SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

PREDICTION OF BLAST-INDUCED GROUND VIBRATION DURING BLASTING AT LAFARGE QUARRY KANTHAN, IPOH, PERAK

By

KHAIRUL SHAZWAN BIN PELAWANG

Supervisor: Dr. Mohd Hazizan Bin Mohd Hashim

Dissertation submitted in partial fulfillment of the requirements for the

Degree of Bachelor of Engineering with Honours

(Mineral Resources Engineering)

Universiti Sains Malaysia

JUNE 2018

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 at Lafarge Quarry Kanthan, Ipoh**". 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.

Name of student : Khairul Shazwan Bin Pelawang Signature:

Date : 25 June 2018

Witness by

Supervisor : Dr. Mohd Hazizan Bin Mohd Hashim Signature:

Date : 25 June 2018

ACKNOWLEDGMENTS

Bismillahirrahmanirrahim.

Alhamdulillah, in the name of Allah S.W.T praise to Him the Most Beneficent and the Most Merciful, with His Blessing, I successfully and smoothly finish the dissertation. I also would like to extend my thankfulness to Mr Pelawang B Mahat and Mrs Norsidah Bt Kudin, my parents for all the moral and financial support during the data collection in Ipoh for 3 weeks straight.

I am especially indebted to Dr Mohd Hazizan Mohd Hashim, my FYP supervisor, Dr Norlia Baharun and Prof Ir Dr Srimala Sreekanthan, FYP Coordinators and technicians of School of Materials and Mineral Resources Engineering for the guidance, motivation and support throughout the process to complete the study.

My study would not be complete if there is no cooperation from Lafarge Aggregates Sdn Bhd (Kanthan Branch) and Osborne & Chappel (O&C) Sdn Bhd. I would especially like to thank Mr Muhamad Yusri Abd Talib, Quarry Engineer of Lafarge Aggregates, Ms Wan Normimiaida Wan Mohamed, Mineral Resources Engineer of O&C and all the staff of Lafarge Aggregates for giving me such attentions, times and helps during the data collections.

Special thanks to my coursemates especially Helmi Halim, Aliah Hazirah, Najihatul Nabihah and Nurwahidah in encouraging by giving technical and morale support so that I optimist in finishing the research. A million thanks for those who direct or indirectly in encouraging me for my research. Thank you.

TABLE OF CONTENTS

Contents **Page**

LIST OF TABLES

LIST OF FIGURES

RAMALAN GETARAN PERMUKAAN SEMASA BEDILAN DI KUARI LAFARGE KANTHAN, IPOH, PERAK

ABSTRAK

Operasi peletupan batuan memberikan impak kepada alam sekitar akibat pembaziran tenaga daripada kerja peletupan seperti getaran permukaan, ledakan udara dan batu terbang. Kesan-kesan getaran permukaan kepada alam sekitar termasuklah kerosakan kepada struktur binaan dan ketidakselesaan kepada manusia. Kajian yang dijalankan di kuari Lafarge, Kanthan Perak untuk mengkaji mengenai getaran permukaan dan perkaitannya di kuari tersebut. Persamaan yang baru akan digunakan dalam menganggar getaran permukaan. Semasa operasi peletupan, nilai pemalar setempat k dan β turut dikenapasti dalam meramalkan getaran permukaan. Untuk membina model ramalan, beberapa parameter utama akan dititiberatkan seperti jarak antara titik bedilan dengan titik pemantauan, jumlah maksimum berat bahan letupan per lambatan dan reka bentuk bedilan. Selain itu, halaju puncak partikal (PPV) turut dianalisa. Hubung kait antara parameter-parameter tersebut dengan halaju puncak partikal (PPV) menentukan nilai pemalar setempat k dan β. Uji kaji sampel lapangan dilakukan menggunakan kaedah ujian beban titik dan ujian kekuatan mampatan unipaksi. Persamaan yang baharu diterbitkan di Lafarge Kanthan ialah $PPV = 2448\ (D/\sqrt{Q})^{-1.7}$ dengan nilai $R^2 = 0.9604$ menunjukkan korelasi antara jarak berskala dengan getaran permukaan yang dihasilkan adalah sahih. Persamaan ramalan yang baharu didapati lebih tepat jika dibandingkan dengan ramalan sedia ada yang menggunakan piawaian Australian (A.S. 2187, 1993) yang diamalkan oleh kebanyakan operator kuari di Malaysia.

