EFFECT OF CONTROLLABLE PARAMETERS ON ROCK FRAGMENTATION AT IMERYS MINERAL (M) SDN BHD

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UNIVERSITI SAINS MALAYSIA
2022

SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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By

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Dissertation submitted in partial fulfillment of the requirements for the degree of

Bachelor of Engineering with Honours

(Mineral Resources Engineering)

Universiti Sains Malaysia

JULY 2022

DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled ‘Effect of controllable parameters on rock fragmentation at Imerys Mineral (M) Sdn Bhd. I also declare that it has not been previously submitted for the award of any degree and diploma or other similar title of this for any other examining body or University.

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ACKNOWLEDGEMENT

Foremost, I would like to express my sincere gratitude to my advisor Associate Professor Ir. Ts. Dr Mohd Hazizan Bin Mohd Hashim for the continuous support of my final year and this project, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I cannot have imagined having a better advisor and mentor for my final year project.

I would also like to thank Imerys Mineral (M) Sdn Bhd for giving me the opportunity to carry out my final year project there. Special thanks to quarry manager, Mr Ali Reza and quarry engineer, Mr Pugalyenthiran of Imerys Mineral (M) Sdn Bhd whose have invested their full effort in guiding me. I would like to thank shotfirer of Spring Energy, Mr Alinoor for helping me exploring new knowledge about blasting in quarry.

I thank my fellow groupmates: Nurhanisah, Afiq Ariff and Nuraizul Azren for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had in the last four years. In addition, I acknowledge the help from technical staff from School of Materials and Mineral Resources Engineering.

Last but not the least, I would like to thank my family for supporting me through my hard times while completing this project and also myself for doing all this hard work and never quitting until this far.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EFFECT OF CONTROLLABLE PARAMETERS ON ROCK FRAGMENTATION AT IMERYS MINERAL (M) SDN BHD

ABSTRACT

Blast design plays crucial part on rock fragmentation. Rock fragmentation should be taken into account in blasting as it affects the subsequence operations such as grinding and crushing. Bad result in blasting will lead to expensive cost and waste of energy. The focus of this study is to investigate the impact of blast design parameters on the rock fragmentation. The goal of efficient blasting can be achieved by investigating the relationship between blast design parameters and fragmentation. The study is carried out at Imerys Mineral Sdn Bhd quarry. The field study takes 2 weeks to acquire muck pile images, blasted samples and blast record. There are two phases that are done for this study. First, field study is done at the quarry such as geological mapping, blast monitoring and grab sampling. Second phase, experimental work such as physical test and analysis are carried out at laboratory. Under the present study a size distribution of blasted limestone quarry is carried out using the Wipfrag image processing software with acquired digital images. Image processing of the data shows that, the mean fragments size of each blast event is good and have fair distribution. The results of physical test showing that the limestone is in soft rock category. A few factors affect the geology of rock and resulting influence the strength of rock. Uniaxial compressive strength has high correlation with mean fragment size, means that mean fragment size will become finer with increase in powder factor.

KESAN PARAMETER BOLEH KAWAL TERHADAP PECAHAN BATU DI IMERYS MINERAL (M) SDN BHD

ABSTRAK

Reka bentuk letupan memainkan peranan penting dalam pemecahan batu. Pemecahan batu perlu diambil kira dalam letupan kerana ia menjejaskan operasi seterusnya seperti mengisar dan menghancurkan. Keputusan buruk dalam letupan akan membawa kepada kos yang mahal dan pembaziran tenaga. Fokus kajian ini adalah untuk menyiasat kesan parameter reka bentuk letupan terhadap pemecahan batuan. Matlamat letupan yang cekap boleh dicapai dengan menyiasat hubungan antara parameter reka bentuk letupan dan pemecahan. Kajian dijalankan di kuari Imerys Mineral (M) Sdn Bhd. Kajian lapangan mengambil masa 2 minggu untuk memperoleh imej longgokan kotoran, sampel yang diletupkan dan rekod letupan. Terdapat dua fasa yang dilakukan untuk kajian ini. Pertama, kajian lapangan dilakukan di kuari seperti pemetaan geologi, pemantauan letupan dan persampelan rampasan. Fasa kedua, kerja eksperimen seperti ujian fizikal dan analisis dijalankan di makmal. Di bawah kajian ini taburan saiz kuari batu kapur yang diletupkan dijalankan menggunakan perisian pemprosesan imej Wipfrag dengan imej digital yang diperoleh. Pemprosesan imej data menunjukkan bahawa, saiz serpihan min bagi setiap kejadian letupan adalah baik dan mempunyai pengagihan yang adil. Keputusan ujian fizikal menunjukkan batu kapur berada dalam kategori batuan lembut. Beberapa faktor mempengaruhi geologi batuan dan kesannya mempengaruhi kekuatan batuan. Kekuatan mampatan uniaksial mempunyai hubungan yang tinggi dengan purata saiz serpihan, bermakna saiz serpihan min akan menjadi lebih halus dengan peningkatan faktor serbuk.

