SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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CORRELATION OF PEAK PARTICLE VELOCITY DURING BLASTING AND PARTICLE SIZE DISTRIBUTION

By

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled “**Correlation of Peak Particle Velocity during Blasting and Particle Size Analysis**”. I also declare that, it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or university.

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LIST OF ABBREVIATIONS

PPV	Peak particle velocity
VOD	Velocity of detonation
ANFO	Ammonium nitrate fuel oil
NG	Nitroglycerin
RQD	Rock unit designation
GSI	Geological strength index
PLT	Point load test
UCS	Uniaxial compressive strength

KORELASI HALAJU PUNCAK ZARAH KETIKA PELETUPAN DENGAN PENGEDARAN SAIZ ZARAH

ABSTRAK

Pengawalan pemecahan batu melalui peletupan boleh diselia melalui beberapa faktor, tetapi faktor yang mengawal gegaran melalui anggaran halaju puncak zarah yang dipantau agak diabaikan sebagai parameter penting dalam peletupan hasil. Dalam mana-mana operasi kuari letupan, pemantauan letupan disebabkan getaran tanah berada di bawah paras yang ditetapkan adalah sangat penting bagi menghalang mana-mana kerosakan kepada struktur berhampiran, melindungi keselamatan awam dan mengurangkan aduan terhadap kerja kuari. Kajian ini adalah khusus untuk melihat hubungan antara letupan disebabkan getaran tanah melalui puncak pemantauan halaju zarah dengan taburan saiz zarah yang dikehendaki. Saiz pecahan batu dari proses peletupan perlu didalam saiz yang telah di tetapkan di kawasan kajian yang di mana telah ditetapkan saiz batu 800 mm kebawah. Kajian ini dilakukan dengan memantau letupan kuari menggunakan geofon dan menganalisis dalam perisian Blastware. Pekali tertentu laman diperoleh untuk membolehkan ramalan halaju puncak zarah. Analisis pemecahan dilakukan melalui analisis imej digital, di mana perisian Wipfrag digunakan. Kajian ini menyatakan halaju puncak zarah tinggi mendorong pemecahan yang baik dan boleh dicapai serta ramalan adalah amat mungkin.

CORRELATION OF PEAK PARTICLE VELOCITY DURING BLASTING AND PARTICLE SIZE DISTRIBUTION

ABSTRACT

Fragmentation control of blasted rock can be regulated through a number of parameters, but governing factor through estimated peak particle velocity by vibration monitoring are somewhat overlooked as a significant parameter in blasting outcome. In any quarry blasting operation, monitoring of blast induced ground vibration to be under stipulated levels is very important to hinder any damage to nearby structures and protect civilian safety and lessen complaints towards the quarry work. This research is dedicated to find correlation between blast-induced ground vibrations through peak particle velocity monitoring with the wanted particle size distribution of blasted rock. Fragmentation for blasting operations have to be in line with demands and in the stated area of study the demand is to be 800 mm in size or lower. The study is done by monitoring quarry blasts using geophones and analyzing in Blastware. Site specific coefficients are obtained to enable prediction of PPV. Fragmentation analysis is done through digital image analysis, where the software Wipfrag was utilized. The establishment stating high PPV induces good fragmentation was achieved and prediction is possible.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Rock excavation and transport in mines and quarries utilizes drilling and blasting as the most viable and economical method for execution as they produce manageable sizes of rocks. These methods are also very important in other sectors such as in civil construction works. Surfaced adverse effects from blasting are unavoidable and cannot be completely omitted. The effects are ground vibrations, airblasts, flyrocks, back breaks, noise. In a number of incidents that resulted in damage to properties, injuries and death, blasting is the cause. Design factors and preparations are crucial in minimizing the effects to a permissible and more tolerable levels. Among the negative effects, the major concern of planners, blast designers and environmentalist goes to ground vibrations. Various research have been done on this matter and a number of suggested some methods to minimize the levels of vibration caused by blasting. Ground vibration directly correlates to the quantity of explosive used and the distance between blast face to the monitoring location (Hosseini, 2013). Geological and geotechnical properties of the worked rock also serve as important parameters in vibration. Despite the negative reviews on ground vibration, blast designers can use the information obtained from vibration data to further enhance blasting efficiency.

