SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

PREDICTION OF BLAST-INDUCED GROUND VIBRATION DURING BLASTING AT BATU TIGA QUARRY MASAI

By

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Dissertation submitted in partial fulfillment

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(Mineral Resources Engineering)

Universiti Sains Malaysia

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DECLARATION

I hereby declared that I have conducted, completed the research work and written the dissertation entitled "**Prediction of Blast-induced Ground Vibration During Blasting**". I also declared that, it has not been previously submitted for award of any degree or diploma or other similar title of this for any other examining body or university.

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Date : 4 July 2017

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LIST OF ABBREVIATIONS

ANFO	Ammonium nitrate and fuel oil
AS	Australian standard
BTQ	Batu Tiga Quarry
MIC	Maximum instantaneous charge
OCCME	Orica-CCM Energy
PPV	Peak particle velocity
SD	Scaled distance
VOD	Velocity of detonation
PF	Powder factor
ICI	Imperial Chemical Industries
ICIANZ	Imperial Chemical Industries of Australia and New Zealand

Ramalan Getaran Tanah Berpunca Daripada Letupan Di Kuari BTQ Masai

ABSTRAK

Kajian menganalisis getaran tanah kerana letupan telah dijalankan untuk menganalisis getaran tanah semasa letupan di BTQ Masai, Johor, Malaysia. Aduan berikut letupan biasanya disebabkan oleh lebihan bunyi, letupan udara, getaran tanah. Objektif utama kajian ini adalah untuk mengkaji mengenai getaran tanah dan hubungannya dengan jarak diskalakan dan mengurangkan kesan alam sekitar. Peranti pemantauan sismograf telah digunakan untuk menentukan bacaan getaran semasa aktiviti letupan dan juga tahap letupan udara. Kerja-kerja makmal seperti Ujian Berat Titik telah dijalankan menurut (ASTM D5731 - 08, 1995) untuk mendapatkan parameter yang berkaitan. Melalui kajian ini, akan ada persefahaman dalam jarak berskala menjejaskan bacaan getaran, penentuan nilai yang malar dan ramalan 95% tahap keyakinan. Keputusan menunjukkan bahawa terdapat faktor yang signifikan antara jarak dari memantau peranti ke kawasan letupan dan caj merta maksimum (MIC).

PREDICTION OF BLAST-INDUCED GROUND VIBRATION DURING BLASTING AT BATU TIGA QUARRY MASAI

ABSTRACT

The study of analysing the ground vibration due to blasting was conducted in order to analyse ground vibration during blasting at BTQ Masai, Johor, Malaysia. The complaints of following blasting are usually caused by an excess of noise, airblast, ground vibration. The main objectives of this study were to study about the ground vibration and its relationship with scaled distance and minimize the environmental effect. The seismograph monitoring device was employed to determine the vibration reading during the blasting activity and also the air blast level. Laboratory work such as Point Load Test was performed in accordance (ASTM D5731 – 08, 1995) to obtain the relevant parameters. Through this study, there will be an understanding on the scaled distance affecting the vibration reading, determination of site constant and prediction of 95% confidence level. Results show that there is significant factor between the distances from monitoring device to the blasting area and maximum instantaneous charge (MIC).

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Drilling and blasting combination is economical and practical method for rock excavation and displacement in quarry usually used in industrial application because it is low cost and simple method to the operation. Many such projects are used blasting operation because application of explosives are economically feasible and low cost especially in the mining and quarry industry. Primary function of the explosives is to break rock for excavation. However, the use of explosives always produces undesirable effects to environment such as ground vibrations, air blasts, fly rocks, back breaks, and noises that not able to be avoided and cannot completely eliminated but definitely can minimize this problem until it reach acceptable level to avoid damage to the surrounding environmental with the existing structures and human discomfort. Among all this effects, the major concern to the planners, designers and environmentalists are ground vibration.

Ground vibration generated by blasts are one of the most problem and controversial issues facing mining and quarries nowdays and this problem not only occurs in Malaysia but all over the world. Ground vibration produced when some of the explosive energy not used in breaking rock travel through the ground and air media when blast is detonated.

Human are quite sensitive to motion and noise that occur with blast-induced ground vibration. Complaints and protest resulting from blast vibration and air overpressure, to a large extent, are mainly due to the annoyance effect, fear of damage, and the starting effect rather than damage. The human body is very sensitive to low vibration and air blast level, but unfortunately it is not reliable damage indicator.

Parameter that effect ground vibration can be separate into two groups:

1. Uncontrollable Parameters

- geological characteristics
- location of existing structures

2. Controllable Parameter

- Burden
- Spacing
- sub-drilling
- stemming
- delay time
- charge type
- weight per delay
- blast direction

Ground vibration consist three different of wave. There are Compressional (or P) waves, Shear (or S) waves, and Rayleigh (or R) waves.

<u>Compressional (or P) waves</u>

Figure 1.1 shows the motion of P wave travelling through the ground. The fastest wave travelling wave through the ground is compressional wave or P wave. The simplest illustration of the motion of the particles within the P wave is to consider a long steel rod struck on the end. The particles of the rod move to and from as the compressive pulse travels along the rod, i.e. the particles in the wave move in the same direction as the propagation of

The P wave moves radially from the blast hole in all directions at velocities characteristic of the material being travelled through.