CHAPTER 1

INTRODUCTION

1.1 Background study

In this chapter, background of study will be told generally. In section 1.2, the purpose of this study is to close the research gap by studying the fragmentation analysis of rock and correlate it with blast design and geology of rock. Blast design plays crucial part on rock fragmentation. It consists of burden, spacing, bench height, drill hole depth, sub-drill, number of holes, stemming and etc is known as controllable parameter. Rock fragmentation should be taken into account in blasting as it affects the subsequence operations such as grinding and crushing. Bad result in blasting would lead to expensive cost and waste of energy.

As efficiency of the quarry operations depends on the size distribution of blast fragments, so analysis and evaluation of fragmentation must be assessed regularly to maintain good tonnage production. The method to assess the blast fragmentation is listed below:

i) Direct Method-Sieving analysis method

ii) Indirect Method-Image analysis method

Fragmentation is an essential thing in blast qualification because it has a significant impact on a mining operation's profit and productivity. Aside from technical results related to safety and the environment, such as vibration and projection, the results are primarily considered from an economic standpoint. As a result, there are other factors that influence profit and productivity. The majority of these factors are determined by how well a blast is designed. In other words, the performance of a blast is primarily determined by the design of the blast. The primary goal of rock blasting is to optimise blast performance while also ensuring adequate operational safety. Rock fragmentation is determined by two groups of variables: rock mass properties, which are uncontrollable, and drill-and-blast design parameters, which can be controlled and optimised. By optimising the blast design parameters to provide target fragmentation, the costs of downstream operations can be reduced. The parameters of target fragmentation are equipment specific and vary by mine category. Because of the high level of mechanisation and the integrated nature of the mining industry's production systems, all units must function with the designed reliability and capacity to meet planned production targets (Singh and Narendrula, 2009).

1.2 Objective of the project

Based on the identified research gap, the objective of this research is to develop a method to analyse discontinuities by mapping and image analysis technique. The process of this research is divided into the following objectives to accomplish the aim of the research

1. To analyse the fragments of limestone after blast process

2. To study the effect of controllable parameters used during blasting

1.3 Scope of Study

The scope of work for this study is limited to image analysis of limestone to evaluate the particle size distribution and also the parameters used in every blast events.

The scope of the study is divided into three main components. The first is to relate the relationship of the geology of rock and fragments of rock through blast parameters using the image analysis process. Next is to analyze weathering and discontinuities by geological mapping. Lastly, verify the image analysis method using Wipfrag analysis.

This study is carried out at Imerys Mineral (M) quarry which is located in Keramat Pulai, Ipoh Perak. The field study takes 2 weeks to acquire muck pile images, blasted samples and blast record. Blasting is conducted three times a week in Imerys Mineral Quarry. The muck pile images are taken using proper camera for the purpose of fragmentation analysis.

1.4 Limitations of study

There are a few limitations while doing this study. Below is the limitations listed:

I. The access into the quarry is limited, only two persons can get into the blast place at one time due to SOP of the quarry

II. Safety at the quarry is the priority. Any persons cannot go near the wall to do observation of mapping

III. Due to rock fall of neighbour's quarry, Imerys Mineral (M) quarry must stop their production for a month

1.5 Thesis Outline

This dissertation is divided into five chapters, where every chapter explains different parts of the study, including introduction, literature review, methodology, results and discussion, and the conclusion. Chapter one present a basic overview of the research study. This chapter aims is to describe the background of the study, state the problem arising from previous research, objectives to achieve the aim of this study, the significance of the study and the scope of work to give a better understanding of the study contents. Chapter two discusses the previous studies about image analysis, controllable parameter, geology parameter which is relevant to the study and research gap analysis. All the information is obtained from several journal articles, websites and books. The methods used to collect information and data for the purpose of this study will be described in Chapter 3. In Chapter 4, the results and discussion on blast design parameter, geological mapping, fragmentation analysis and point load test will be further analysed. The relationship between these outcomes will be discussed in this chapter. Lastly, Chapter 5 which is conclusion will conclude the comparisons of all results and some suggestions to produce optimum fragmentation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents about (section 2.2) significant of blasting which is usually the first step in a communication process followed by crushing and grinding followed by (section 2.3) controllable parameters due to size of the rock after the blast is very important because it will affect the cost and time used for upcoming stages. It will give direct impact on the economy of mining activities. Secondary blasting will result from poor rock fragmentation. Rock fragmentation by blasting is controlled by three main aspects:

i. explosive specifications
ii. rock mass geomechanical properties
iii. geometry of the blast.

Good blast requires application of explosives energy which consists of five factors which will be explained in section 2.4. Next, section 2.5 will explain about test for the rock strength. There will be a few tests that will be run to test the strength of the rock. Section 2.6 will explain on the factors that affect the rock strength. Meanwhile in section 2.7 blast ability index of rock will be discussed to relate the geology of rock with the fragmentation rock. In section 2.8, fragmentation measurement techniques will be discussed as the image analysis software has different benefits. Last, the summary of the chapter 2 will be wrapped up related to gap analysis of research and conclusion of this chapter in section 2.9.