PREDICTION OF BLAST-INDUCED GROUND VIBRATION DURING BLASTING AT LAFARGE QUARRY KANTHAN, IPOH, PERAK

ABSTRACT

Blasting works give impacts toward environment due to waste-energy produced from blasting such as ground vibration, air blast and fly rock. Effects of ground vibration to environment including damage of structure and annoyance of human. Study was conducted at Lafarge Quarry, Kanthan, Perak to study ground vibration and its relationship in the quarry. A new predictor will be used to predict ground vibration. During the blasting, value of site constants k and β will be determined in predicting the ground vibration. To construct the model of predictor, a few parameters will be taken into account such as distance between blast point and monitoring point, maximum amount of charge per delay and blast design. Besides that, peak particle velocity (PPV) also will be analysed. The relationship between these parameters with peak particle velocity (PPV) will determined the site constant value k and β. Laboratory work such as point load test index and uniaxial compressive strength (UCS) will be applied. A new established prediction in Lafarge Kanthan is $PPV = 2448\ (D/\sqrt{Q})^{-1.7}$ with value of $R^2 = 0.9604$ which indicate the correlation are valid between scaled distance and ground vibration produced. The new predictor is more accurate compare to the existing practices that used the Australian Standard (A.S. 2187, 1993) which practiced by most quarry operators in Malaysia.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The mining business is a standout amongst the most imperative primary areas in building up a nation. To guarantee the business remains a win, the most extreme extraction of mineral must accomplish while keeping in see the natural, financial and rent limitation. A few elements may be considered in enhancing the creation, for example, hardware portion, ceaseless mining framework with an enhanced outline, explosives and frill, use of data innovations and increment in the selection of mechanized mine arrangement and control.

Most of the economic mineral deposits occur within a massive hard rock. (Balasubramanian, 2017). Since the rock masses need to fragment so that the production can be achieved, a cheap yet efficient way has to be done. Proper adoption of the blast design and good selection of explosives and initiators might contribute significantly towards the production and profitability, but if otherwise, certain environmental issues will be the main topic to be discussed (Sannasy, Labuson, Goh, & Din, 2015).

An improper blast design and a weak geological factor of rock may lead to certain environmental issues like back break, airblast, flyrocks and ground vibration. Dissipated energy from explosive which designed for rock fragmentation causing the vibration and airblast (Adam, Fatt, & Goh, 2015). Vibration in term of mining and quarrying field is repeating movement about the position of rest (Bhandari, 1997) while in context of mining engineering is a movement of a particle on the ground due to blasting or mining activities. There are two types of source of ground vibration which are controllable and uncontrollable parameters.

The uncontrollable parameters are the geological factor on blasting site, material strength and properties, weather conditions and presence of groundwater while the controllable parameter is mainly about blast design (including burden, spacing, stemming etc.) (Chiappetta & Borg, 1983). The minimum vibration that human being can be triggered is in a range between 0.254 to 0.838 mm/s (Siskind, Stagg, Kopp, & Dowding, 1980) while ("Human Perception," 2018) state that most people will feel the vibration of 0.51 mm/s. The obvious effects of human due to vibration are annoyance, interference, work proficiency and health. For structural response, USBM R.I 8705 (1980) has stated the safe vibration level in **Table 1.1.** The table shows the allowable vibration depending on the frequency of blast, **f** and type of structures.

Table 1.1 Safe Peak Particle Velocity for Residential Structures (USBM R.I 8705)

Type of Structure	**f < 40 Hz**	**f > 40 HZ**
Modern homes - Drywall Interiors	19.05 mm/s	50.8 mm/s
Older Homes - Plaster on Wood lath for interior Walls	12.7 mm/s	50.8 mm/s

According to USBM R.I 8705 (1980), type of damage for a public structure is divided into three levels which are the threshold, minor and major. USBM stated that for threshold damage, the effects are loosening of paint, crack of small plaster at construction element joint and lengthening of old cracks. For effects of minor damage are loosening and falling of plaster, cracks in masonry around openings near the partition, hairline to 3 mm cracks and fall of loose mortar, while for major damage are cracks of several mm in walls, rupture of opening vaults, structural weakening and fall of masonry. According to Malaysia Mineral and Geoscience Department (JMG), the allowable blast-induced ground vibration and airblast for mining and quarrying operations are 5 mm/s and 120 dB(L) (Yusof, 2010).

To ensure the blasting work is efficient yet eco-friendly, certain mitigation steps need to be considered. Since there are two source types of ground vibration; controllable and uncontrollable, as a capable, experienced shot-firer, he must alter the controllable parameters that fulfilling the uncontrollable parameters. The quantity of explosive charge and distance between blast points to monitoring point is a great deal in controlling the emission of ground vibration. To achieve a great production yet maintain the green environment is difficult. According to (Duncan Minto, 2015), there is no right or best answer to develop a method that can fulfil all the requirement. If the shot-firer want to reduce the ground vibration, he will encounter less explosive, thus less fragment or if he still wants to reduce ground vibration but use the same amount of explosive charge, he needs to encounter the quality of stemming hence the cost of drilling increase.

In estimating the ground vibrations and damage of structure, peak particle velocities or PPV is used and particle velocity is the best ground-motion descriptor (Kuzu, 2008) (Kumar, Choudhury, & Bhargava, 2016). JMG has applied the USBM standard as fixed predictors to all mine and quarry companies. The predictor is shown below:

$$v = k\left(\frac{D}{Q^{\alpha}}\right)^{-\beta} \tag{1.1}$$

where v is the PPV (mm/s); D is the distance from blast point to the monitoring point (m); Q is the maximum amount of explosive per delay (kg); α is a blast method constant (½ is for surface blasting while ⅓ for underground blasting); k and β are the site constants.

The main focus of this study is to concentrate the understanding of measurement and control of ground vibration induced by blasting activity. There will be a discussion on the predictors, causes, impacts and mitigation of this environmental issue by sufficient approaches of monitoring and interpretation of the site data.