Ground vibrations caused by blasting is a result of employing explosives that, in the past, have been very difficult to meritoriously contract. The involvement of many variables and site constants in specific equations, result in the representation of vibration waveforms produced from the confined blast. Minimizing unwanted effects of ground induced vibration boils down to proper application of blast design and field controls during drilling and blasting operation. Well-designed blast plan would return an evenly-distributed blast energy. This would ultimately maximize the utilization of the energy of the blast in crushing of rock and separation from the worked bench. Valuable data of the particle velocity can be obtained by the monitoring of the ground induced vibration. Not only can the data collected be used for measuring the permissible levels of vibration and biding the laws of blasting, the data can also be used for production efficiency calculation as a result of the blast and that can contribute in blast designs in the future. Efficiency of operation and production cost are of important aspects that determines the life of mine. One of the aspects of production that can be efficiently improved by ground induced vibration is the fragmentation of blasted rocks for initial crushing.

Adequate and even fragmentation of blasted rocks are desired in any blasting operation as managing oversized rocks would consume more production and transportation time thus causing delay, uses unnecessary energy and increase significantly in terms of costs. Fragmentation refers to the sizes of blasted rocks produced by the initial blasting of the bench. Proper design and execution of the blasting are crucial in producing the wanted fragmentation of rocks. Various measuring methods have been proposed in order to measure fragmentation of blasted rock. Basic evaluation methods such as sieving of the blasted rocks are simply not possible due to its high costs and causes delay in the production cycle. Therefore, an alternative method is chosen to be used in this research is via the digital image analysis method.

1.2 Problem Statement

Efficient and effective mine management is absolutely important in determining the life of mine. Proficiency in production plays a huge part in mine operation and blasting is considered to be the initiation stage of production. Proper blast design will result in adequate fragmentation, which will reduce downstream expenses associated to hauling, equipment maintenance and crushing.

The parameters that influence the propagation and intensity of ground vibration during blasting are dependent on a number of factors; controllable and uncontrollable. The majority of the controllable factors are closely regarding to blast designs of the operation with the charge weight being the most influential. Vibration and peak particle velocity are controllable blasting parameters that are able to determine the outcome of fragmentation.

Vibration intensity have to be under regulatory limitations to avoid flyrock and airblast. Vibration data on the intensity can also be used for fragmentation outcome of the operation. This research requires vibration monitoring via seismograph and fragmentation measurement via digital image analysis.

1.3 Objectives

The objectives of this research are:

- To predict peak particle velocity levels of a blast in reference to the charge weight-distance relation.
- To optimize peak particle velocity data with scaled distance analysis model.
- To analyze fragmentation of blasted rocks on the note to its relativity to peak particle velocity of the blast.

1.4 Scope of Work

The thesis consists of five chapters. Chapter 1, an introduction towards the research which includes the objectives and problems related to this research. Chapter 2 is the literature review on vibration and particle velocity monitoring and the parameters that influence ground vibrations. Fragmentation measurement via selected method is also reviewed in this chapter. Chapter 3 explains about the experimental work including monitoring and measuring method chosen throughout the course of this research. Chapter 4 discusses the results obtained from the research. Lastly, chapter 5 is the conclusion and suggestions to improve this research.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

One of the most important process in most mines and quarries production is utilizing controlled explosives for blasting due to the fact they are cheap in expense and fast in production and process. Manageable factors that exist that directs blasting process are blast design, delay time, confinement, sub-drill, charge type and its weight per delay. Confined explosive energy produces very high temperatures and pressure in a very short period of time. High pressure gases are vented out by the explosives causing the surrounding rock to melt and crushed due to the powerful forces exerted upon them. Detonation of explosive also produces ground vibrations and airblast to be released to the surrounding rock body and environment. These vibrations travels through distances that would ultimately arrived to populated buildings and residential areas and would cause a stir in the community. Escaped flyrock from blasting poses threats to the nearby residents as they can result in property breakage, injuries and death.

Explosion during blasting produce wave forms that travel out to the surroundings, namely body waves that travel through the rock mass and surface waves which travel along the surface layers of the earth. A position close to a blast would experience wave motions that consists of both elastic and inelastic wave forms that can reach a high frequency of greater than 25 Hz. The waves would achieve their elastic property and proliferate drastically at about 30 meters at about the normal frequency of the rock mass 10 – 50 Hz.