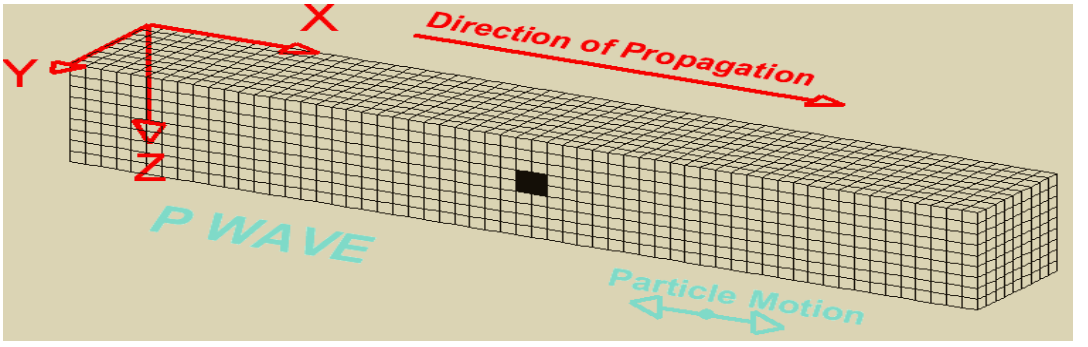

Figure 1.1 : The motion of P wave

Shear (or S) wave

Figure 1.2 shows the motion of S wave travelling through the ground. The shear or S wave travels at approximately 50-60% of the velocity of the P wave. The motion of the particles within the wave can be illustrated by shaking a rope at one end. The wave travels along the rope, but the particles within the wave move at right angles to the direction of motion of the wave. The P and S waves are sometimes referred to as body waves because they travel through the body of the rock in three dimensions.

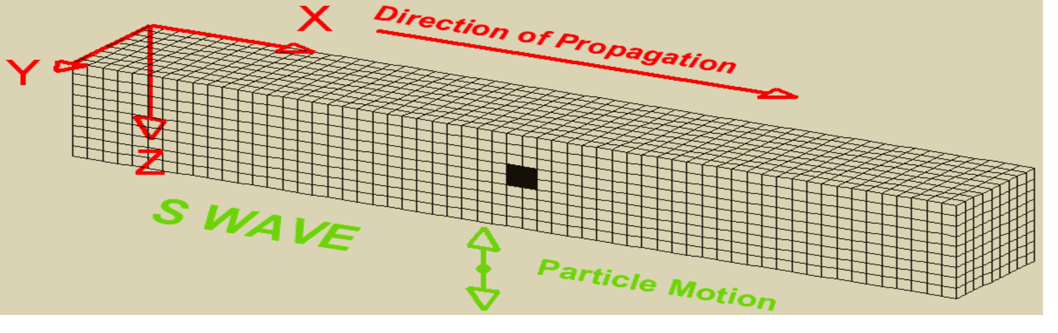

Figure 1.2 : The motion of R wave

Rayleigh (or R) waves

Figure 1.3 show the motion of R wave travelling through the ground. The Rayleigh or R wave is a surface wave, which fades rapidly with depth and propagates more slowly than the other two waves. The particles within the wave move elliptically in a vertical plane in the same direction as the direction of propagation. At the surface the motion is retrograde to the movement of the wave.

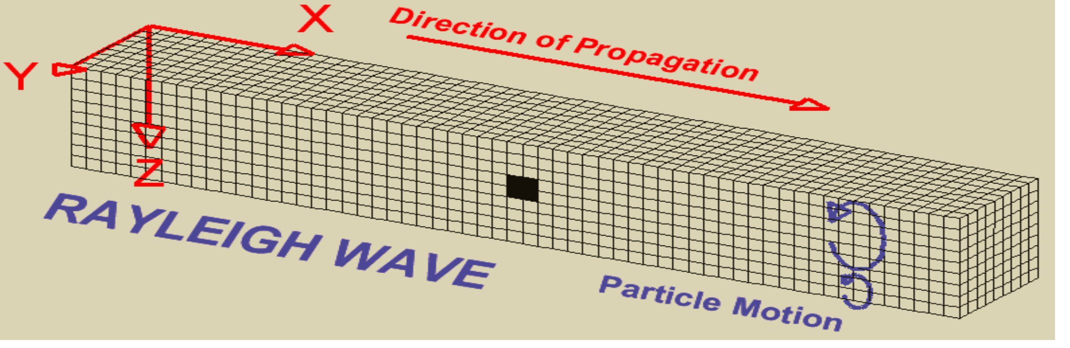

Figure 1.3 : The motion of R wave

Various of methods to minimize the ground vibration level during blasting have been suggested by number of researchers. The quantity of explosive used and distance between blast face to monitoring point besides geological and geotechnical condition of rock units in excavation area have directly relation to ground vibration. The only factor that we can control and estimated is the quantity of explosives that based on certain formulae that have been proposed by the different researchers to make ground vibration in acceptable level.

The only alternative for smooth progress rock removal process are proper blasting and rock friendly blasting. In the present investigation, few important and widely used predictors have been used to predict the peak particle velocity (PPV) and computed results are compared with actual field data. There are three methods to predict ground vibration. There are Artificial Neural Network (ANN), Multivariate Regression Analysis and Empirical relations. The main focuses of this study to concentrate prediction vibration by using empirical relation.

All of these influences can be simplified as the equation as shown below :

$$\text{PPV} = \text{K}\ (\frac{R}{\sqrt{Qmax}})^{-\beta}$$

(USBM equation)

Where PPV the peak particle velocity (mm/s), R the distance between the point of blast and the point of interest(m), Q the maximum amount of explosives per delay (kg), the explosive power (1/2 for spherical blast and 1/3 for cylindrical blast), and K and β the site constants. The main focuses of this study are to concentrates on the understanding, measurement and control of the blast-induced ground vibration that caused by quarry activities. The nature of these environmental impacts is discussed in terms of their prediction, cause, impact, and how to reduce it by sufficient approaches to the monitoring and interpretation of site data are then described.