1.2 PROBLEM STATEMENT

Research efforts have been concentrated on determining various parameters of ground motion is closely related to building damage. Damage can affect from amount of ground movement, velocity of the movement and/or acceleration of the force hit the structure. From those data and research, damage of residential structure is proportional to ground particle velocity (Duvall & Fogelson, 1962). 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. The strains across the building elements are proportional to the base velocity in the vicinity of the natural frequency of SDF system. U.S Bureau of Mines stated that if one or more of the three mutual perpendicular components of vibration excess with 50 mm/s and near with structures, there is a possibilities that the structure will have damage due to the vibration.

Currently, all quarry and mining operators in Malaysia are adopting the USBM R.I 8705 predictor and applying Australian Standard (AS 2187 - 1993) for constant k and β in the predictor. The application of Australian Standard can affect the integrity of measurement due to different in geological features between Australian and Malaysia. The Australian Standard has fixed the value of k and β is 1140 and 1.6 respectively regardless of any type of rocks.

Despite the efforts of the competent blaster go through the necessary precautions and design to ensure that the level of vibrations is within the international as stipulated by USBM, but there will still be complaints.

1.3 RESEARCH QUESTIONS

Since the vibration levels obtained in furthermost of the activities are within the stated threshold and complaints are increasing, this therefore prompts the questions for this research:

i. What is the actual value of k and β in Lafarge Quarry at Kanthan, Perak?
ii. Does the value fulfil the Australian Standard?
iii. Does the rock mass properties affecting the ground vibrations?

1.4 OBJECTIVES

The objectives of the study are:

1. To find the actual value of site constants, k and β of the predictor used by Lafarge Quarry, Kanthan.
2. To study the ground vibration and propose a new predictor based on USBM predictor for safety and environment impact at Lafarge Quarry, Kanthan.

3. To investigate the relationship between the strength of rock and effect of ground vibration in Lafarge Quarry, Kanthan.

1.5 SCOPE OF STUDY

This study focusses on ground vibration impact to the nearest residential area at Lafarge quarry, Kanthan which is Taman Dovenby (600 m) from nearest blast point. The determination of site constant can alert the operator to be more competitive in design the blast design especially involving the public community.

Lafarge Kanthan located about 25 km north from Ipoh and 28 km to the east from Kuala Kangsar. The quarry operates 182 hectares of limestone hill and produces cement as their main product. Quarry of Lafarge is divide by two quarry - Quarry A and Quarry B. Basically, the study only focus at Quarry B since the effect to community are higher than Quarry A. **Figure 1.1** shows the location of quarry and the nearest risky residential area while **Figure 1.2** shows the distance between blast point in Quarry B to monitoring point in Taman Dovenby which is 600 m. The monitoring point was fixed by JMG due to the functionality of the point to the public compared to the nearest house which already empty.

The data collection was conducted for 4 weeks (once per week) from 17 January to 7 February 2018. The data included the vibration reading, scaled distance and rock samples. The vibration data has to go regression analysis to investigate the relationship between peak particle velocity, PPV and scaled distance. The analysis also will prove the actual site constants value so that the operator can improve their blasting activity.

Figure 1.1 Location of Lafarge Quarry and nearest risky Residential Area.

Figure 1.2 Distance from blast point in Lafarge Quarry to monitoring point.

The collected rock sample is to determine the uniaxial compression strength (UCS) of rocks and to study the effects of UCS to the emission of ground vibration. The determination of UCS is through point load test method. Basically, the blast design remains the same due to operator's research to get a good fragmentation.

1.6 DISSERTATION OUTLINE

This dissertation comprises of five chapters which are Introduction, Literature Review, Methodology, Result and Discussion, and Conclusion. Chapter 1 (Introduction) describes the overview or brief of the research. It justifies the study and generalises the main idea of the study.

Chapter 2 (Literature Review) will discuss all that has already been written regarding the study. The literature involved mainly will support the main idea and prove the hypothesis. The literature composes of books, book section, article journal, and websites.

Chapter 3 will explain all the method involved in data collection. From site at Kanthan to the point load laboratory at School of Materials and Mineral Resources Engineering, USM. The physical data (blast design, vibration reading) will translate into electronic data through regression analysis.

Once the data already interpreted, the result will be shown in Chapter 4. This chapter will show all the result regarding the dissertation and will be discussed. The discussion will show the improvement and alternatives of blast design to get better ground vibration thus lead to the recommendation of the study.

Chapter 5 will conclude all the results and relate it back to past research, thus answering the problem statement in Chapter 1.