Generation of vibrations are dependent on a few factors than happened and designed up to the point of blasting. Different types of rock mass would produce varying vibration results. Rock that poses high strength or high moduli would yield a greater percentage of breaking energy and would produce bigger spans of seismic waves. Weathered, weak rock near the earth's surface may produce lower than normal vibration intensities in blasting.

Varying types of explosives give out different amounts of shock and heave power considering the bore hole pressure and the level of confinement. In blasting, the maximum charge weight per delay is imperative and contribute to the intensity of vibration PPV value. Constructive interference between delays occurs and produces increasing levels of vibration, dependent of delay interval.

The ultimate goal of blasting process is to detach wanted rocks and from the rock faces and at the same time produce rocks with manageable and permissible sizes of rock fragmentation. Fragmentation notes the overall sizes of broken rock after blasting and it can be controlled depending on the parameters that governs it. Blasting is the first stage of reducing the sizes of broken rock. Different fragmentation sizes are appointed with different mines and quarries as they are solely dependent on the end sizes of the product.

Further comminution of the blasted rocks using breakers would have to be executed if the outcome sizes of the rock is too massive for feeding into crushers. This part of the production process is cost and time consuming delivering delays to crushers and postponing production line in the long run. Managing time and expenses is very crucial in a life of mine because it translate to its efficiency and its success with the top goal of maximizing profit.

Fragmentation analysis of the run of mine through sieving is generally not possible owing to its high cost and disrupts production cycles. Innovations and continuous development for fragmentation measurement had been approached by numerous researchers to deliver efficiency and ease in the said matter. Alternative methods to fragmentation measurement are belt scale readings at different selected positions, production data of the various size fractions, and digital image analysis. Selection of analysis method is to a large extent site-dependent.

2.1 Explosives

The act of blasting and rock crushing are made possible through the mechanism of explosives. Since the introduction of black powder and constant dedication in research, explosives have been the primary method in rock loosening activity (Orica Quarry Services, 2008). Proper initiation of commercial explosives rapidly convert chemical reaction into exertion of high temperature gases in high pressure. The rapid expansion of this gases in confinement of rock, results in extremely high strains in the rock, for example, a liter of explosive expands up to 1000 liters of gas in milliseconds.

2.1.1 Classification of explosives

Industrial explosives can be classified into two types where they differ in terms of their requirements for detonation, which are low and high explosives. Low explosives consist of explosive material that does not require a detonator for initiation. Examples of low explosives is black powder or gun powder. Normally, low explosives can readily set off through flame ignition that provides heat or spark which is provided by the spit of either a safety fuse, a wick or an electric fuse head. The ingredients that make up the mechanical mixture, does not chemically combined to form a new compound and not an explosive by themselves.

One other type are high explosives where there are two classes of their own, primary and secondary. Primary high explosives are used as starter explosive in detonators. They are extremely sensitive to any form of shock, friction and heat and so they respond by rapid burning or just detonating. Lead azide, mercury fulminate, and lead styphnate are examples of primary high explosives. Moreover, secondary high explosives are relatively insensitive to forms of shock, friction and heat. They may be ignited when exposed to heat or flame in small unconfined quantities but detonation can occur. Their power is utilized when they are added to detonators to boost power. Examples of secondary boosters are dynamites, emulsion, watergels and also cast booster such as pentolite. The velocity of detonation (VOD) is between 4000 m/s and 7500 m/s depending on composition, densities, degree of confinement and diameter.

2.1.2 Explosive ingredients

Explosives contain the following essential ingredients:

1. Oxidizer: The chemical that provides oxygen for the reaction to occur.
2. Fuel: Reacts with oxygen to provide sufficient heat to the mixture.
3. Sensitizer: Generally air or gas, that provide voids that act as ‘hot spot’ for which reactions would occur.

2.1.3 Types of explosives

Mining industry uses different types of explosives in the rock loosening process from benches, namely; Ammonium nitrate and fuel oil (ANFO), gelignite, watergels and emulsions (Kumar, 2013).

