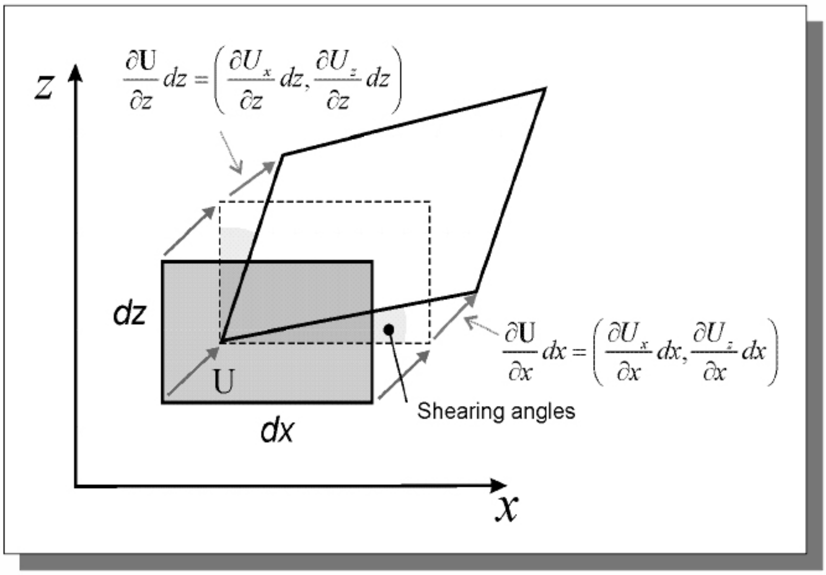


If we consider a small cube within the elastic rockmas body . Assume dimentions of the cube equal '1' Both the forces and torque acting o the cube from the out side are balanced.



In consequence , the stress tensor is symmetric :
Strain is a measure of deformation , i.e. variation of relative displacement as associated with a particulatr direction with the body of rockmas considered. Like stress it is decomposed into normal and share components. Seismic waves yield strains of $10^{-10} = 10^{-6}$. So we relay on infinitesimal strength theory

Elemantary strain is simply
$e_{ij}= dU_i/dX_j$
How ever anti – symmetric combination of e_{ij} above yield simple rotations of the body without changing its safe. To character deformation only the symmetric components of the elementary strain is used

Original Volume V= $d_x\, d_y\, d_z$

Deformed volume V+dv – (1+Exx)
(1+Eyy) (1+Ezz) $d_x\, d_y\, d_z$

Dilatational Strain : $$\Delta=\frac{\delta V}{V}=(1+\varepsilon_{xx})(1+\varepsilon_{yy})(1+\varepsilon_{zz})-1\approx\varepsilon_{xx}+\varepsilon_{yy}+\varepsilon_{zz}$$

Therefore $$\Delta=\varepsilon_{ii}=\partial_i U_i=\vec{\nabla}\vec{U}=div\,\vec{U}$$

Shear strain does not change the volume
Describes the stress developed in a deformed body F-kx for an ordinary spring (I-D) (Hooke's Law)
$\sigma \sim \varepsilon$ (in some sense) for a '*linear*', '*elastic*'
3-D solid.

Wave equation of velocity of propagation of seismic waves as per the convention of classical physics.
(Propagation of compression /acoustic waves)

To show that these three equations describe several

types of waves, first let's apply divergence operation to them:

$$\rho\frac{\partial^2\Delta}{\partial t^2}=(\lambda'+\mu)\nabla^2\Delta+\mu\nabla^2\Delta=(\lambda'+2\mu)\nabla^2\Delta$$

This is a wave equation; compare to the general form of equation describing wave processes:

$$\left[\frac{1}{c^2}\frac{\partial^2}{\partial t^2}-\nabla^2\right]f(x,y,z,t)=0$$

Above, c is the wave velocity.
We have:

$$\left[\frac{1}{c^2}\frac{\partial^2}{\partial t^2}-\nabla^2\right]f(x,y,z,t)=0$$

This equation describes compressional (P) waves
P-wave velocity:.
(Propagation of shear waves)

$$v_p=\sqrt{\frac{\lambda+2\mu}{\rho}}=\sqrt{\frac{K+\frac{4}{3}\mu}{\rho}}$$

Similarly, let's apply the curl operation to the equations for **U** (remember, **curl**(**grad**) = 0 for any field:

$$\rho\frac{\partial^2}{\partial t^2}\mathrm{curl}\,\mathbf{U}=\mu\nabla^2\,\mathrm{curl}\,\mathbf{U}$$

This is also a wave equation; again compare to the general form:

$$\left[\frac{1}{c^2}\frac{\partial^2}{\partial t^2}-\nabla^2\right]f(x,y,z,t)=0$$

This equation describes shear (S), or transverse waves.
Since it involves rotation, there is no associated volume change, and particle motion is across the wave propagation direction.
Its velocity:VS < VP,

$$V_s=\sqrt{\frac{\mu}{\rho}}$$

For anisotaropic rockmas the seismic wave follow the all the above equations
Inhomogeneous wave equation describes waves generated by a source like Blast induced explosion (Generate seismic waves).

This also includes all the free waves and therefore it needs boundary conditions to specify a unique solution :-

And we get the velocity of compressional wave (P) as written above
V_P = is the velocity of compressional wave (P)
P= Density of the medium
U= rigidity modulus [Both λ and μ are called Lame constant]
k- Bulk modulus

V. Conclusion of the Study

1. Load On Mine Pillar Due to Seismic Excitation shall be Considered with Vertical Load due to depth of cover
2. The Numerical Analysis shall be effective In Underground Metal Mine where LPDT(low profile dumper truck)are being used And Mine Road ways are competitively of high dimension
3. In the four way junction of the underground mine it is very effective rather than the temporary narrow road way.
4.Proper application of Geophysics, Rockmechanics,Applied Geology shall be introduced before any mining operation for appropriate load bearing capacity of the excavation
5.According To Stress —Strain behaviour of rockmass support designer can give actual real model in every individual zone of the mine area which gives more safety as there shall be a minimum probability of roof and side collapse
6. Load due to Seismic Excitation during heavy blasting can easily be calculated before any excavation apart from verticaload due to high depth of cover
7.Rock burst prone or the zone of Geological disturbances may be supported prior to any critical mining operations

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