CHAPTER 2

LITERATURE REVIEW

2.1 BLASTING PRINCIPLE

2.1.1 Blasting Theory & Fragmentation Mechanism

The sources of generation of fragmentations are;

a) Fragments formed by new fractures created by detonating explosives charge
b) In-situ blocks that have simply been liberated from the rock masses without further breakage, and
c) Fragments formed by extending the in-situ fractures in combination with the new fractures. (Sharma, 2012)

According to Bhandari (1997) and Sharma (2012), the rock fragment through blasting is achieved by dynamic loading introduced into the rock mass, which are shock wave and gas pressure. **Figure 2.1** shows the way both by-products of detonated explosive, shock waves and gas pressure travel and crack the rock. Bhandari stated, once an explosives detonates inside the blast hole, a pressure around 10G Pa which enough to shatter the rock near hole and stress wave with velocity of 3000 - 5000 m/s emitted while Sharma. The leading wave emitted is compressive but closely followed by tensile, which the main component of rock breakage. Bhandari added, once compressive stress reach nearby exposed rock surface, it will reflect and become tensile strain pulse. Rock kindly prefer to break in tension compared to in compression because rock has compressive strength 7 times higher than its tensile strength (Sharma, 2012). The fracture will progress backward from free surface. The gas pressure generated during the process also act to widen and extend stress-generated cracks and natural joints (Bhandari, 1997). **Figure 2.2** shows the cooperation between explosive, by-products and cracking stage.

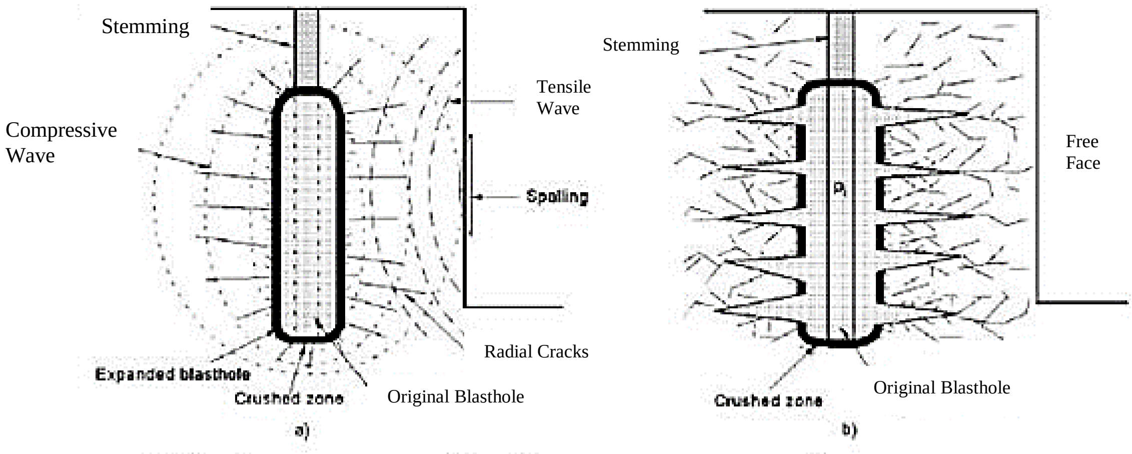

Figure 2.1 a) Shock wave propagation, b) Gas pressure expansion

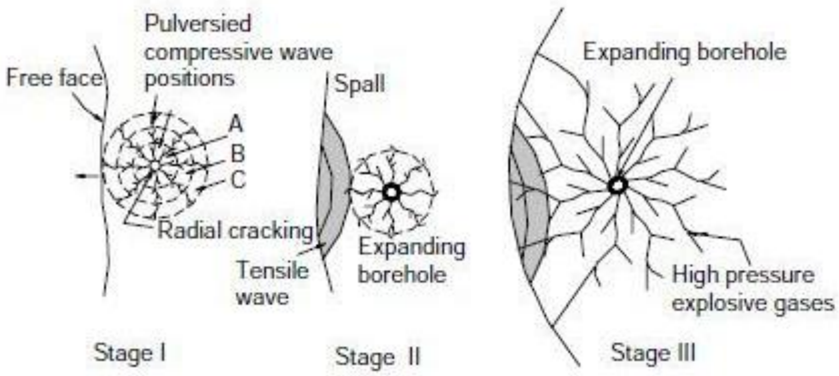

Figure 2.2 Stages of rock fragmentation

Further fragmentation takes places when the blasted rock moved forward and outward. More forces (shearing, tearing, colliding cracking and tumbling) on rock masses acted. The subjected rock will break due to flexural bending effect along mid-section of a bench and along minor and tightly closed joints that has escaped previous breaking process. High pressure gases generated at high temperature in the blast hole will wedge along the cracks and joints to be free to free face and atmosphere. In order to derived maximum work done, the shock wave and gas pressure must be contained as long as possible. Thus, the stemming play an important role to contain both energy. Insufficient stemming provide massive airblast and flyrocks.

2.1.2 Blast Design

The objectives of the blast design are to ensure an optimum result of the fragmentation of rock with low cost and to provide an adequate changing situation such as cavities, wet holes, clay bands or layered hard rock and fracture planes. **Figure 2.3** shows a typical design of surface blasting.