1. Gelignite: The chemical compound being based of nitroglycerin (NG), manufactured in a form of gelatinous or semi gelatinous. Due to their high cost and stricter safety requirements, the use of gelignite in the mining industry is somewhat decreasing.
2. ANFO: A mixture of inert chemicals to make an explosive compound when associated together within the correct proportion. The optimum proportion for the mix is 94.3% AN: 5.7% FO and the result is an effective blasting agent. ANFO cannot be detonated by a detonator alone, for detonation it needs a primer.
3. Watergels: The invention of watergels was to overcome the deficiencies of ANFO in wet conditions. They contain a gelatinizing agent, also known as a thickener that modifies their consistency. Watergels possess a lower toxicity and safer manufacture, transport and storage.

4. Emulsions: Fine droplets of ammonium, sodium or calcium nitrates are finely disperse into continuous phase of fuel oil. This emulsion is the stabilized against liquid separation by an emulsifying agent. Emulsions have excellent water resistance properties.

2.1.4 Properties of Explosives

Physical characteristics of the explosives describe their method of handling because they differ in terms of physicality. ANFO types are loose, while emulsion type have a syrupy consistency. Each type of explosive display their own unique characteristics that are suitable for respective suitable blasting conditions.

Explosive strength measures the amount of energy released during blasting operation hence their ability to do work. The total of the energy released from detonation consists both useful energy that causes rock fragmentation and waste energy that spreads out causing ground vibration, air vibration, noise, heat and light.

The rate at which the detonation wave passes through a column of explosive is the VOD. The shock energy upon detonation increase rapidly with this velocity. Most of the high explosives used in mines have a VOD between 2500-5500 m/s. Higher VOD of the explosive are required for satisfactory rock fragmentation.

The density of the explosives chosen for the blasting operation determines how much of the energy of the shot being concentrated brings for efficient rock breakage. Most densities of commercial explosives is between the range of 0.8 g/cm^3 to 1.6 g/cm^3.

Water resistance is defined as the ability of an explosive to tolerate exposure to water without either losing power or becoming desensitized. The energy released of ANFO when placed into holes of wet conditions would be far less because they have low water resisting properties. It is much more reliable to use a gelatinous or slurry explosive in wet environments.

The measure of amount of toxic gases, primarily carbon monoxide (CO) and nitric oxide (NO_x), produced by the detonation of an explosive is called the fume class. In blasting, slurry explosive and AN based explosives are preferable. Factors like insufficient charge diameter, inadequate priming, improper delay timing and water deterioration may change the chemistry of an explosive during detonation.

Explosive sensitivity refers to the ease of which it will explode. Explosives must fall upon safety reasons as they have to be insensitive for manufacture, handling and, placement in blast holes, yet sensitive enough to be easily detonated upon initiation when required. Sensitivity describes the explosive reaction to shock, impact, friction, electrostatic discharge and heat.

2.2 Blast design

To obtain optimum results from blasting, part from the geological setting of the blasting site, the blast design should be of optimal decision. The blast design, as illustrated in Figure 2.1, consists of:

I. Bench height
II. Blast hole diameter
III. Burden
IV. Spacing
V. Sub-drilling
VI. Initiation sequence for detonation of explosive
VII. Powder factor

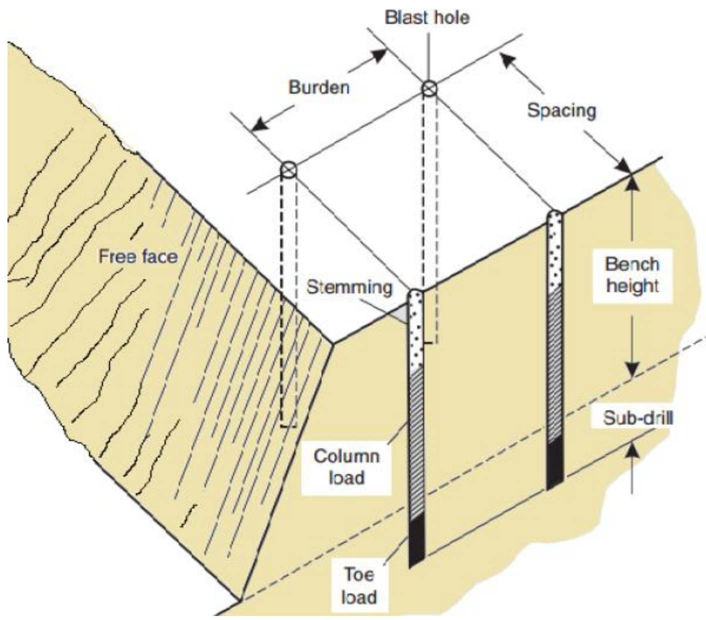

Figure 2.1: Geometrical design of blast hole (Kumar, 2013)