1.2 PROBLEM STATEMENT

According to Rockwell 1927, building damage due to blasting vibrations has been under investigations since 1927. Research efforts have been concentrated on determining what parameter of the ground motion is closely related to building damage. For example, damage could be due to

1. Displacement or the amount of movement
2. Velocity or the speed of movement
3. Acceleration or the force that effect structure

From the statistical analysis of the published data of damage to structures caused by blasting vibration, Duvall and Fogelson (1962) concluded that damage to residential structures is proportional to ground particle velocity. This conclusion has been widely accepted and can be justified by modelling a structure as a single degree of freedom (SDF) system excited by a vibrating base. Under these circumstances, one will find that the strains across the building elements are proportional to the base velocity in the vicinity of the natural frequency of the SDF system. Based on the studies by Nicholls, et al (1971) the U.S. Bureau of Mines concluded that if one or more of the three mutually perpendicular components of vibration in the ground near the structure have a PPV in excess of 50 mm/s, there is fair probability that damage to the structure may occur.

This study will investigate the constant (β) and (K) used in PPV equation adopted by most of the quarry and mining operator in Malaysia for blasting based on the study area (BTQ Masai). Currently, quarry in Malaysia, the constant (β) and (K) value is basically based on Australia Standard (AS 2187-1993) while it reliability still can be due to the dissimilarity of geological features between the Australia and Malaysia. Besides, scale distance also is the main parameter of this study. Moreover, blast design is considered as critical factor for every blast that can cause vibration impact. Hence, it is important to rectify the best blast design practice in which related to mechanical properties of rocks, blasting parameter and the explosive characteristics.

The study will be concerned with the following questions:

i. What is the value of site constant law at quarry BTQ Masai?

ii. Does the PPV values follow the Australia Standard?

iii. How the blasting parameter (scaled distance) affecting the vibration reading?

1.3 OBJECTIVES

The objectives of the study are:

1. To determine site constant law that can adopt in PPV in USBM equation to predict ground vibration by quarry in Malaysia
2. To know the relationship between ground vibration and scaled distance

1.4 STUDY AREA

For this study, I had undergoes an attachment with Orica-CCM Energy (OCCME) in conducting the study at OCCME customer's quarry site. The location of Batu Tiga Quarry is at Masai, Johor. The vibration reading has taken for granite quarry. The rock samples were collected for further analysis such as point load test. The data was collected only at BTQ Masai, Johor due to time restriction.

It is worth highlighting that due to the Malaysia geological setting, it is postulated that the granite rock was different among the states mainly with related to the geological setting and weathering indexes. Most of the quarry produces aggregates for constructions and roadwork.

Geology of Peninsular Malaysia

The capital of Malaysia is Kuala Lumpur and divided into 12 states, each having own capital town. The climate is tropical characterized by uniformly high temperature and seasonal rainfall. Most of the region is covered by a tropical rain forest. Up to 1903, all geological work had been reconnaissance. In 1903, J.B. Scrivenor was appointed as the first government geologist and this begun the new era of geological work in Peninsular

Malaysia. Systematic mapping by the Geological Survey was started in the 1930's. Since the 1970's there has been a rapid increase in the geological knowledge of Peninsular Malaysia. The latest geological map (1:50,000) of Peninsular Malaysia was published in 1985 by the Geological Survey of Malaysia (now known as Minerals and Geoscience Department Malaysia).

On the basis of tectonostratigraphic terrains, Malaysia is a part of Sibumasu block and East Malaya block. Peninsular Malaysia can be divided into three belts; West Malaya, Central Malaya and East Malaya. Each of these three belts is characterized by its own stratigraphy, igneous suite and geological history. In West Malaysia, the oldest rocks exposed are Cambrian in age, consisting of about 3000m of predominantly sandstone-shale deposited in a shallow water and deltaic environment. This rocks well expose in northwest Peninsular Malaysia and are conformably overlain by the thick sequence of shallow water limestone of Ordovician to Silurian age. Both sequences then overlie by the rock of Upper Devonian to Lower Carboniferous which is dominated by mudstone, sandstone and thin of pebbly mudstone.

Limestone and siliciclastic of Triassic age are best developed in northwest Peninsular Malaysia and were intruded by granite of latest Triassic to Jurassic age. In Central Malaya, the oldest rocks exposed are Silurian-Devonian rocks called as Bentong Group. These rocks exposed in a narrow zone and consist of schists, amphibolites, conglomerates and other siliciclastic deposits with some bodies of serpentinite and melange deposits.

During Triassic period, deposits are dominated by marine sediments and overlain in some areas by Jurassic-Cretaceous continental deposits. Marine Permian and Triassic rocks were deposited over the Bentong Group and cover the greater part of the Central Malaya. East Malaya is dominated by Carboniferous and Permian clastics, carbonates and volcanic.

Triassic sediments absent and the upper Jurassic continental rocks lie uncomfortably on the Carboniferous-Permian sequence.

The main intrusive body in west Malaya is the Main Range Granite (S-type) extending 3000km from the southern tip of Peninsular Malaysia to Northern Thailand. In Central Malaya granitic intrusives extend from the Thai border southwards to Johor. In East Malaya, granites are abundant forming elongated north-south trending bodies (classified as I-type) as shown in figure below. It illustrates the granite deposited in Peninsular Malaysia (Azman, 2008).

Figure 1.4 below illustrate the distribution of granite and metamorphic rock occurrence in Peninsular Malaysia. For this study, the research was focused in southern region of Malaysia which is Johor. Figure 1.5 and 1.6 shows location of study area in southern region of Peninsular Malaysia. Appendix E shows full image of quarry face.