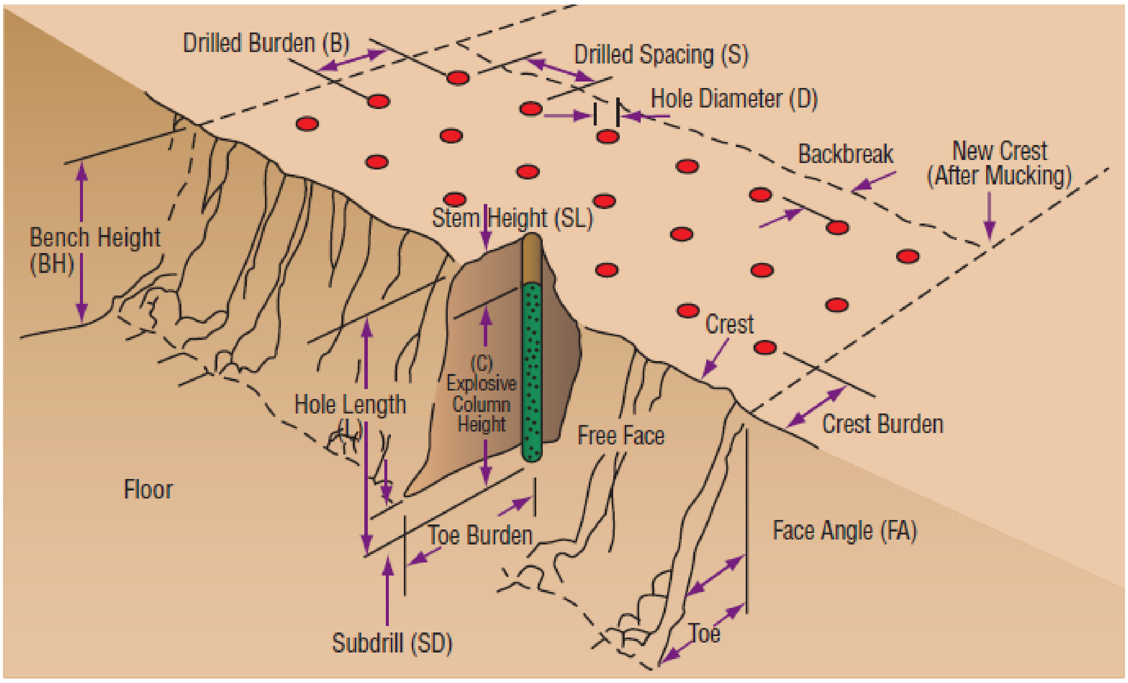

Figure 2.3 Typical Design of Surface Blasting (Nobel, 2010)

According to (Krolikowski, 2015), there are 8 parameters that contribute to a good blast design which are explosives;

- blast holes diameter and drilling
- burden
- bench height
- spacing
- detonation
- stemming
- rock properties,

In a meantime (Singh et al., 2016) conclude in their study, the main parameters that involved are:

- Burden to blast hole diameter hole ratio
- Spacing to burden ratio
- stemming column length
- stiffness ratio
- explosive type and amount
- initiation mode
- Powder factor.

While Balasubramaniam (2017) stated that factors affecting the blast design are:

- explosives and energy factors
- type and quantity of explosives used
- diameter of blast holes
- orientation of ore body
- rock properties

As conclusion, the main parameters of blast design and affecting fragmentation of rocks are:

- blast hole diameter
- burden,
- bench height
- spacing
- powder factor
- explosive and rock properties

Characteristics of explosives and rock properties will be discussed in Section 2.3

(a) Bench Hole Diameter

The determination of blast hole diameter, type of explosive and type of rock will lead to determination of burden amount and all other blast dimensions are a function of the burden (Dick, Fletcher, & D'Andrea, 1983). Factors affecting the determination of the diameter are the size of operation, bench height, type of explosive and rock properties (Bhandari, 1997). Dick et al. (1983) stated and supported by Bhandari, the larger the diameter, the lower the cost of drilling and blasting due to the amount of drill per unit volume and cheaper of blasting agents used in big quantity, but increasing in the diameter, gives result in large burden, thus coarser fragmentation. If the operator insists to do large diameter, but good in fragmentation, perhaps he can keeping the burden unchanged and elongating the spacing alone (Bhandari, 1997).

Increasing in hole diameter also resulting high ground vibration due to large amount of explosives used in a blast hole. Another effect of large diameter is, large fragment will produce, and thus more in handling after the blast include the transportation and processing of boulder size fragment which will increase the cost of material handling. Hole diameters vary from 35 mm (small bench) to 440 mm (in large bench). Since Malaysian operator normally used Australian Standard, Australian using large diameter with lower bench height. In Lafarge Kanthan, the bench height and blast hole diameter is 10 m and 89 mm respectively.

(b) Burden

Burden is defined as the shortest distance to relief (free face) once the hole detonates (Konya & Walter, 1991). **Figure 2.4** shows the isometric view of blast bench with dimension of spacing, S and burden, B. According to Konya and Walter (1991), the selection of burden is the most critical in design the dimensions and it is the most important parameter to decide. An insufficient burden will cause flyrock and airblast due to excessive energy of explosive, while too large a burden will affect the size of fragmentation, which will cause large boulder, toe problems and excessive ground vibration (Bhandari, 1997; Dick et al., 1983)