2.3 Rock Fracturing

Blasting is the most accepted and practiced technique for rock breaking (Dhekne, 2015). During detonation, explosives are rapidly converted into a high temperature and high pressure gas. This energy conversion would be exerted against the confined walls of a blast hole, fracturing and breaking the rock that makeup the walls. The energy transmitted to the surrounding in the form of compressive strain that travels at a velocity of 2000-6000 m/s (Kumar, 2013).

According to Orica Mining Services Manual, 2008, understanding of blasting principles can be achieved through the core understanding of the resulted rock fragmentation process. Blasting operation results are significantly affected by rock properties more than by the physical and chemical properties of the explosive materials used. The geological setting of the site largely determines significant amounts of explosive energy to be wasted or actually utilized completely in breaking rocks. Faults, joints and fractures that are pre-existing in rock can be wedged open and extended by explosive energy and new fractures must be established to achieve the required fragmentation. The dynamic processes of rock breakage when an explosive charge detonates are as follows (Orica Mining Services, 2008):

2.3.1 Blast Hole Expansion and Crushing

For most explosives, instantaneous pressure produced by the explosion exceeds the compressive strength of the rock, resulting in the expansion of the blast hole diameter which ultimately causing crushing of rocks. The energy that worked on expanding the blast hole walls is termed as the shock energy.

2.3.2 Radial Cracks

Radial cracks around the circumference of the blast hole are created due to expansion blast hole walls. Rocks are unable to stretch so they fracture in tension (Orica Mining Services, 2008).

2.3.3 Shock waves

A compressive shock wave travels out radially from the blast hole in all directions through the rock mass. These compressive energy in the form of strain waves will continually travel through the rock until they encounter cracks or joints (Figure 2.2). Some of this energy reflect back inwards as a tensile wave, often causing rock to fail. In a strong, solid, massive rock mass, these energy waves will spread out through long distances without losing their kinetic energy (Orica Mining Services, 2008).

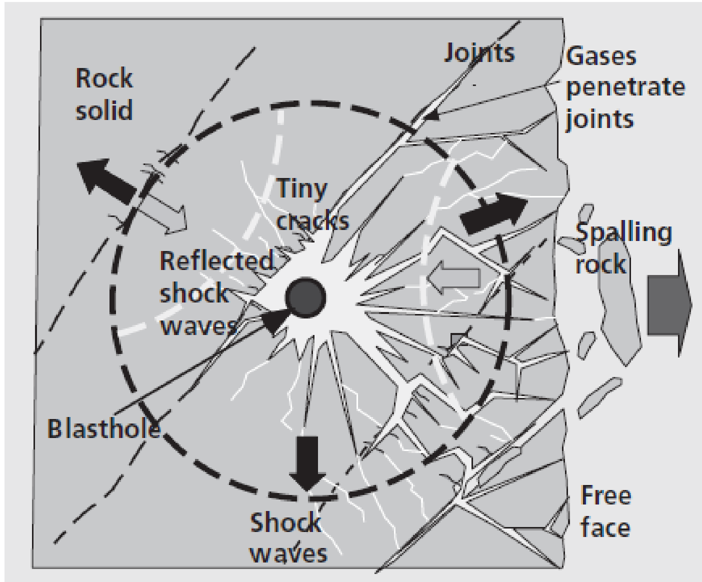

Figure 2.2: Radial shock wave in blast (Orica Mining Services, 2008).

2.3.4 Free Face Reflections and Cracking

Major reflections of shock waves occur at open joints, causing spalling and slabbing of rock fragments. Large blocks of rock will detach from the rock mass when the shock waves encounter a major free face and end up as over size boulders (Orica Mining Services, 2008).