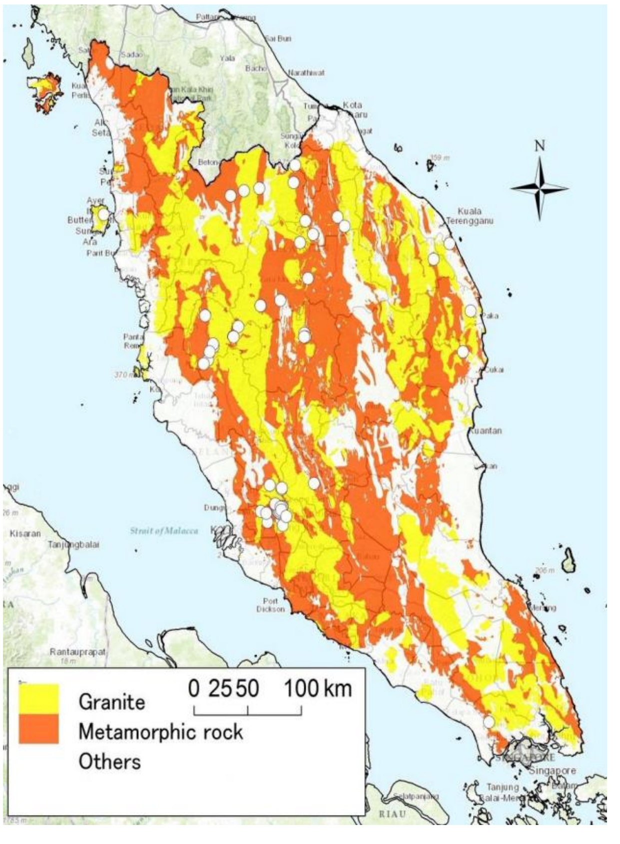

Figure 1.4 : The location image of deposited granite in Peninsular Malaysia

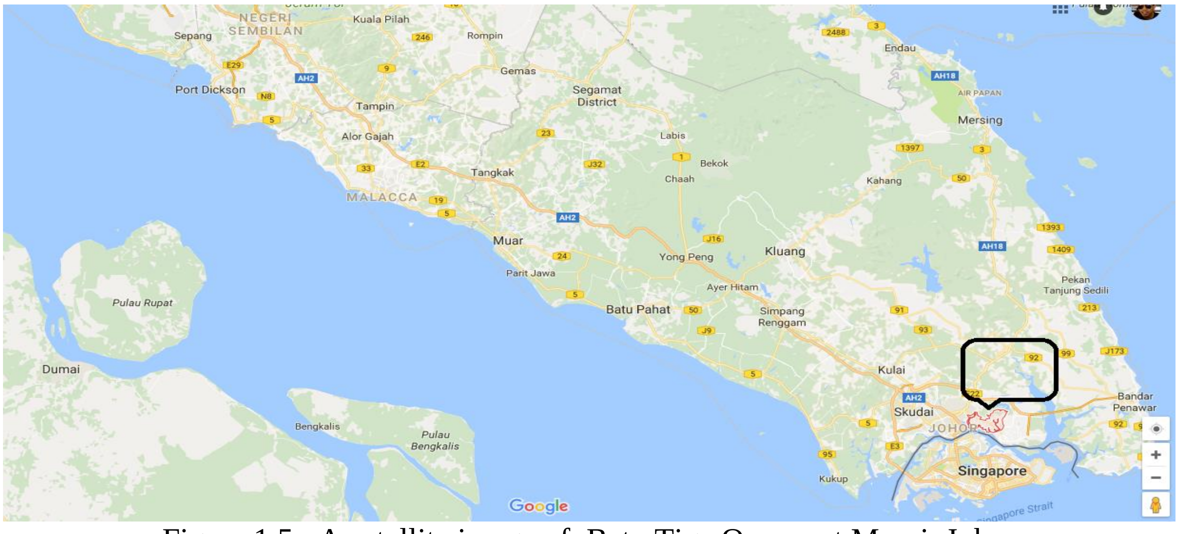

Figure 1.5 : A satellite image of Batu Tiga Quarry at Masai, Johor

Figure 1.6 : Map of study area in southern region

1.5 SCOPE OF STUDY

Site investigations were carried out in southern region of Peninsular Malaysia of granite quarry which is Masai. The data collection was conducted within 3 weeks visit in Masai, Johor and the information were recorded. These include the vibration data, blast design and parameter considered in the blast design.

I have been in 4 weeks in site to monitoring all the vibration data for 11 blast event. All the vibration data have been recorded to do regression analysis to observe the relationship between PPV and distance between blast site and monitoring device located (scaled distance) and to find the value of site constant law. Blast design and parameter considered in the blast design have been collected and recorded too. These include spacing, burden, blast pattern, stemming, type of explosive and depth of the hole. Under normal condition, usually all the blast design remain same and constant to get the optimize fragmentation and good blast.

CHAPTER 2

LITERATURE RIVIEW

2.1 INTRODUCTION

This chapter is explained about the literature review that related to this research. The literature review has been extracted from related journal, research and book done by number of researchers. It is related to the explosives, blasting theory and generation of vibration toward surrounding.

2.2 EXPLOSIVES

Since introduction of black powder, the first method of breaking and loosening rock is explosive after largely through dedication to research and development in quality and safety, have developed into today's wide range of safe and cost-effective products. Commercial explosives are quickly changed into gases at high temperature and pressure when it properly initiated. When detonated unconfined, a litre of explosive expands to around 1000 litres of gas in milliseconds and expanding explosion gases lead to extremely high strain within the rock when confined by rock. The energy released during detonation acts equally in all directions but, as one would expect, tends to escape through any path(s) of least resistance. Therefore, charged and stemmed are required to blast hole so that the gases are confined for enough time to provide optimum breakage, displacement and looseness of the blasted rock (Orica Quarry Services, 2008).

2.2.1 Explosives Ingredients

All explosives contain the following essential ingredients:

Oxidiser

Chemical that provides oxygen for the reaction is known oxidiser. The most common oxidiser is ammonium nitrate (Orica Quarry Services, 2008).

Fuel

Fuel will reacts with oxygen to provide heat. Fuel oil and aluminium powder are common fuels used to provide heat (Orica Quarry Services, 2008).

Sensitizer

The reaction will start during detonation when sensitizer provides voids that act as 'hot spots' that generally most part of sensitizers are air and gas in the form of very small bubbles, sometimes represented in glass micro balloons (GMBs). Examples of how these are utilizes as part of various sorts of explosives are given in Table 2.1 (Orica Quarry Services, 2008).

Table 2.1 : Types of explosive and the ingredients (Orica Quarry Services, 2008)

Component	ANFO	Emulsion
Oxidiser	Ammonium Nitrate	Ammonium Nitrate
Fuels	Fuel Oil	Fuel Oil
Sensitizers	Entrapped Air	Entrapped Air
Others		Emulsifier

2.2.2 Properties Of Explosives

ANFO (Ammonium Nitrate and Fuel Oil)

ANFO contain a mixture of 94% Nitropril® AN and 6% fuel oil (by mass) and usually will mix on site at quarries before blasting. Under normal conditions, correct mixing guarantees a uniform distribution of the fuel all through the AN oxidiser. Explosive can be producing by various of carbonaceous materials (fuels) with ammonium nitrate (e.g. Nitropril®) but in any case, fuel oil (distillate) has turned out to be the best fuel. To create a uniform mix of ANFO distillate is more reliable and more sensitive than mixture of Nitropril® and powdered fuels because it is readily available, relatively cheap and can easily be mixed with Nitropril® AN. More volatile fuels like petrol or kerosene can make ANFO more sensitise however it is not offer different advantage to the strength of explosive. These fuels can introduce the risk of vapour explosion during mixing and charging because it have lower flash points. According to Australian Standard 2187-2, 2006, it states that the fuel oil must be perfect and and have a flashpoint surpassing 61°C. Alternatives to fuel oil incorporate reused engine and hydraulic oils and by products from reusing other hydrocarbon based materials. These choices ought not be introduced as a substitute with fuel oil until similarity test work has been finished to guarantee optimum performance of explosives and assessment of potential risks (Orica Quarry Services, 2008).

Emulsion

Emulsions are prepared in the form of water in oil emulsions. The internal phase is composed of a solution of oxidizer salts suspended as microscopically fine droplets, which are surrounded by a continuous fuel phase. The emulsion thus formed is stabilized against liquid separation by an emulsifying agent. A bulking agent, for density control, is then dispersed throughout the basic emulsion matrix. The bulking agent can be either ultrafine air bubbles or artificial bubbles from glass, resin, plastic, or some other material. The bulking agent determines and controls the sensitivity of the emulsion product, which influence whether the final product is detonator sensitive or a blasting agent requiring a booster for initiation. Since the presence of oily exterior that covering to each microcell, the emulsions have excellent water resistance and do not depend on a package for their ability to function in water (Explosive And Rock Blasting, 1987).

Sensitivity

Sensitivity is a measure of the ease with which an explosive can be detonated by heat, friction, impact or shock. The pattern in commercial explosives is towards lower sensitivity to initiation without reducing from detonation efficiency. The explosives can be initiated by mechanical impact or friction if the sensitivity of explosives are very high, especially in the presence of grit. In practice, initiation of commercial explosion will accomplished by shock from primer, detonator or detonator cord. Density of the explosive and the blast hole diameter must be consider to achieve proper explosion. In general, to decrease the sensitivity of explosives toward impact and friction, the replacement of Gelignite and other nitro-glycerine based compositions by ANFO and emulsion explosives has been accompanied. This decrease in sensitivity has reduced the probability of unplanned detonation and has led the more secure manufacture, transportation, storage and utilization of explosives (Orica Quarry Services).

Critical Diameter

The critical diameter of an explosive is the diameter below which a stable detonation can't be maintained. Critical diameter is generally named for explosive charges that explode unconfined (i.e. in open air). Small critical diameter blasthole is use for high sensitive explosive. However, other factor such as the intimacy of mix and fineness of ingredients may bring to the unusually small critical diameter (Orica Quarry Services, 2008).

Recommended Minimum Diameter

Explosive supplier usually will recommend a minimum diameter for their products to make sure reliable initiation under normal condition of utilization. The suggested minimum diameter must be larger than the critical diameter to guarantee reliable results under most condition. This value is acquired by endeavouring to initiate the explosive in different diameter blast hole (Orica Quarry Service, 2008).

Water Resistance

The water resistance of an explosive refers to its ability to detonate after its exposure to water (Explosive And Rock Blasting, 1987). The water resistance of an explosive relies on its ingredients and the way they are combined during the manufacturing process. Under normal conditions, emulsions have excellent water resistance, boosters are effectively waterproof but ANFO not excellent water resistance. Because of that, many mining and quarries in Malaysia more prefer to use emulsion rather than ANFO. Decay of bulk explosive increases with the severity and time of exposure to water. For example, in still water, bulk emulsions ordinarily withstand exposure for considerable timeframe.

However, in flowing or dynamic water, they can decay fall apart quickly to the time at which the product fails to detonate. Under these conditions, packaged explosives also can decay if the cartridge is tore or penetrated. With all explosives firing the blast immediately after charging to minimum the period of exposure to blast hole water (Orica Quarry Services, 2008).

Density

An explosive's density is its weight per unit volume and is expressed in grams per cubic centimetre (g/cm3). Density of water is 1.00g/cm3. An explosive will sink in the water if the density is greater than 1.00g/cm3 (provided that the blast hole water does not contain appreciable amounts of suspended solids or salts). However, if it is less than 1.00g/cm3, the explosive floats (Orica Quarry Service, 2008).

Desensitisation

Most blasting agents will turn out less sensitive at higher densities. This relationship is more obvious for those compositions that are gas or GMB sensitised. For example, emulsion explosives and ANFO-type mixture have greater sensitivity than for booster because of the different density. Destruction of air/gas bubbles or micro balloons are the main caused of physical desensitisation, which give the hot spots on which initiation depends. Desensitisation by compression is termed "Dead Pressing". Dead pressing of an explosive can happen in the following ways:

• By hydrostatic pressures

• By dynamic (i.e. blast-induced) pressures

• By a combination of hydrostatic and dynamic pressures

Velocity of Detonation (VOD)

The velocity of detonation (VOD) is the rate at which the detonation wave travels through an explosive an explosive column (Explosive And Rock Blasting, 1987). Two explosive may perform quite differently in a blast having same strength but different VODs. As a general rule, the higher the VOD, the greater the shock energy and the lower the heave energy. In any case, it is important nopt to mistake shock energy with fragmentation energy. Quarrying are usually used VODs of explosives vary between about 3000 m/s and 7500 m/s. The VOD of most explosives increases with charge diameter and confinement. The emulsion explosives usually maintain a very high VOD even with poor confinement and in small diameters because of their high degree of refinement and efficiency (Orica Quarry Service, 2008).

Temperature

High Temperatures

Detonating or burning at raised temperatures put explosives or initiators are at risk as initiation sensitivity increases with temperature. When at high temperature the The physical properties like firmness and plasticity may also change, and capacity life/sleep time can be lessened for a few explosives. Chemical reactions and decay may start, rendering some explosives futile and inactive, while others can produce heat and continue to detonation when temperature higher than the safe value. Some mineral present in rock like pyrite can produce heat with explosives, producing dangerously high in-hole temperatures through reaction of exothermically. Many explosives can burn to detonation under extreme condition. There have been instances under extraordinary conditions where blast holes have detonated early. The selection of resistant formulations or the utilization of modified blasting practices can avoid the rapid 'heating to detonation'. Seek immediate advice from blasting's sub-contractor representative like Orica if temperature surpassing 55°C or reactive ground conditions exist in a quarry. The maximum temperatures that are considered safe for different explosives are given in Table 2.2.

Table 2.2 : The maximum temperature for explosives

Explosive	Temperature
Emulsion	100
ANFO	100
Booster	70
Detonators	80
Detonating Cord	80

Low Temperatures

At lower temperature, all explosives will less sensitive, but under normal condition the loss in sensitivity is not enough to causes failure to detonate. (Orica Quarry Service, 2008)

<u>Shelf Life</u>

The explosive must be kept for a long time, often under bad condition such as heat, cold, and humidity before use that the main reason shelf life of an explosive is important. Emulsion should not be stored above 90°F for long periods of time because it will cause the ammonium nitrate in the explosive to undergo rearrangement of crystals. (Explosive And Rock Blasting, 1987)

2.3 BLASTING THEORY

According to Dheke 2015, the most reliable and practiced technique for the breakage of rock is blasting. The energy of transformation will take place the explosive during blasting. Under normal condition, usually ground vibrations, noise, dust, fumes and flyrock will generate during rock breakage in blasting process. This environmental issue give a great challenge to the safety of the building vicinity to the blast area and community nearby.

According to Orica Mining Services 2008, blasting principles contained both the engineering and scientific aspects of blasting. To understand this principles, it is important to know rock fragmentation first and then follows the detonation of the explosives in a blasthole. The explosion in blasting process is an extremely fast burning, in which the energy contained in the explosives is discharged in the form of heat and gas pressure. Figure 2.1 shows the stages of transformation of rock during blasting.

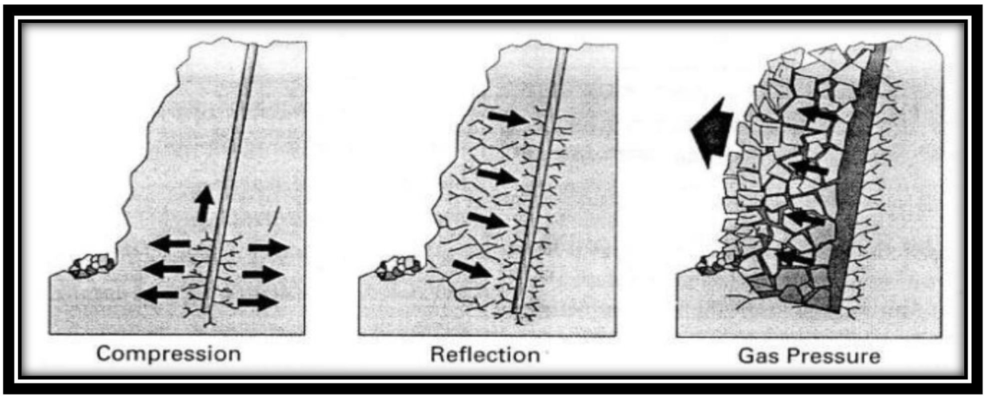

Figure 2.1 : Rock breaking sequence in blasting (Orica Mining Services, 2008)