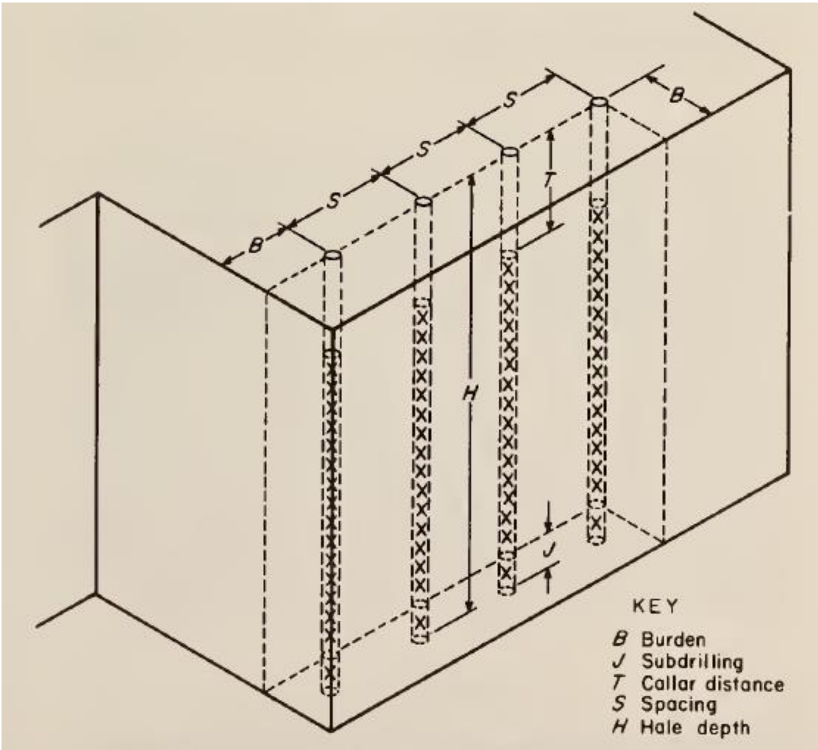

Figure 2.4 Isometric View of Bench Blast (Dick et al., 1983)

The burden is a function of blast hole diameter. The burden to diameter ratio is seldom less than 20 or seldom more than 40 even in extreme cases. According to Dick, usage of Ammonium Nitrate - Fuel Oil (ANFO) type of explosive, the ratio between burden and diameter hole are 28 (light rock with density 2.2 g/cm^3), 25 (average rock with density 2.7 g/cm^3) and 23 (dense rock with density 3.2 g/cm^3).

The recommended formula by (Nobel, 2010) which imply the burden-diameter ratio is stated as below :

$$\textbf{Burden}, \mathrm{B\ (m)} = (25 \text{ to } 40) \times \mathrm{Diameter, D\ (m)} \quad (2.1)$$

where 25 is used for very hard massive rock while 40 for soft rock. In Lafarge Kanthan, since the quarry operates limestone quarry, the operators use 40 as their constant to fix the burden values.

(c) Bench Height

Another perimeter to consider in blast design is bench height, H. Relatively, bench height is constant and the value is set to ensure the working specification of loading equipment can tolerate. According to Dick et al. (1983), bench height and burden need to be compatible. Hole depth less than 1.5 burden might contribute to excessive airblast and flyrocks, coarse and uneven fragmentation, but if the ratio between the height and burden exceed 4, toe problem and the higher the height, the more error in inclination of blast hole.

The bench height is a degree of heaping and spreading of materials broken by blasting, thus affecting the displacement (Bhandari, 1997). Generally, 10 - 18 m of height is already consider as the most economical and the safest to operate. Bhandari stated the use of large diameter blast hole (310-380 mm) and shallow benches (12-14 m) prevent efficient distribution of charge to fragment the rock especially alongside the stemming column. To overcome this, the length of stemming need to reduce and increase the ratio of charge length to burden. There is no any advantage to do high bench height. Lower benches give more efficient blasting result, drilling cost will reduce and much more safer from an equipment operation standpoint (Dick et al., 1983).

(d) Spacing

Spacing is defined as a distance between two adjacent blast holes which perpendicular to burden (Bhandari, 1997; Dick et al., 1983). The purpose of spacing is to control the mutual effect between holes. Spacing is calculated as a function of burden and timing of the delay between holes. Commonly ratio between spacing and burden is 1.2 to 1.3. Too close of spacing will causing the crushing and cratering between holes, boulders in burden and toe problem while too far of spacing will resulting inadequate force to fracture between holes, humps in the face and toe problem between holes.

Since the measurement of spacing in function of burden is effected by the blast pattern and delay between holes, Bhandari concluded that:

i. For sequence delays in the same row → **S = B**
ii. For simultaneous timing in the same row → **S = 2B**
iii. For multiple rows with sequence timing between holes in the same row, the entire round should be drilled in a square arrangement, particularly if identical timing is used for holes located laterally with one another in adjacent rows.
iv. Staggered patterns are preferred between rows where all holes in a single row are fired simultaneously but timing between rows are delayed.