2.3.5 Gas Pressure – Crack Extension

High temperature and pressure gases generated during the blast wedge through and along cracks and joints, working their way to the path of least resistance to free faces and the atmosphere. This wedging effect by the gases causes cracking, dislodging and displacing of the rock towards the free face, also known as heave energy. The heave energy gives the muckpile its final profile and looseness of the muckpile. Energy that reaches the free face to the atmosphere will not do any more useful work and if at high levels of intensity, will cause airblast or flyrock (Orica Mining Services, 2008).

2.3.6 Flexural Bending – Fractures in Movement

Further fragmentation of the rock mass can occur as slabs of brittle rock can be flexed and cracked. The action of further shearing, tearing, colliding and tumbling can break block of rocks in tightly closed joints (Orica Mining Services, 2008).

2.3.7 The Influence of Free Faces

The condition of the bench and free faces constantly correlates to the muckpile outcome of the blast. Field experience form blasting operations supports the influence of powder factors and degree of confinement in a blast pattern.

2.4 Ground Vibration

2.4.1 The Nature of Blast Related Ground Vibration

Upon detonation of explosives in a blast operation, the rocks surrounding the charge will undergo fracturing. The correct conditions and designs have to be met for the blasted rock to be displaced in the allocated area. The blast would definitely produce ground vibrations that spread out to the surroundings posing concerns for citizens living nearby. The ground vibrations will travel to a certain degree from the blast hole and the explosive energy would gradually decrease to a level that's no longer causes structure shattering or displacement, and continues to travel through surface rocks as an elastic ground vibration.

Ground vibration radiates proportional to the perception of travelling distance. The intensity decreases with the distance they traveled. Ground vibration at significantly high levels would in turn causes damage buildings and can be alarming to residents of the buildings. Explosive energy travels in the form of waves and that can be illustrated by the action of a still pool of water. Concentration of waves as a result of the stone being dropped near the spot of impact is much higher and with higher amplitudes, but gradually decreases as the waves spread wider outwards (Richards A. and Moore A., 2005), as illustrated in Figure 2.1.

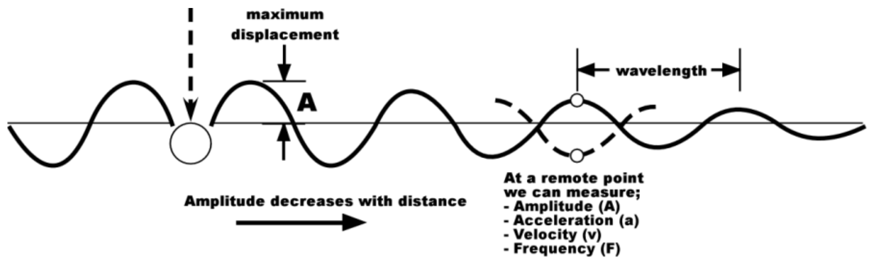

Figure 2.3: Wave terminology (Richards A. and Moore A., 2005)

In uniform rock conditions, ground vibration will equally spread radially and reduce in all directions.

2.4.2 Wave Types

Ground vibrations are formed from seismic events that consists of three different types of waves, which are:

- Compressional waves, P.
- Shear waves, S.
- Rayleigh waves, R.

Essentially the compressional P wave is the fastest when it travels through the ground. It moves radially in all directions from the blast hole at speeds characteristics of the medium being travelled through. Wave movements are illustrated in Figure 2.2.

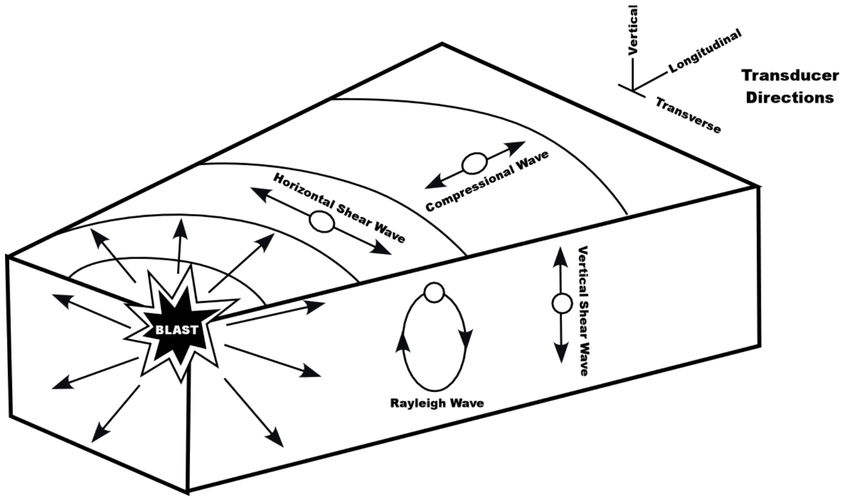

Figure 2.4: Wave movements (Richards A. and Moore A., 2005)