2.3.1 Rock Breakage Process

<u>Free Face Reflection And Cracking</u>

One of the first approaches to explain analytically mechanism of rock breakage when a concentrated explosive charge is detonated in borehole near a free surface was with the reflection theory. The concept was simple, straightforward, and based strictly on the well-known fact that rock is always less resistant to tension than to compression. Detonation of an explosive charge, moves through the rock in all directions with a decaying amplitude then will produce a compressive strain pulse and is reflected only at a free face. The compressive strain pulse is transformed into tensile strain pulse at free face surface that progresses back to its point of origin(see figure below). It is easily pulled apart by the reflected tensile strain pulse and damage at the face seems in the form of spalling since the rock is weakest in tension. The high-pressure, expanding gases are not supposed directly responsible for major degree of fracturing that happen (Explosive And Rock Blasting, 1987). Figure 2.2 show the concept of free face reflection and cracking

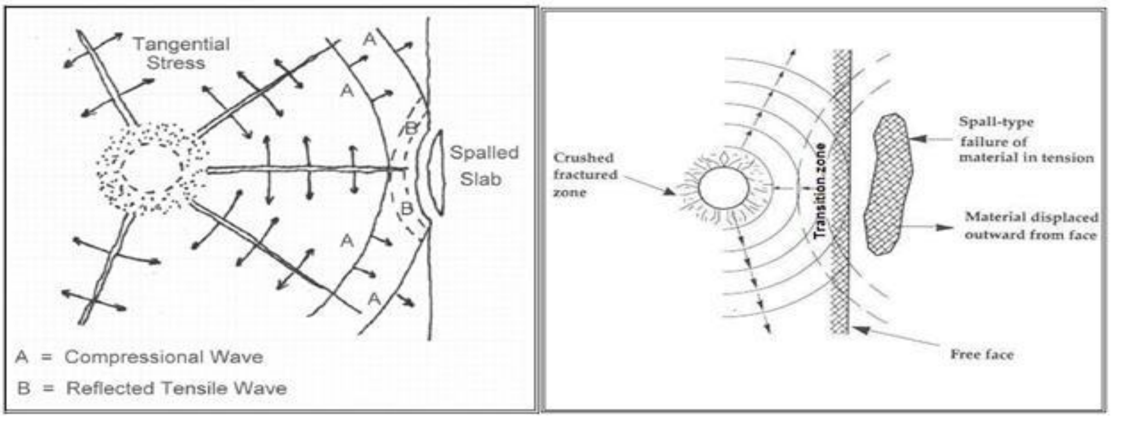

Figure 2.2 : The concept of free face reflection and cracking

<u>Blasthole Expansion And Crushing</u>

For most explosives, the blast hole will increase their diameter and crushing occurs if the explosion pressure surpasses the compressive strength of the rock instantly after detonation. The crushed zone may be just millimetres thick for hard rocks condition. The energy utilized in extending the blast hole diameter to balance (in pressure) is termed the shock energy. This will relate the number of crack initiate however not really the resultant fragmentation (Orica Quarry Service, 2008). Figure 2.3 the concept of blasthole expansion and crushing.

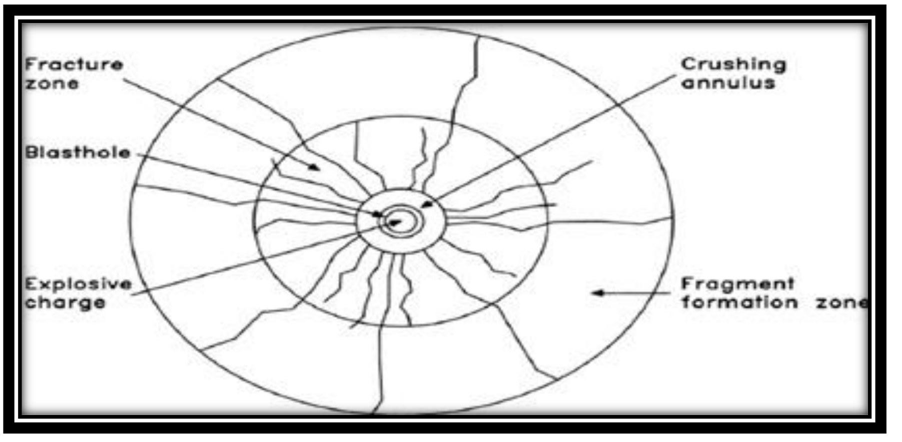

Figure 2.3 : The concept of blasthole expansion and crushing

Shock Waves

A compressive shock wave emit out from the blast hole in every which way through the solid rock mass. At whatever point, this strain wave experiences crack or joint, some energy is reflected (as a tensile wave) regularly causing the rock to fail. These shock wave will travel large distances without losing (or using) all their kinetic energy in a strong, massive rock mass (Orica Quarry Service, 2008).

Gas Pressure (Crack Extension)

Blast hole (around 1000 times the volume of the first explosives) wedge and work their way into and along crack or break and joint, looking for the easiest path of least resistance to free face and the atmosphere that will create high-temperature, high-pressure gases. It is the wedging, pushing, scouring impact of these gases that crack open, dislocate and displaces the rock mass toward the free face. This gives the heave of the muck pile and give the main factor impacting the final profile and looseness of the muck pile. The energy remaining in these explosion gasses won't any more useful work once released to the atmosphere and if sufficiently enough can affect the environment such as air blast or fly rock (Orica Quarry Service, 2008). Figure 2.4 show the concept of shock wave and gas pressure.

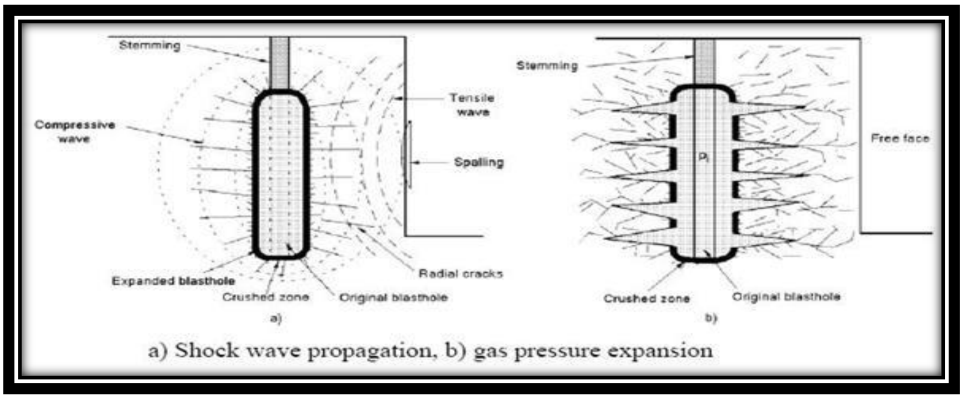

Figure 2.4 : The concept of shock wave and gas pressure

Flexual Bending (Fracture in Movement)

Further fragmentation takes place as the movements of blasted rock moves forwards and outwards. Further shearing, tearing, colliding, cracking and tumbling of the rock masses take effect. Rock mass will break under flexural bending effect, along mid-section of a high bench and also along minor and tightly closed joints that has escaped previous breaking processes (Shot-firer Course Manual, 2007).

Radial Crack

The rock around the blast hole, being unable to stretch, fails in tension, resulting in the formation of small radial cracks around the circumference of the blast hole as the blast hole expands (Orica Quarry Service, 2008). Figure 2.5 show radial crack formation.

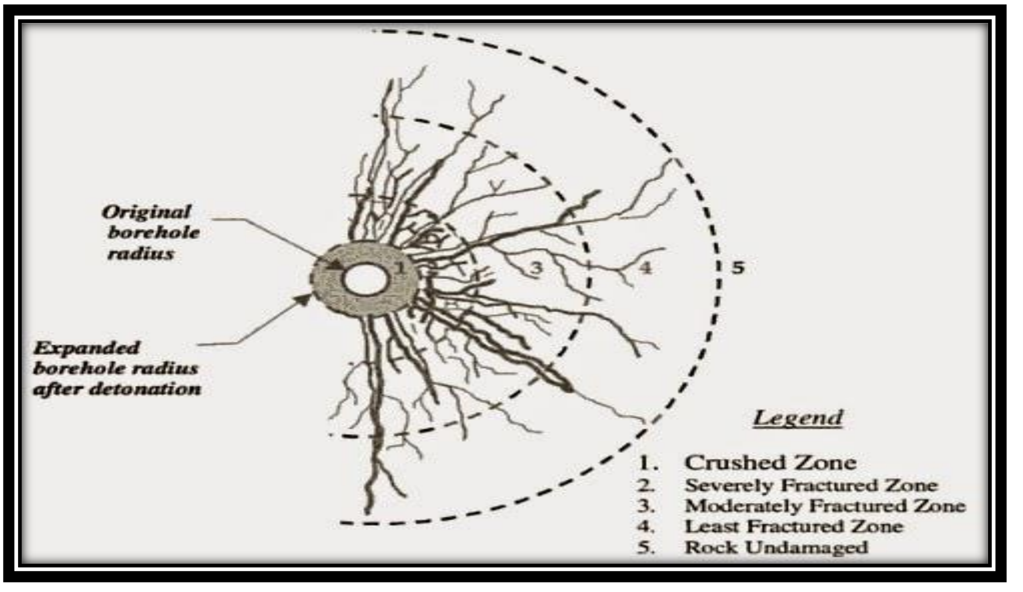

Figure 2.5 : Radial crack formation

2.3.2 Blast Design

Figure 2.6 the term that used in the design of blasting in quarry to before the design is fired.

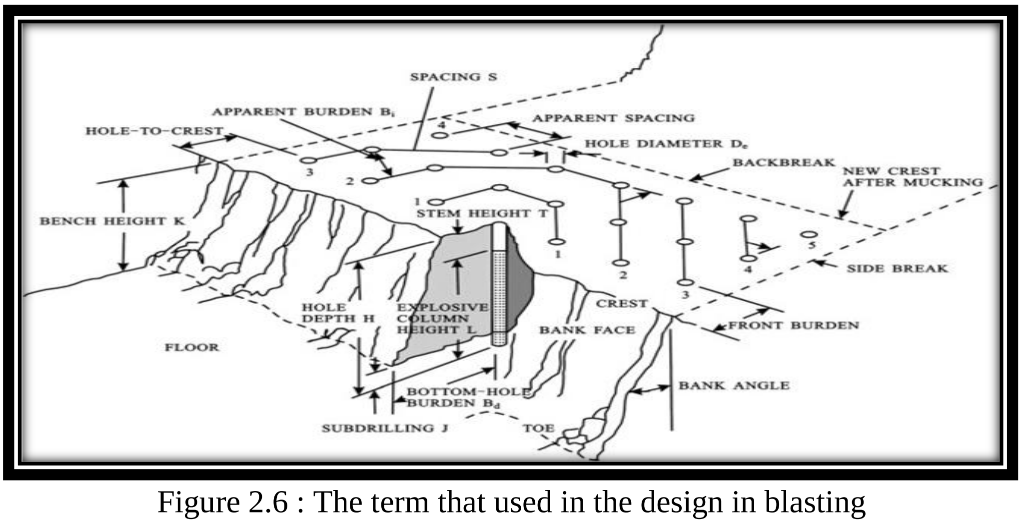

Figure 2.6 : The term that used in the design in blasting

Free Face

Free faces and open joints play a major part in the rock breakage process. This is confirmed by the field involvement of quarry operations where powder factors and blasting