2.2 Theory of blasting

Blasting theory is one of the most contentious issues in rock excavation. There is no single accepted theory that fully explains the mechanism of rock breakage in every situation. Some of the results are discussed further below.

I. Nature of Detonation

Chapman and Jouquet defined a space as a self-sustaining shock wave produced by a chemical reaction. This space of negligible thickness is bounded by two infinite planes - the unreacted explosive on one side of the wave and the exploded gases on the other, as shown in the figure below.

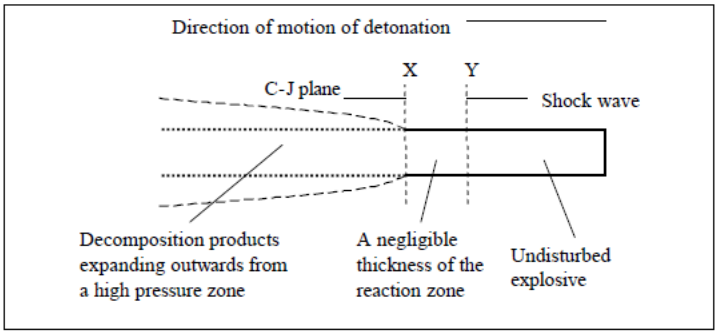


Figure 2.1 Detonation process of explosive cartridge

There are three distinct zones:

a. the undisturbed medium ahead of the shock wave

b. a rapid pressure at Y leading to a zone in which chemical reaction is generated by the shock, and complete at X

c. a steady state wave where pressure and temperature are maintained.

This condition of stability condition for stability exists at hypothetical X, which is commonly referred to the Chapman-Jouquet (C-J) plane. Between the two planes X and Y there is conservation of mass, momentum and energy. A simplified and approximate velocity of detonation (VOD) can be obtained from the following empirical relation:

$Cd = v J (1 + 1.3r)$ (Equation 1)

Where Cd = VOD in m/s

J = heat of reaction in MJ/kg

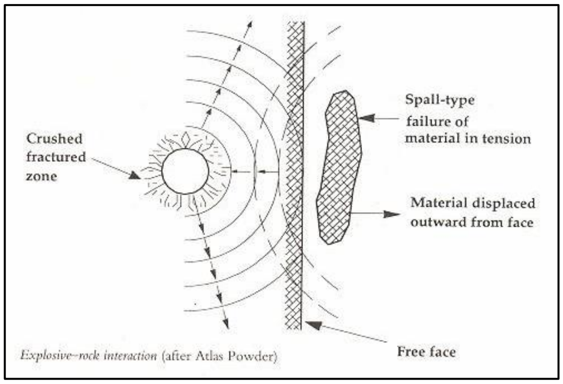
r = specific gravity of the explosive

The detonation of explosives in cylindrical columns and in unconfined conditions leads to lateral expansion between the shock and C-J planes resulting in a shorter reaction zone and loss of energy.

The detonation of explosives in cylindrical columns and in unconfined conditions leads to lateral expansion between the shock and C-J planes resulting in a shorter reaction zone and loss of energy. Thus, it is common to encounter a much lower VOD in unconfined situations than in confined ones.

II. Detonation and Interaction with rock

On detonation of an explosive charge, the rock immediately surrounding the blasthole is crushed, owing to explosion pressure as shown in Figure 2.2.



Explosive–rock interaction (after Atlas Powder)

Figure 2.2 Explosive-rock interaction

After passing through the crushed zone, the outgoing shock wave travels at speeds ranging from 3000 m/s to 5000 m/s, creating tangential stresses that cause radial cracks. The expanding shock wave from the blast source creates compressive pressure. When the shock wave reaches a free face, it returns to the blasthole at a lower pressure but in the form of a tension wave through the rock. This is how rock blasting works. Generally, the various stages of rock breakages are:

1. Expansion and Crushing of Blasthole

   Within a few milliseconds from the detonation of the explosives in a blasthole, the explosion pressure builds up to greater than the compressive strength of the rock. The explosive energy forces the blasthole to expand in diameter. A pulverized or crushed zone of a few mm thickness resulted around the blasthole.

2. Radial Crack

   As the blasthole expands, the rock closer to the hole fails in tension, forming radial cracks around the blasthole's circumference.

3. Shock Waves

   From the blasthole into the rock, compressive shock waves radiate in all directions. Some of the shock waves are reflected, causing the rock to fail in tension. Shock waves in massive rock can travel long distances without losing all of their kinetic energy.

4. Reflection and Cracking

   Shock energy is reflected at major joints, causing spalling or parting of large rock slabs. Rock fragments are beginning to separate from the main rock mass. Large rock fragments may be produced, resulting in oversize materials.

2.3 Significant of blasting

A mining company's economy is based first on ore extraction and recovery, and then on productivity. This section primarily tells about blasting affects total energy consumption and productivity. Blasting gives big impact on mining especially drilling, loading, crushing and grinding. Blasting increases the productivity of excavator and loader if the activity goes according to the structured plan. This is due to higher bucket and truck fill factors, as well as increased diggability capacity. Thus, it helps to decrease the energy consumption of crusher and grinder.

Explosives used for rock fragmentation are characterized by the resulting pressure pulse transmitted on the cavity walls. The pulse is transmitted to the rock as compressive longitudinal pressure waves which create localized fractures near the borehole and reflect in tension at free-surfaces. Burden removal by blasting results from the combination of localized peak stresses and the propagation of cracks from reflected tensile pressure waves (Field and Ladegaard-Pedersen, 1971, Langefors & Kihlström, 1978).

The last destination of blasted rock is to be loaded into primary crusher for which size distribution is very important. Hence, blast design plays crucial role because it relates with the fragmentation of rock. The size of the fragment is a key component in determining blasting efficiency and output. However, size of rock fragment can be evaluated further by using selective analysis. Through the analysis the production of rock can be improved. Oversize and unwanted rock can be avoided.

If the cost of drilling and blasting is increased due to the high explosive charge value, the cost of subsequent operations will be reduced due to the finer fragments produced. Excessive explosives, on the other hand, must be avoided in order to minimise environmental damage and the generation of disproportionate fines. Elevli (2012) states blasting is also one of the crucial processes in quarry/ mine operations since it effects the productivity and efficiency of mine/quarry activities which is based on rock fragmentation.

If the fragmentation after blasting does not produce the desired size, the operational cost will rise due to unneeded secondary blasting. To reduce mining costs, blast designs for specific blasting events should take rock fragmentation into account. Also, drilling and blasting constitute 15 to 20% of the total mining cost, and hence the need to tailor blast design towards optimal results to enhance efficiency of the quarrying process.

Blasting has a significant impact on mining and milling that extends beyond the ability to efficiently dig and load ore. A growing body of blasting research indicates that it has a significant impact on crushing and grinding. These include increased output and fewer delays for bridging and jamming due to oversize. Furthermore, better suited fragmentation to the crushing and grinding system is indicated to reduce energy consumption by these activities, an important result in today's environment. Micro-fracturing within individual fragments appears to be an important component of optimal fragmentation for this purpose. This is in contrast to fragmentation criteria for loading, which are primarily concerned with fragment size. As a result, in order to achieve satisfactory results throughout the operation, blasting must be thoroughly examined.

As a result, knowing that the fragmentation distribution is adequate is very important, but not sufficient, in the process of optimising blasting. Consideration must also be given to how blasting will precondition individual fragments through internal fracturing. While the first factor is now directly measurable, the second must be assessed through a study of production, energy consumption, and supply cost.

Two factors stand out as critical in determining crushing and grinding effectiveness. The first is productivity. There are undoubtedly examples of processing plants where poor crushing and grinding output has limited overall plant output. The second consideration is energy consumption. Large hard rock mines use enormous amounts of energy, which has a cost. Crushing and grinding consume a significant amount of this energy. Grinding, in particular, consumes a lot of energy. The reason for this is that the transition from feed size to product size in grinding is typically much greater than in crushing.

There is significant evidence that blasting does affect crushing and grinding results, and that large savings in cost can accrue (Eloranta, 1995; Paley and Kojovic, 2001). It is reasonable to postulate that the size distribution of blasted fragments, and the internal softening of individual fragments by blasting can affect crushing and grinding effectiveness, even though these processes are two to three unit processes downstream from drilling and blasting. In Figure 2.3 shows the flow on how the drilling and blasting affect the down-stream operation.

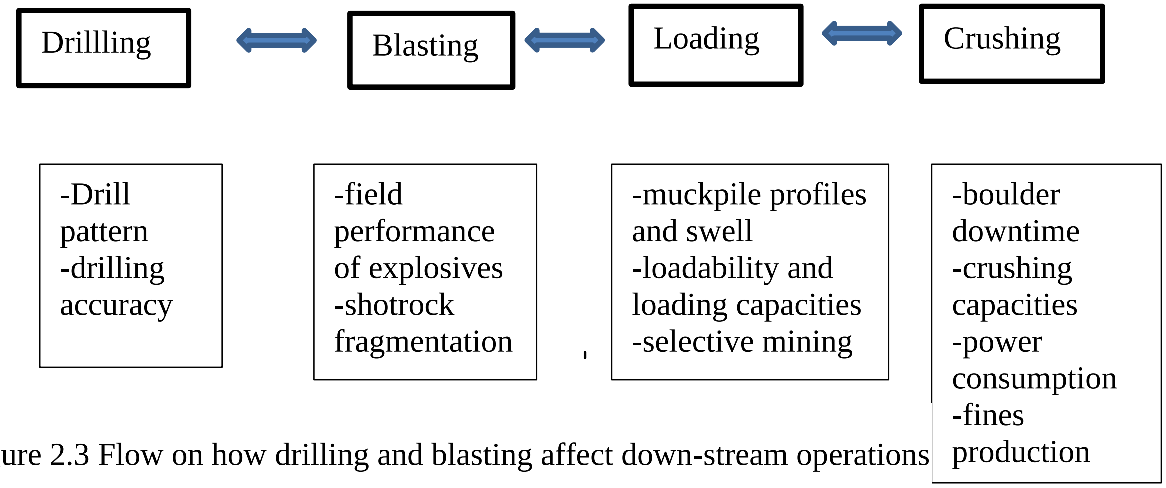


Figure 2.3 Flow on how drilling and blasting affect down-stream operations

The role of microfractures is very important, especially at the grinding stage. It is generally considered that fragments become harder at each stage of sizing, because the feed is smaller and there are fewer geologic and blast induced fractures present in the fragments. Since grinding feed is typically less than 3/4 inch, it will only be the smallest macrofractures, and the microfractures that survive to reduce the resistance to grinding. There have also been studies in operational plants that show significant improvements in crushing and grinding production as well as cost savings associated with blasting changes.

Mineral liberation is a third factor in crushing and grinding effectiveness. More liberation means better downstream recovery. A question that remains unanswered is whether blasting that creates more microfractures around or through mineral grains improves liberation and recovery. Meanwhile, the relationship of the blasting cost and other subsequent quarry operations cost such as hauling, crushing and loading are interrelated with each other. To totally optimize costs and to make informed decisions, all production costs must be considered when selecting drilling and blasting methods. Drilling and blast are the first phase of the production cycle but influences all costs for all the other activities. Thus, it is very important to appraise blast fragmentation as it can affect loading, hauling, crushing operations.

2.4 Controllable Parameters

Controllable variables are those, which can be manipulated or changed by trial and error depending on the characteristics of ground vibration. Blast design parameters such as burden, stemming, subdrilling, spacing and initiation timing must be carefully determined in order to have a blast function efficiently, safely and within reasonable vibration and air blast levels.

The important controllable variables associated with the characteristics of ground vibration are (Siskind, 1973; Wiss and Linehan, 1978):

- Type of explosive
- Charge per delay
- Delay interval
- Direction of blast progression
- Burden, spacing and specific charge.

Most of these variables are interrelated. A change in one variable in the operating system can change the others. The net change in the magnitude, frequency and duration of ground movement is the combined influence of all variables rather than anyone of them independently. It is of course a very difficult task to quantify the measures or extent of the effect of each variable individually. Basic parameters involved in the process of optimum blasting may be classified as follows:

I. Blast Geometry
II. Initiation pattern
III. Explosive pattern
IV. Rock mass parameters

2.4.1 Blast geometry

The blast geometry plays a big role in fragmentation, displacement, and explosive consumption. The following are basic blast geometry parameters:

(i) Spacing (m) and Burden (m)

Burden is the distance between the bench face to the first row of blasted hole. Normally the value of burden is equal to the range of 20 to 40 D, depending upon the properties of the rock mass.

Spacing is the distance between the two successive holes in any row. Spacing is a function of the burden, delay timing between blast holes and initiation sequence. This parameter basically depends upon the diameter of drilling hole, bench height of the face and the desired degree of fragmentation and displacement.

As shown in the figure 2.4 below, for “V” pattern and box cut, spacing usually set between 1.0B –1.5B. In Malaysia, the normal practice is 1.2 B.

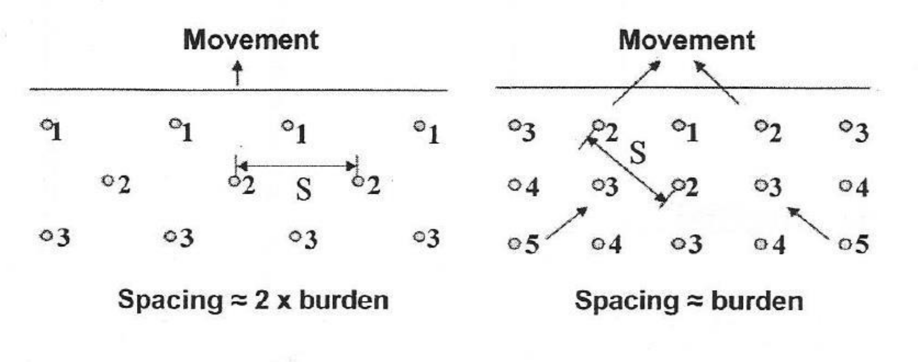


Figure 2.4 Pattern

(ii) Bench Height (m)

Basically, bench height of the face will affect the spacing. Bench height is vital in terms of total quarry production cost, safety, and ore dilution, so it must be carefully evaluated. The economical determination of bench height may vary depending on the machinery and equipment used, topography, drilling machine capacity, environmental conditions, operation plans, and so on. To keep costs low, determining an economical bench height must be based on individual economic assessments of quarrying operations, followed by consolidation of individual assessments.

(iii) Stemming (T)

The portion of a blast-hole between the hole collar and the explosive charge, and is usually filled with some inert confining material. Water, drill cuttings, sand, mud, or crushed rock can all be used as stemming materials. Dry angular crushed rock (30mm) is the best because it forms a compaction arch that locks into the blast hole wall, increasing its resistance to ejection. Stemming column are generally between 0.5B –1.3B or 20D. A good first approximation for stemming height is about 1B. The following formula can be used to calculate the optimal stemming length:

$$Ts = \frac{12Z}{A}\left(\frac{QS}{100}\right)^{1/3}$$

Equation 2.1

Z = Flyrock factor (1 for normal blasting and 1.5 for controlled blasting

A = Rock factor (6 for very soft and 14 for hard rock (see table 1)

Q = Mass (kg) of explosives in 8 holes diameters or if the charge length is less than 8 holes diameters, the total mass of explosives

S = Relative weight strength of explosives (ANFO) = 100

(iv) Charge factor (kg/m^3)

The charge factor can be described as the amount of explosive required for the breakage of one cubic meter volume of the rock mass. The optimum charge factor results in the proper breakage of rock layer with minimum burden and maximum productivity.

(v) Diameter of hole (mm)

The holes should never be larger than one-half inch in diameter than the explosive. The shock energy is absorbed by the air gap around an explosive charge, resulting in poor fragmentation. Any cost analysis that includes explosives must always consider the borehole diameter and depth.

For a six-inch diameter hole, the relatively expensive explosives necessary for efficient performance in a three-inch diameter hole may be unfeasible in terms of cost. Despite the fact that drilling a six-inch hole in equivalent material will cost at least twice as much as drilling a smaller hole, less expensive explosives may normally be used in the larger hole without sacrificing explosive effectiveness.

2.4.2 Initiation pattern

For correct fragmentation, proper throw of blasted materials, and fewer blasting risks, the initiation pattern is crucial. The following are the two most regularly utilised initiation pattern parameters:

(i) Delay interval (ms)

Delay intervals between holes in a row less than 3 mili-seconds per meter of spacing are not recommended due to air blast and fragmentation considerations. Delay intervals between rows less than 6 m/s per of burden can cause stemming ejection, fly rock and excessive back break.

(ii) Delay pattern or connection

In addition to these aspects, there is yet another factor which plays a dominant role. That is the blast timing and triggering sequences. It is called delay pattern. Delay patterns and varying the holes array to fit natural excavation topography, allow for more efficient use of the explosive energy in the blast. Benches may be planned and conveyed forward with more than one face so that simple blasting patterns can be utilized to eliminate the rock.

On the off chance that the openings are terminated in diagonal columns as in Figure 2.5, the rock mass would be tossed to one side during blasting.

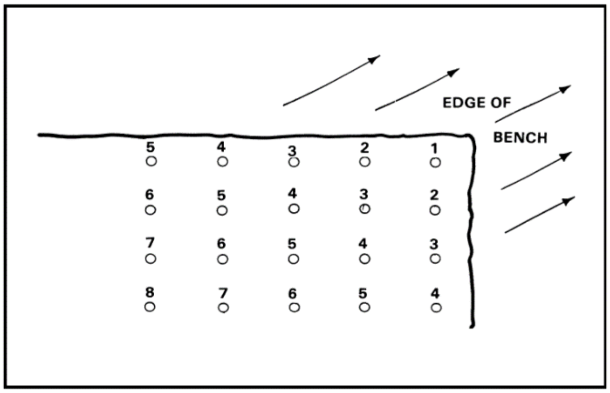


Figure 2.5 Diagonal column

2.4.3 Explosive properties

The central point affecting the mine operator’s ultimate decision of the correct explosive is blasting cost. The following simple example illustrates how certain basic considerations could influence the selection of explosives. (Roy, 2005).

N = Number of boreholes

W = Weight of explosives loaded in each hole (kg)

C = Cost of explosive per kg

D = Cost of drilling and loading of each hole

Then total cost becomes

$T = N (D + W. C)$ (Equation 2.2)

When comparing total cost for different explosives, A and B, the formula is:

$TA - TB = NA (D+ WA.CA) - NB (D+WB.CB)$ …………………… (Equation 2.3)

The criterion for determining the quality of explosive for a given job is simply whether the left-hand side of the equation is positive or negative. If it is positive, explosive B is better than explosive A. if it is negative, the reverse is true.

Characteristics of explosives also should be considered in selecting it. They are concern environmental factors:

1. Sensitiveness

The characteristic of an explosive which defines its ability to evaporate through the entire length of the column charge and controls the minimum diameter for practical use.

2. Water resistance

The ability of an explosive to withstand exposure to water without it suffering detrimental effects in its performance. These explosives dislodge the water up, yet are not entered by the water and show no inconvenient impacts whenever terminated inside a sensible timeframe. Outside water opposition is given not by the unstable materials itself, but rather by the bundling or cartridging into which the material is set. As an example, some emulsions and water gels can be pumped directly into boreholes filled with water.

3. Fumes

The fume class of an explosive is the proportion of how much harmful gases delivered in the explosion cycle. Carbon monoxide and oxides of nitrogen are the essential that are considered in the fume class evaluations. Although most commercial blasting agents are close to oxygen-balanced to limit fumes and upgrade energy discharge, fumes will occur and the blaster should be aware of their production.

4. Flammability

The flammability of an explosive is defined as the characteristic which deals with the ease of initiation from spark, fire or flame. Some explosive compounds will explode from just a spark while others can be burned and will not detonate fast.

5. Temperature resistance

Explosive compounds can suffer in performance if stored under extremely hot or cold condition.

2.4.4 Firing pattern

The firing pattern provides a path for the detonation wave of the explosive charged in the holes. The most important requirement in any blasting programme is the sequential generation of free face with the blast progression. The free face is known to provide a reflection surface for the shock wave, which is required for rock mass fragmentation (Bhanwar Singh Choudhary, 2013). Blast rounds may produce extremely poor results if there is no free face. To that end, the firing pattern determines rock movement and direction by leaving a free face for subsequent blast holes and rows (Bhanwar Singh Choudhary, 2013). In mines/quarry, various firing patterns such as row to row, chevron, echelon and diamond, are used to detonate explosives.

Row by Row - This firing pattern can be used in a pure Row by Row initiation sequence with only delay times between rows or in a pattern with short delay times between holes and long delay times between rows to avoid row interaction. At least one free face is required for this design. Figure 2.6 shows row by row firing pattern.

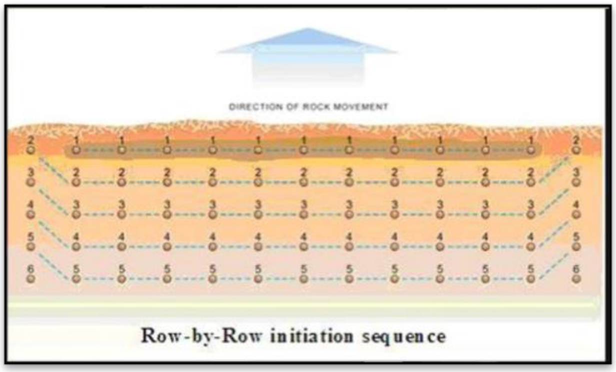


Figure 2.6 Row-by-row initiation

Chevron-The delays between holes and rows in a Chevron firing pattern are chosen so that the firing sequence results in a V formation. The angle of the V formation can be changed by using different delays. At least one free face is required for for the Chevron design. A closed chevron pattern results in a high-profile rock pile with secondary fragmentation from impacts between rocks thrown in opposite directions. An open chevron pattern produces evenly spread rock piles that are especially suitable for front end loaders and may result in fewer toe problems. Below is the Figure 2.7 Chevron firing pattern.

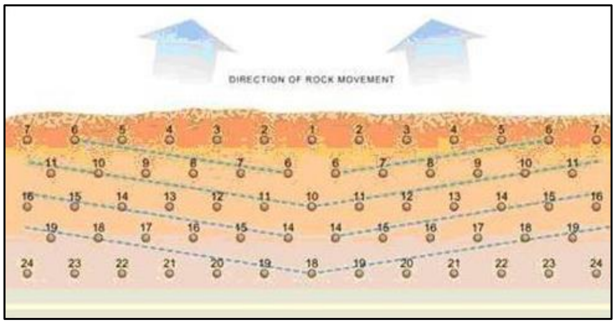


Figure 2.7 Chevron firing pattern

Echelon- The Echelon firing pattern is simply one half of a Chevron pattern. Echelon pattern requires at least two free faces. Figure 2.8 shows Echelon firing pattern.

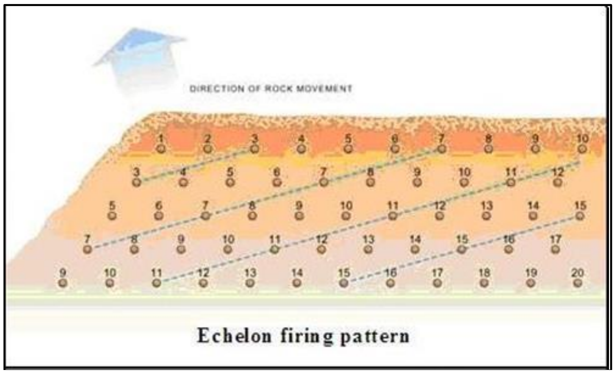


Figure 2.8 Echelon firing pattern

Diamond/diagonal- For box cuts, sump blasts and other applications where there are no free faces parallel to the blast holes, a diamond firing pattern is used. The broken rock will be displaced upwards, increasing the possibility of fly rock. Figure 2.9 below shows diamond firing pattern.

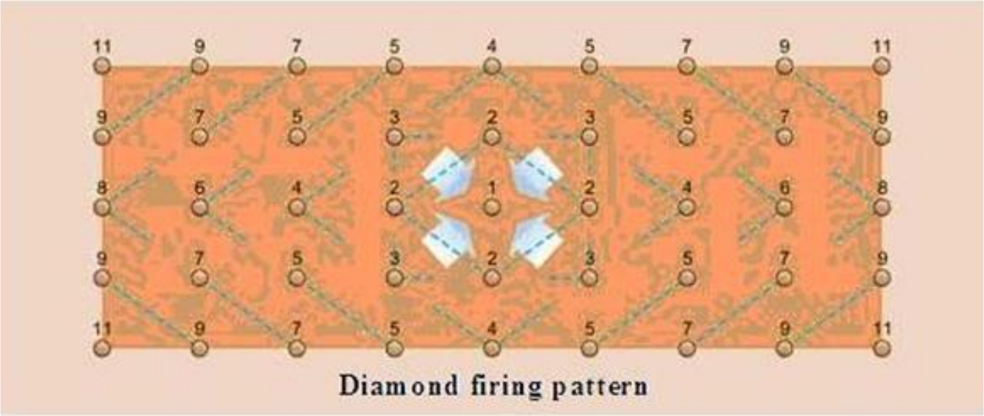


Figure 2.9 Diamond Firing Pattern

A proper pattern selection for a blast round can provide optimal blast performance in terms of fragmentation, throw, and wall control, among other things. This is due to the significance of firing burden in any blast round. By changing the firing pattern, the firing burden, and thus the spacing-to-burden ratio, changes. Proper sequencing of inter hole and inter row delay timing is another important contributor to good blast results in the firing pattern. The systematic release of energy associated with appropriate burden is critical in maintaining continuous momentum for interrow displacements. Inadequate delay in a multirow blast results in poor back row breakage, resulting in coarse fragment size, large collar boulders, tight muckpile, and back breaks/over breaks. Furthermore, any change in spacing and/or burden must be accompanied by a change in delay timing. Proper timing influences the number of rows and thus the number of holes blasted in a pattern.

2.4.5 Rock mass parameters (Bohloli, 1997)

Geological conditions are of fundamental importance to the design of blasting. The most important parameters are as follows:

a. Joint pattern and orientation control the in-situ block size distribution and migration of the explosive gases.
b. The foliation of the rock mass affects size distribution of the blasted material.
c. Rock grain size both affects strength of the rock and controls generation of fines.
d. Petrology determines generation of fine materials. Depending on the mineral content, different rocks generate more or less fines. Quartz-Feldspar rich rocks, for instance, have more tendency to produce fines than Amphibole-Pyroxen rich ones.
e. The density of the rock mass is an important parameter concerning energy required to move the rock mass.
f. Rock mass stiffness affects development of pressure in the blast hole and partition of the explosive energy into shock and heave.
g. Compressive and tensile strength of the rocks' controls crushing and fracture extension of rocks respectively.

2.5 Blast Performances

Good and efficient blast requires utilisation of explosive energy which consist of 5 main factors.

1) energy distribution,
2) energy confinement,
3) energy level,
4) relief or free face
5) explosive ratio

2.5.1 Energy Distribution

Uniform fragmentation will result from equal energy distribution in the rock. The diameter of the blast hole is the most important design consideration. Small diameter and big diameter have different advantages. Below are the benefits of small diameter:

- Small charges drilled on smaller pattern (i.e., smaller burden) that distribute uniformly throughout the rock mass. This will maximise the explosive energy distribution. Thus, advantage is used to overcome the blasting limitation in highly fractured rock;
- Shorter stemming length increase the breaking of rock at the top thus reduces the oversize;
- Reduce the energy concentration at the collar thus reduce the risk of flyrock

Large hole also has its benefits. Below are the advantages:

- Less number of holes are drilled for given tonnage compare with smaller diameter holes since burden is larger;

- Less drilling time is required for given tonnage when compare with smaller holes;
- Drill holes are straighter and less prone to deviation

2.5.2 Energy Confinement

The explosive energy must be held in blasting for a long enough period of time for the detonation gases to expand and increase pressure without premature venting. If the gas pressure is lost prematurely due to poor confinement, the fragmentation produced will be poor. Loss of confinement occurs in areas with low-burden, weak geological areas such as fracture zones, and stemming ejection. A sufficient burden with suitable and adequate stemming materials is required to achieve good fragmentation.

2.5.3 Energy Level

The total explosive energy applied to the rock mass is referred to as the energy level. For fragmentation and rock mass movement, each type of rock necessitates a different amount of explosive energy. The total energy of an explosive is determined by the explosive's energy per unit weight and density. In Malaysia, two types of blasting agents are commonly used: ANFO and bulk emulsion (pure emulsion and heavy ANFO). The density of bulk explosive is approximately 1.15 gm/cc, with a velocity of detonation of 4,000 to 5,000 m/s and a relative volume strength of 112-120, with ANFO being 100. Bulk emulsion has a higher relative volume strength, density, and VOD than ANFO. As a result, bulk emulsion results in better fragmentation.

2.5.4 Relief

The presence of a free face in the rock mass large enough for the blasted rock to expand and occupy is referred to as relief. The spalling effect of free face also enhances fragmentation.