(e) Powder Factor

Powder factor is the ratio between the total weights of charge explosives in blast holes to amount of broken rock (Bhandari, 1997) but according to Dick et al. (1983) powder factor is not the best perimeter to be considered in blast design but a best tool in estimate the cost accounting. The general equation for powder factor as defined by Bhandari is:

$$\textbf{Powder Factor}, \mathrm{P.F}\ (\mathrm{kg/m^3}) = \frac{\text{weight of explosive (kg)}}{\text{amount of rock } (\mathrm{m^3})} \tag{2.2}$$

where

$$\textbf{amount of rock}\ (\mathrm{m}^3) = \text{burden (m)} \times \text{spacing (m)} \times \text{blast hole height (m)} \qquad (2.3)$$

The amount of powder factor depending on the amount of explosives, strength of rocks and blast dimension. Higher energy from explosives, higher amount of rock can break compare to lower energy of explosives. Commonly, most used explosives products contain same amount of energy and thus, have similar rock breaking capabilities. Soft rock required less energy of explosives compare than hard rock. Thus, less amount of explosives which will save cost for explosives purchasing.

Massive rock with few cracks or weakness, requires a higher powder factor compare to those who have geological flaws. Lastly, the more free faces, the lower the powder factor need to be. **Table 2.1** shows the typical powder factors for surface blasting proposed by (Dick et al., 1983).

Table 2.1 Typical Powder Factors for Surface Blasting (Dick et al., 1983)

Degree of Difficulty in Rock Breakage	**Powder Factor (kg/m^3)**
Low	0.15 - 0.24
Medium	0.24 - 0.44
High	0.44 - 0.74
Very High	0.74 - 1.48

According to Bhandari (1997), to obtain good fragmentation and efficient for loading operation, the explosive consumption is higher in quarrying. Bhandari (1997) stated, for soft laminated strata type of rock, usually the ratios may as low as 0.15-0.25 kg/m^3. For harder sedimentary strata, the powder factor around 0.45 kg/m^3 while for jointed igneous rock, it might reach 0.6 kg/m^3. Generally, 1 kg of explosives may break around 8-12 tons of rock.

2.2 EXPLOSIVE THEORY

Explosive is a material (solid or liquid) usually mixture which on application of a suitable stimulus to convert into other more stable substance (largely or completely gaseous) with heat and pressure as by-product. The very hot gases with high pressure produced will be the agent for rock fragmentation.

2.2.1 Classification of Explosives

According to Bhandari (1997), explosives can be group into low explosives and high explosives. For high explosives, further classification of explosives will be primary explosives and secondary explosives. He stated, normally, low explosives were the earliest to be developed. The rapid form of combustion lead to the explosion which the particles burn at their surface and more of the bulk until all been consumed. The reaction usually slower than the speed of sound. Typical examples are the blasting/gun powder, propellants in ammunition, rocket propellant and pyrotechnics.

High explosives detonates at velocities of 1500-8000 m/s (depending on their composition) and react faster that speed of sound. The reaction produce large amount of gases at considerably heat and extremely pressure. Further classification of high explosives are primary and secondary explosives. Primary explosives usually sensitive to stimuli like weak mechanical shock, sparks and the application which take the explosive from state of deflagration to the state of detonation. Primary explosives usually used as initiating charges in the initiating devices likes detonators. Examples of these explosives are mercury fulminate, tetrazene and other mixtures. Secondary explosives can functioning under shock-wave influence, normally induced by detonation of primary explosives. Example of secondary explosives are nitro-glycerine, emulsion, watergels and ammonium nitrate-fuel oil (ANFO).

A successful blasting requires suitable initiating devices like detonators and another high explosives or blasting agent such as ANFO, some slurries and some emulsion (Bhandari, 1997). **Figure 2.5** shows the classification of explosives.

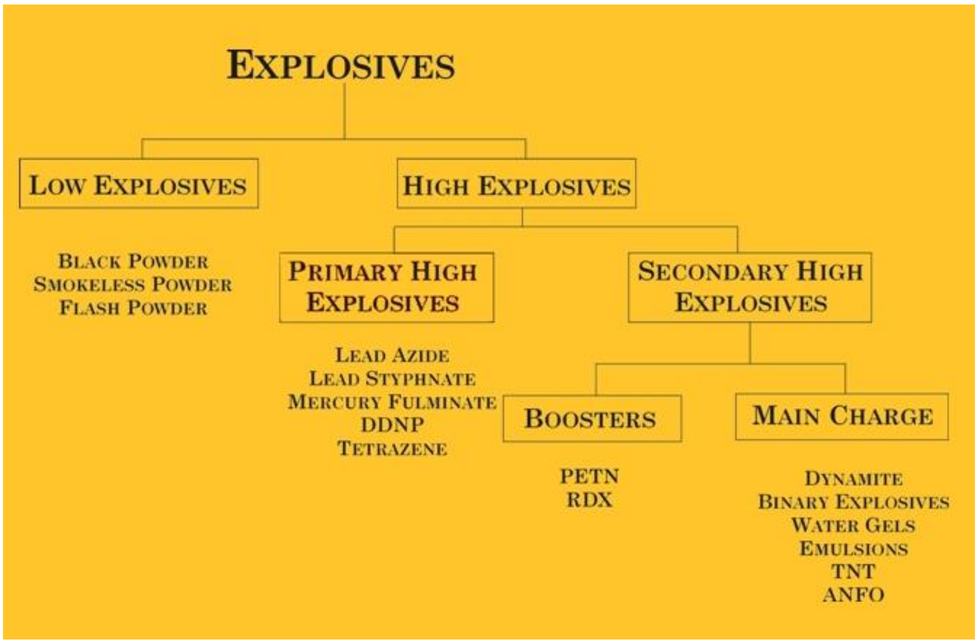

Figure 2.5 Classification of Explosives

2.2.2 Characteristics of Explosives

There are 5 characteristics considered in selection of explosives which concern the environmental (Konya & Walter, 1991), they are:

- sensitivity and sensitiveness
- water resistance
- fumes
- flammability
- Temperature resistance.