The movement of P wave can be simply illustrated as a long steel rod being struck at one end. Particles move to and fro passing their energies to adjacent particles along the rod as in Figure 2.3. Particles move in the same direction as the propagation of the wave.

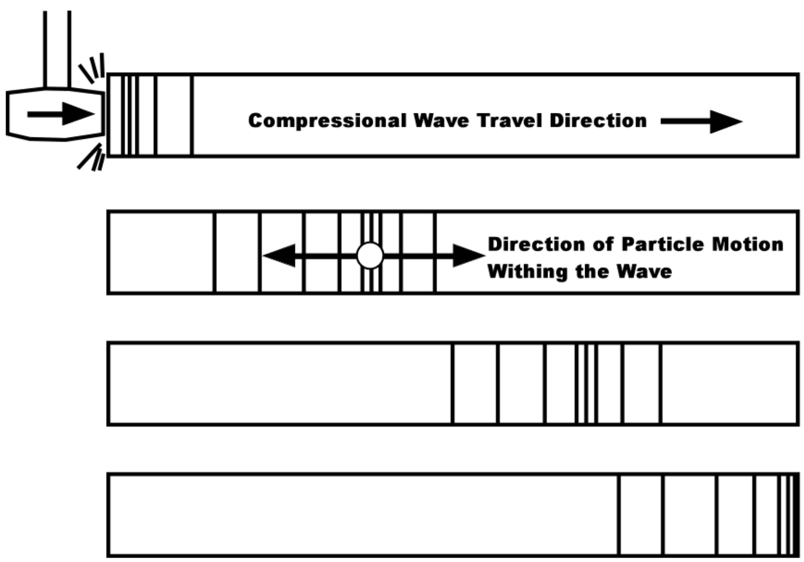

Figure 2.5: Compressional (P) wave motion illustration (Richards A. and Moore A., 2005)

The velocity of the shear or S wave is approximately 50-60% of the velocity or P wave. Just like shaking a rope at one end that it creates a wave travelling down the rope, the particles within the wave move at right angles to the direction of motion of the wave as pictured in Figure 2.4. The P and S waves are referred to as body waves as they travel through the body of rock in three dimensions.

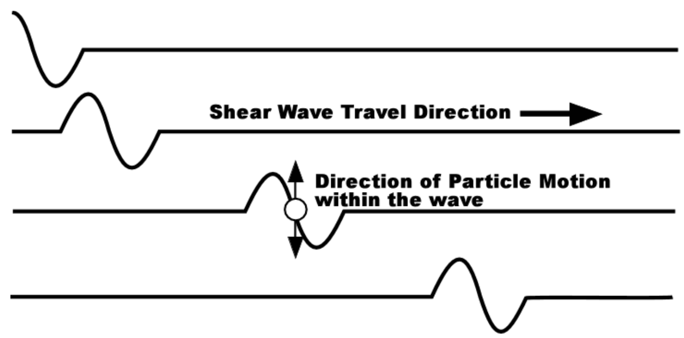

Figure 2.6: Shear (S) wave motion illustration (Richards A. and Moore A., 2005)

Rayleigh waves travels along the surface and fades rapidly with depth and propagate slower than body waves. Particles move elliptically in a vertical plane along the direction of propagation.

2.4.3 Vibration Parameters

The level of intensity of the energy escaped as ground and air vibration depends on a number of parameters. These parameters exhibit control on the amplitude, frequency and duration of emitted vibration and they are divided in to groups of non-controllable and controllable parameters. The local geological setting of the blasted site and rock characteristics are parameters that cannot be controlled. However, controllable parameters are the ones that can be of variable in vibration supervision, as they are (Kumar, 2013):

1. Charge weight per delay
2. Confinement
3. Delay interval
4. Spatial distribution of charges
5. Type of explosives
6. Burden, spacing and specification and specific charges
7. Blast progression direction
8. Coupling

2.4.4 Reduction of Ground Vibration

Reducing propagation of blast-induced vibrations falls into applicable techniques which are (Kumar, 2013):

A. Decreasing the charge weight per delay which can be controlled by:
    i. Reducing the hole depth
    ii. Use holes with small diameters
    iii. Delay initiation of deck charge in the blast holes
    iv. Increase the number of delay detonator series
    v. Using sequential blasting machine
B. Reducing confinement of explosives by:
    i. Reducing burden and spacing
    ii. Removing buffers in front of blast holes
    iii. Using optimal stemming

iv. Increasing sub-grade drilling

v. Allowing at least one free face

vi. Using decoupled charges

vii. Blast holes parallel to bench face

viii. Drilling accuracy

C. Limit the explosive confinement

D. Drill pattern

E. Limit frequency of blasting

F. Blasting with high ambient noise levels

G. Use explosives with a low VOD and low density

2.4.5 Peak Particle Velocity

Prediction of peak particle velocity level, as noted by Kahriman, 2004, are done through the observation of parameters of scaled distance (charge quantity per delay and the distance between the blasted bench and the observation point) by means of vibration monitors and put through a series of statistical evaluations.

Numerous experiments and evaluations have been done over past decades to find empirical relationships of blast-induced vibration factors PPV that are site-specific, as this parameter is commonly considered in estimation in blast designs. However, uncertainty of in situ conditions and variations in rock makeup in turn make the empirical relationships inconsiderable. R. Kumar et al in 2015 collected 1089 published data of various previous research from different sites and used them to proposed a generalized empirical model for

PPV that accounts to rock parameters such as unit weight, rock unit designation (RQD), geological strength index (GSI), and uniaxial compressive strength (UCS). Site-specific experiment are studied to carefully predict and control effects from blasting. Displacement, velocity and acceleration that correlate with their respective frequencies are important parameters that associated with vibration (Kumar et al., 2015). Generally a good index of damage to buildings and structures is the PPV (Monjezi et al., 2010; Kumar et al., 2012). Concerns on citizens and structure safety have arose from the act of blasting because of the risks that they posed to the public. Therefore, studies on blast induced vibrations and PPV are very important in lessen these concerns. Through the research, a general relationship between PPV and scaled distance (D) can be written as

$$v = kD^{-b}$$

where v is the PPV (m/s); D represents the scaled distance (m/kg$^{1/2}$) that defined as the ratio of distance from charge point, R (m), divided by the square root of charge mass, Q (kg), and k and b are site constants. Site constants k and b are determined through blast experiments. The available empirical equations to predict PPV does not determine the same empirical relationship, PPV predicting purposes, in other places. They only imply to their corresponding site where the experiments take place (Kumar et al., 2015). Equations in calculating PPV in literatures are stated in appendix A.

2.4.5.1 Case study

In 2010, a study was being conducted in a quarry located in the Istanbul province of Turkey, investigating the relationship between ground vibration, particle size and seismic energy caused by blasting performed by Ozer and Aksoy. In this study, blast induced ground vibrations were monitored using vibration monitors to estimate site-specific attenuation of ground vibration components. Blast governing parameters; charge per delay, distance between the blasted bench and vibration monitors, were carefully recorded. The blasting pattern, drilling pattern and explosive charges for the test shots are kept constant for the whole study. Vibration data are then observed simultaneously after each blast.

A total of 9 shots through 15 events were monitored and recorded. This paper also studies Seismic Energies produced during the blasts. Split Desktop software were used in analyzing particle size distribution of blasted rocks. Statistical analysis construct the relationship between PPV and SD to predict peak particle velocities were established by log-linear regression analysis. The method of simple logarithmic regression analysis were performed on the obtained PPV and SD values to achieve specific attenuation formula of the blasting site. Regression coefficient and site specific geological constants “K and β” were then determined. The research established a relationship between PPV and SD in the below equation. Correlation coefficient, r, was estimated to be 0.89.

$$PPV = 2828\left(\frac{R}{{W_d}^{1/2}}\right)^{-2.11} \quad (\mathrm{r} = 0.89)$$