(a) Sensitivity and Sensitiveness

According to Dick et al. (1983), sensitivity is defined as susceptibility of explosives to initiation. If the mixture is too sensitive to No. 8 test blasting cap (a measure of standard detonator strength), the mixture classified as explosives, while if not, it will be blasting agent. They add, the sensitivity of blasting agent is depending on ingredients, particles size, density, charge diameter, confinement and presence of water. Basically the supplier will specify a minimum recommended primer for their products. Generally, larger primer are consider as less susceptible to accidental initiation and safer to handle.

Sensitiveness is an ability of explosives to propagate through the entire length of column charge and controls the minimum diameter for practical use. Sensitiveness is measured by determining the critical diameter of explosive (Konya & Walter, 1991). Critical diameter is defined as minimum diameter for explosive to detonate reliably. The diameter will determine the maximum of blast hole. Sensitiveness also measured from the ability of explosive to propagate from cartridge to another cartridge (hole to hole) usually maximum distance between primed donor cartridges to unprimed receptor cartridge, where detonation transfer will occur. Extremely sensitive explosives allows the propagation while insensitive may fail the propagation due to its diameter is too small (Dick et al., 1983) .

(b) Water Resistance

Water resistance is an ability of an explosives to withstand water penetration (Bhandari, 1997). He states, water resistance measure from time taken usually hours for the explosives submerged in static water and still can detonate reliably. There are two type of resistance towards water; internally and externally (Konya & Walter, 1991). Internal water resistance is a resistance provided by the explosive composition itself. This applicable to watergels and some water-based emulsion which can directly pumped into a blast hole filled by water. The explosive will displaced the water upwards and no water can penetrate the explosive, thus can functional well.

External water resistance is provided by packaging. ANFO has low water resistance, thus once mixing ANFO with water, the detonation will fail. To make it success, before fill the blast hole with ANFO, ANFO will packed into polyethylene tubes or waterproof-plastic bag to avoid the ANFO-water mixture form.

(c) Fumes

Fumes of an explosives is a measure of amount of toxic gases emitted in detonation process (Konya & Walter, 1991). Example of primary toxic gases are carbon monoxide (CO) and oxide of nitrogen. According to Bhandari (1997), the composition of explosive is said to be balance when contained oxygen combines with carbon and hydrogen to form carbon dioxide and water. The amount of oxygen contain inside the ingredient of explosives influence the formation of toxic gasses or fumes. Insufficient amount of oxygen led to carbon monoxide formation while excessive oxygen will result the existence of oxide of nitrogen.

Dick et al. (1983) states the formation of fumes also relates to the blast design. Perimeters that may contribute are insufficient of blast hole diameter, lack of primer, water deterioration, removal of wrappers and the use of plastic borehole liners. Usually fumes is consider important when there is underground blasting in tunnels, shaft and other confined space. Konya & Walter (1991) mention the value of fumes and its safety level to surrounding as below:

(a) < 0.16 cubic feet of toxic fumes per 200 grams of explosives: **Class 1** (Very good)

(b) 0.16-0.33 cubic feet of toxic fumes per 200 g of explosives: **Class 2** (Good)

(c) > 0.33 cubic feet of toxic fumes per 200 g of explosives: **Class 3** (Poor and danger)

Bhandari (1997) also state the same standard and advised that explosive in Class 2 and 3 must not be used underground unless several precaution steps has been taken including sufficient ventilation system.

(d) Flammability

Flammability is a measure of ease of initiation from spark, fire or flame. Flammability is important in determining the way to store, to transport and to determine the standpoint of explosives. Some explosive may detonate from just a spark, while others not. Liquid oxygen explosives (LOX) is a type of explosive commonly used in 1950's is an example that sensitive to spark and because of that, most of explosive used today are not flammable as LOX for safety factor (Konya & Walter, 1991).

(e) Temperature resistance

Since explosive is made of chemical substance, the performance of explosive also related to surrounding temperature. Extremely hot or extremely cold may defect the explosive. For example, storage of ammonium nitrate in temperature above 32°C can defect the ANFO's performance and safety of the product. Most compound will slowly decompose, change properties and shelf life decrease once expose to extreme temperature. Extreme cold condition also gives impact to the explosive especially slurry type of explosives. ANFO and slurry explosives become progressively stiffer and less pliable as temperature lowered. Under certain conditions, slurries become hard and less sensitives to normal levels of initiation (Bhandari, 1997)

2.2.3 Explosives Selection Criteria

To select an explosives, one should consider these parameters to ensure the blast produce efficient and economical enough (Dick et al., 1983). These parameters are: