SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

EFFECT OF BLAST DESIGNS ON ROCK FRAGMENTATION AT LAFARGE KANTHAN QUARRY, CHEMOR, PERAK

by

NUR ALIAH HAZIRAH BINTI AWANG KECHIK

Supervisor: Dr Mohd Hazizan 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

May 2018

DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled “Effect of Blast Designs on Rock Fragmentation at Lafarge Kanthan Quarry, Chemor, Perak”. I also declare that it has not been previously sent for the award of any degree or diploma and other similar title for any other examining body, institution or university.

Name of Student : Nur Aliah Hazirah binti Awang Kechik Signature:

Date :

Witnessed by:

Name of Supervisor : Dr Mohd Hazizan bin Mohd Hashim Signature:

Date :

ACKNOWLEDGMENTS

I would like to express my deepest appreciation to all those who provided me the possibility to complete this study. First of all, a special gratitude I give to my supervisor, Dr Mohd Hazizan binti Mohd Hashim who had contributed in stimulating suggestions and encouragement and helping me to coordinate my project especially in writing this report.

Moreover, I would also like to acknowledge with much appreciation to Lafarge Kanthan Quarry for giving an opportunity to carry out my final year project at the quarry. Special thanks goes to the quarry engineers, Mr Yusri and Mr Hafiz whose have invested their full effort in guiding me. I would like also thank to the consultant engineer, Mdm Wan Mimi Aida, who also helped me in doing a lot research and I came to know about so many new things in blasting.

I am thankful and fortunate enough to get constant encouragement, support and guidance from all the teaching staffs of School of Materials and Mineral Resources Engineering which helped me in successfully completing my project. I would also like to express my special thanks to all assistant engineers in laboratory for their timely support.

Last but not least, I am grateful to my parents and siblings who have provided me through moral and financial support in my life. I would not forget to mention my dearest coursemates, Khairul Shazwan and Nurwahidah for their encouragement and timely support till the completion of my field study at Lafarge Kanthan Quarry.

TABLE OF CONTENTS

Contents Page

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATION

Legend	Symbol
10% passing size	D10
25 % passing size	D25
50% passing size	D50
75 % passing size	D75
90% passing size	D90
Bench height	H
Bench height to burden ratio	H/B
Burden	B
Mean fragment size	X_{50}
Maximum fragment size	X_{max}
Spacing	S
Spacing to burden ratio	S/B
Uniaxial compressive strength	UCS
Uniformity index	n

KESAN REKA BENTUK LETUPAN KE ATAS PEMECAHAN BATUAN DI KUARI LAFARGE KANTHAN, CHEMOR, PERAK

ABSTRAK

Kajian ini bertujuan untuk mengkaji kesan parameter reka bentuk letupan pada pemecahan batuan. Kajian lapangan dijalankan di Kuari Lafarge Kanthan, Chemor,Perak selama 3 minggu. Selepas operasi letupan dijalankan, imej-imej serpihan batu telah diambil menggunakan kamera yang sesuai. Imej-imej tersebut kemudian dimuat naik ke dalam perisian WipFrag untuk menganalisis pemecahan yang dihasilkan. Graf pengagihan saiz zarah yang diperolehi daripada perisian itu telah dikaitkan dengan reka bentuk letupan. Peratusan kumulatif melepasi bagi penghancur batu dengan saiz suapan 1500 mm antara 92.8 hingga 100%. Parameter reka bentuk letupan seperti ketinggian undak kuari dan faktor serbuk mempunyai korelasi yang tinggi dengan pemecahan batuan. Ketinggian undak kuari kepada nisbah beban (H/B) menunjukkan korelasi yang tertinggi terhadap saiz min serpihan dengan nilai R^2 = 99.7%. Kajian turut menunjukkan apabila faktor serbuk meningkat, lebih kecil saiz pecahan min. Faktor serbuk juga mempunyai korelasi tinggi terhadap kekuatan mampatan unipaksi. Kekuatan mampatan unipaksi batu pecahan adalah antara 66.01 hingga 115.81 MPa. Keputusan menunjukkan bahawa semakin tinggi kekuatan mampatan unipaksi batuan, semakin tinggi faktor serbuk yang diperlukan. Kajian ini menunjukkan jarak kepada nisbah beban (S/B) mempunyai korelasi yang sangat lemah dengan pemecahan batuan. Walaupun terdapat penghasilan pecahan batu yang bersaiz besar, semua kerja letupan telah menghasilkan pemecahan batuan yang baik dengan indeks keseragaman bervariasi dari 2.09 hingga 2.28.

EFFECT OF BLAST DESIGNS ON ROCK FRAGMENTATION AT LAFARGE KANTHAN QUARRY, CHEMOR, PERAK

ABSTRACT

This study was sought to study the effects of blast design parameters on rock fragmentation. The field study was carried out at Lafarge Kanthan Quarry, Chemor, Perak for the duration of 3 weeks. After blasting, the images of muck pile were taken using suitable camera. The images then were uploaded into the WipFrag software to analyze the fragmentation generated from the blasting. The particle size distribution graphs obtained from the software had been correlated with the blast designs. The percentage cumulative passing for gyratory crusher with the feed size of 1500 mm ranges between 92.8 to 100 %. Blast design parameters such as bench height, powder factor, stemming have high correlation with the rock fragmentation. Bench height to burden ratio (H/B) shows the highest correlation to the mean fragment size with the value of R^2=99.7%. Moreover, it is indicated that as the powder factor increases, the finer the mean fragment size. Powder factor also has a high correlation with the uniaxial compressive strength of the rock. The compressive strength of blasted rocks ranges between 66.01 to 115.81 MPa. The results show that the higher the uniaxial compressive strength of rock, the higher the powder factor needed. In this study, spacing to burden ratio (S/B) has a very weak correlation with the rock fragmentation. Even though there was an occurrence of oversize rocks, all blasting events had generated a good rock fragmentation with uniformity index varies from 2.09 to 2.28.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Generally, this study will be focused on the effect of blast designs on the rock fragmentation. There are two types of parameters which can be classified as controllable parameter and uncontrollable parameter. Burden, spacing, bench height, drill hole depth, sub-drill, number of holes, explosive per hole, stemming length, delay sequence, blast pattern, detonation velocity, number of delays and delay time between decked charge and powder factor are classified as controllable parameters. Non-controllable parameters which are also known as fixed parameters cannot be controlled or adjusted by a quarry engineer. For example, geological properties like joint, dips, strike, strength of the rock, mineral compositions and rock properties.

In quarrying operations, good fragmentation which is fine and loose enough can ensure the efficiency of all the subsequent operations such as loading, hauling, crushing and grinding. If the size of blast fragments is larger than the suitable feed size of the equipment can handle, the tonnage production will decrease. Secondary blasting and usage of hydraulic breaker can be practiced in order to reduce the oversize rocks. However, secondary blasting should be avoided if possible as it is very costly and high risk.

Rock fragmentation is very crucial factor that should be taken into account in blasting as it gives major influence to the subsequent operations such as crushing and grinding. The energy costs will decrease if the feed size of the primary crusher has been reduced. Besides that, it also influences maintenance cost and operational life of the equipment. The maintenance cost will be higher and the operational life of equipment will be shorter if the size of fragments is not compatible with the ability of equipment can handle. Therefore, the blasted rock fragments should be fine enough in order to be fed into the primary crusher.

The efficiency of all quarry operations depends on the size distribution of blast fragments. Hence, analysis and measurement of fragmentation should be assessed regularly in order to maintain the tonnage production. In this new era, there are various methods available to assess blast fragmentation. These methods are generally divided into direct and indirect methods. Table 1.1 shows the methods that are applicable for assessment of blast fragmentation.

Table 1.1: Methods for assessment of blast fragmentation

Direct Method	Indirect Method
• Sieving analysis method • Oversize boulder count method	• Observational • Experimental • Image analysis methods

Digital image analysis has been in widespread used for many years to evaluate efficiency of comminution process whether by blasting, crushing, grinding or material handling processes. It is the most favourable to use in blasting as the gradation measurements can be automated, thus eliminating the subjectivity of manual measurements. Besides that, it is extremely low per unit cost and resulting in lower sampling errors. The results can be obtained in a very short time and allowed adjustments to the production methods.

1.2 Problem Statement

In Lafarge Kanthan Quarry, fragmentation is very crucial factor that should be considered after blasting. From the observation during a site visit, boulder blasting had to be carried out to reduce the size of oversize rocks. The size of oversize rocks are larger than the feed size of the gyratory crusher which is 1500 mm. This is due to poor fragmentation produced from primary blasting.

1.3 Objectives

The study was sought to study:

- The effect of blast design parameters on rock fragmentation in order to determine the relationship between burden, spacing, stemming, powder factor, bench height and mean fragment size of blast fragments.
- The relationship between uniaxial compressive strength and powder factor needed for blasting operations.

1.4 Scope of Study

This study was carried out at Lafarge Kanthan Quarry which is located at Gunung Kanthan in Chemor, Perak. It is one of 45 limestone hills within Kinta valley which has many commercial uses such as cement, aggregates and marble. There are two study areas which were Quarry B and E-Hill.

The field study took about 3 weeks to acquire muck pile images, blasted samples and blast records. Blasting was conducted thrice a week in Lafarge Kanthan Quarry to achieve 300,000 TPM. The muck pile images were taken using suitable camera for the purpose of fragmentation analysis. Particle size distribution graph was generated based on the size of fragmented rocks. A few blasted samples with sizes between 35 to 55 mm were collected to determine the strength of the rock. The results obtained from the fragmentation analysis and point load test were analyzed and correlated with blast design parameters.

1.5 Thesis Outline

This thesis comprises five main chapters which are Introduction, Literature Review, Methodology, Results and Discussions as well as Conclusions. Chapter 1 which is Introduction gives a general introduction about the study which summarizes background study, problem statement, objectives of research and scope of research work. Literature Review which is in Chapter 2 provides description, summary and evaluation which is relevant to the research. All the informations were obtained from several journals and articles. The methods used to collect information and data for the purpose of this study will be fully described in Chapter 3. In Chapter 4, the results and discussions on blast design parameters, 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 good fragmentation.

CHAPTER 2

LITERATURE REVIEW

2.1 Significant of Blasting

Choudhary (2013) suggests that rock fragmentation is important factor to evaluate the efficiency and productivity of quarry blasting. According to him, if rock fragmentation is not accessed regularly, production cost and time delay in quarrying process can increase due to unnecessary secondary blasting and usage of hydrallic breaker. Prasad *et al.* (2017) also agrees that drilling and blasting represents 15 to 20% of the total mining cost.

Elevli (2012) also states that blasting is one of the crucial process in quarrying operations since it effects the productivity and efficiency of quarrying processes which is based on the rock fragmentation. If the fragmentation after blasting do not generate desired size, there will an increase in operational cost due to unnecessary secondary blasting. Thus, blast designs for certain blasting event should take rock fragmentation into account to cut down mining costs.

In 2010, Kulatilake *et al.* (2010) had mentioned that blasting could give significant impact on subsequent processes if mining such as loading, crushing and grinding. According to them, improvement in blasting could increase loader and excavator productivity. This was due to the increased bucket and truck fill factors as well as diggability capacity. It also stated that suitable and uniform particle size distribution could increase crusher and mill throughput. Thus, it helped to decrease the energy consumption of crusher and grinder.

According to Workman and Eloranta (2003), it is suggested that the relationship between the blasting cost and other subsequent quarry operations cost such as hauling, crushing and loading. The study shows that if the drilling and blasting cost is increased due to high explosive charge value, costs of subsequent operations will be reduced due to finer blasted fragments as shown in Figure 2.1. Hence, it is very important to assess blast fragmentation as it can affect loading, hauling, crushing operations.

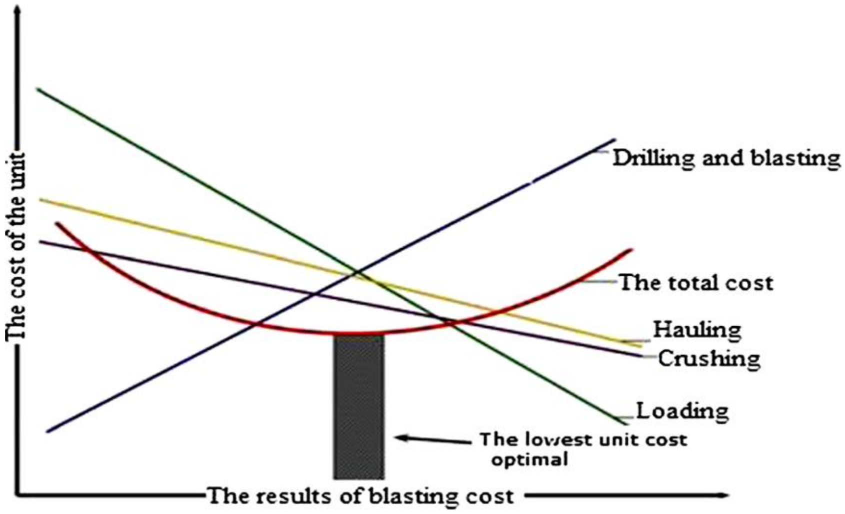

Figure 2.1: The relationships between quarry operations in term of cost

(Workman and Eloranta, 2003)

Workman and Eloranta (2003) suggests that the size distribution of blasted fragments can be evaluated qualitatively as good or poor fragmentation. The size of fragments is very crucial in crushing stage as it effects the production tonnage and equipment downtime. Coarse fragments will reduce the maximum rate of production of primary crusher as downtime for clearing crusher bridging and plugging increases. At the end of their study, they had concluded that improved blasting with good fragmentation can increase productivity in crushing and grinding and more undersize can bypass stages of crushing.

Bozic (1998) also mentions that poor fragmentation from blasting requires secondary blasting of oversize to reduce it to a size that can be handled by excavators. Excavators also require extensive manoeuvring to load large rocks which can cause increasing in cycle time.

This study coincides with Kanchibotla *et al.*(1998) which also states fragmentation from blasting can give major effect on digging and hauling. As stated by them, a finely fragmented muck pile can increase the diggability of an excavator. However, if the size of fragments larger than the size of an equipment can handle, secondary blasting costs and equipment down time will increase. It can also reduce the productivity.

2.2 Fragmentation Modelling

Singh *et al.* (2015) had discovered that there was a variety of blast fragmentation modelling that have been used to predict fragmentation size after blasting. The most popular model is probably Kuz-Ram model and has been widely used in the industry. In their study, it was stated that average fragment size (X_{50}) can be estimated using a model that had been developed by Cunningham in 1983.

Cunningham had modified the model using the Kuznetsov's equation for ANFO based explosives. The Kuznetsov's equation is expressed in Equation 2.1.

$$k_{50} = A\left(\frac{V}{Q}\right)^{0.8} Q^{\frac{1}{6}} \tag{2.1}$$

Where: A = rock factor;

Q = quantity of explosive in one blasthole

V = rock volume broken by one blasthole (m^3)

Singh *et al.* (2016) mentioned that A is equal to 7 for medium rocks, 10 for hard, high fissured rocks, and 13 for hard, weakly fissured rocks. Then, he had combined it with the Rosin-Rammler equation to predict the entire size distribution. The Rosin-Rammler equation is stated in Equation 2.2.

$$R = e^{-(\frac{x}{x_c})^n} \tag{2.2}$$

Where: R = fraction of material retained on the screen

x = the screen size

x_c = characteristic size

n = uniformity index

Typically, the values of uniformity index are between 0.6 and 2.2. A value of 0.6 shows that the muck pile is non-uniform which means it consists mainly with dust and boulders. In contrast with that, a value 2.2 means that a muck pile is uniformly distributed with majority of fragments which is close to the mean size.

Then, the both two equations were combined and further simplified to the following equations shown in Equation 2.3 and Equation 2.4:

$$k_{50} = A(K)^{-0.8} Q^{\frac{1}{6}} \left(\frac{115}{E}\right)^{0.633} \tag{2.3}$$

$$\mathrm{R} = 100 - \mathrm{e}^{-0.693\left(\frac{\mathrm{x}}{\mathrm{x}_{50}}\right)\mathrm{n}} \tag{2.4}$$

Where: A = rock factor;

K = powder factor

Q = quantity of explosive in one blasthole

E = relative weight strength of explosive;

ANFO = 100 and TNT = 115

R = percentage smaller than x

x = size of rock

n = uniformity exponent

Cunningham then further developed an equation as shown in Equation 2.5 to estimate the index of uniformity “n” of the Rosin-Rammler distribution curve from blast design parameters.

$$\mathrm{n} = \left(2.2 - 14\ \frac{\mathrm{B}}{\mathrm{d}}\right)\left(1 - \frac{\mathrm{W}}{\mathrm{B}}\right)\left(1 + \frac{\frac{\mathrm{S}}{\mathrm{B}}}{2}\right)^{0.5}\ \left(\frac{|\mathrm{L_B} - \mathrm{L_C}|}{\mathrm{L_B} + \mathrm{L_C}} + 0.1\right)^{0.1} \frac{\mathrm{L}}{\mathrm{H}} \tag{2.5}$$

Where: B = burden (m)

d = hole diameter (mm)

W = standard deviation of drilling accuracy (m)

S/B = spacing to burden ratio

L = charge length above grade (m)

L_c = the column charge length (m)

H = bench height (m)

Even though the Kuz-Ram model has been used widely to estimate blast fragmentation, it has some disadvantages as following:

- The rate of rock quality factor is based on a very subjective description such as massive, blocky or friable.
- The energy factor depends on the explosive energies which derived from the ideal detonation codes.
- It also underestimates the amount of muck pile
- There is no large block size

Kuz-Ram model also underestimates the contribution of fines in the muck pile. Therefore, Swebric function was developed by Ouchterlon (2003). The new model had been improved to predict the fines distribution in the muck pile. It is mentioned that sieving data for blasted or crushed rock can be fitted with three-parameters of the Swebrec function.

The x_{50} prediction equation can be retained from the Swebrec function. Besides that, a new prediction equations for x_{max}, the largest fragment size, and b can also be sketched. It is also stated that x_{50} and x_{max} of Swebrec function are valid fragmentation descriptors for any sieving curve. Thus, Swebrec function is more preferable to predict fragmentation in blasting compared Rosin-Rammler distribution.

2.3 Fragmentation Digital Analysis

There are many methods that are available to access blast fragmentation such as sieving analysis method, laboratory experimental and image analysis methods. However, Elevli, Topal and Elevli (2012) had mentioned that image digital programmes had replaced direct methods such as visual analysis, boulder count and sieving analysis.

Some of the programmes for image analysis that are widely used in industry are Gold Size, WipFrag and Split Online. Split Desktop is the most recent software for this purpose. All the programmes are basically worked the similar way. Image digital programmes includes capturing image of muck pile, scaling the image, filtering the image, segmenting the image and measuring. The following steps shown in Figure 2.2 are applied to determine the particle size distribution after blasting using digital analysis:

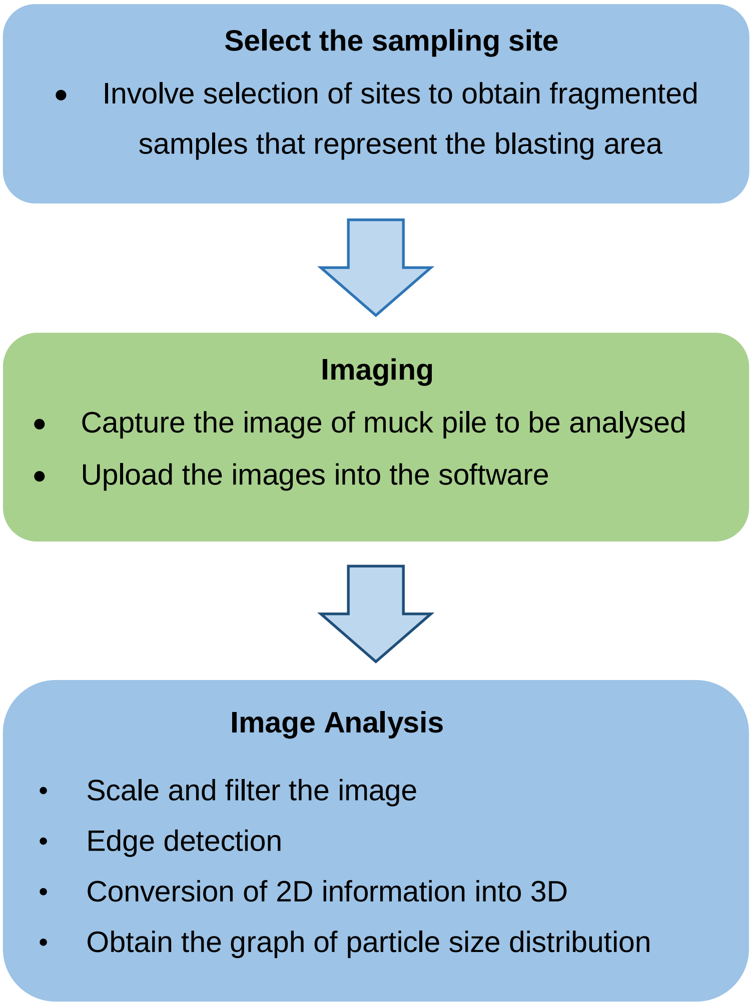

Figure 2.2: Steps on Using Digital Image Analysis

According to Elahi and Hosseini (2017), there are many advantages of image analysis. Firstly, there is no limitation on the mass size and volume. Images can be prepared quickly and do not disrupt the production process. Besides that, the results based on the parameters of the blast pattern can be analyzed quickly. Many images of muck pile can be prepared to reduce analysis error. This method is also affordable as the price of equipment is cheaper than sieving analysis. Moreover, it also save time compared to laboratory experiments which requires a lot of time to prepare the samples.

However, one of the disadvantages of image analysis is that the images should be acquired from a reference surface. Besides that, high quality images should be prepared in order to have precise detection of fragments and reduce errors. Elevli, Topal and Elevli (2012) also suggests that even though this method can provide rapid and accurate fragmentation size distribution assessments, there were still some disadvantages in using image digital analysis. The disadvantages are stated as follows:

- These programmes only can analyze rocks that is on the surface
- Fine particles size can be underestimated especially in a muck pile
- Imprecise results as the analysed particle size can be over-split or combined. As for an example, big boulders could be split into smaller particles while smaller particles could be combined into larger particles.

2.4 Controllable Parameters

Several researches had been conducted on the rock fragmentation after blasting. From the outcomes of the researches, it can be concluded that fragmented by blasting is correlated to blast design parameters. Burden, spacing, bench height, drill hole depth, sub-drill, number of holes, explosive per hole, stemming length, delay sequence, blast pattern, detonation velocity, number of delays and delay time between decked charge and powder factor are classified as controllable parameters. Figure 2.3 shows the blast design parameters used in a bench blast.

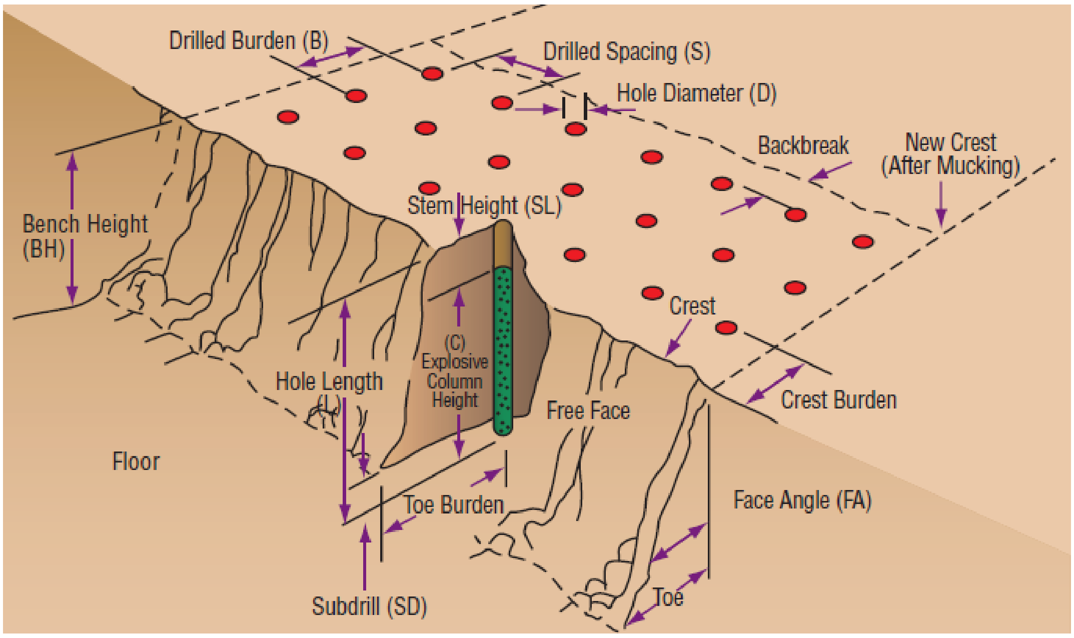

Figure 2.3: Blast Design Parameters

2.4.1 Burden and spacing

Burden is the distance between the bench face to the first row of the blasted hole. As stated in Dyno (2010), burden can be expressed as in Equation 2.6:

$$(25\ to\ 40) \times D \tag{2.6}$$

Spacing is the distance between the two successive holes. It is calculated based on the diameter of drill hole, bench height of the face and degree of fragmentation required. Spacing with 1.15 times the burden gives an equilateral pattern.

Rai and Yang (2010) discovered some blast designs that may be crucial factor on rock fragmentation. Based on the study, burden and spacing need to be carefully decided. Excessive burden restrains the flexural rapture due to increased bench stiffness. Besides that, it also causes an early loosening of stemming column which resulting in sudden drop of blast hole pressure to adversely affect the fragmentation. On the other hand, it urges rapid release of gases to the atmosphere causing air blasts which leading to poor fragmentation.

According to Rajpot (2009) excessive burden resists penetration by explosive gases to effectively fracture and displacement of rock. This causes the presence of total confinement and vibrations levels which can be up to five times those bench blasting. However, small burden lets the gases escapes and expand with high speed towards the free face, forcing the fragmented rock and projecting it uncontrollably. This phenomenon causes an increase in overpressure of air, noise and fly rock.

Very small spacing causes excessive crushing between charges and superficial crater breakage, large blocks in front of the blast holes and toe problems. Excessive spacing between blast holes can cause inadequate fracturing between charges, along with toe problems and an irregular face.

2.4.2 Blast Hole Inclination

Generally, there are three main blast hole design which are horizontal, vertical and inclined. In quarrying operations, horizontal blast design is not preferable because rock fragmentation generated from the blasting may vary from average to poor. The degree of boulders will be between 25 - 35 %. Moreover, horizontal hole blasting may also generate overhanging of rock depend on the height of the slope. Therefore, it is vital on the part of the quarry operator to clean up the overhanging rock or any loose rock before any further rock extraction works may proceed.

As stated by Sharma (2011), blast fragmentation could be better and more economic with inclined blast hole. When using inclined blast hole, toe problem could be greatly resolved. Moreover, inclined drilling also gives various benefits as follows:

- Reduce misfire caused by cutoff from burden movement
- Less sub-drilling and better use of explosive energy
- Better displacement and swollen of muck pile as burden is kept almost uniform along the length of blast hole as shown in Figure 2.4.

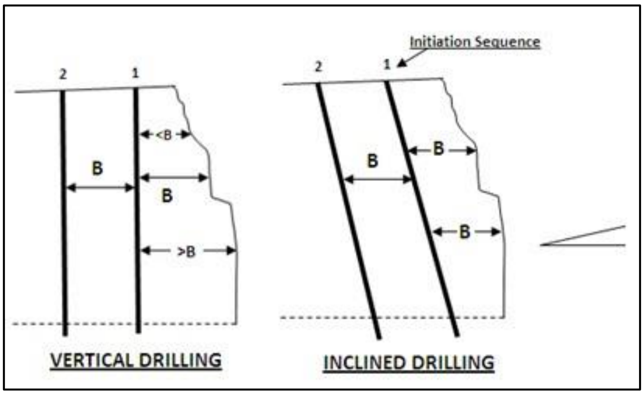

Figure 2.4: Uniform Burden in Inclined Drilling

There are some disadvantages of inclined drilling which are stated as follows:

- Increased drilling length and deviation when drilling long blasthole.
- More wear on the bits, drill steel and stabilizers.
- Less mechanical availability of the drilling rig.
- Poor flushing of drill cuttings due to friction forces, requiring an increase in air flow.

2.4.3 Stemming

Stemming contains explosive energy within a blast hole so that it will break and move the rock without generating flyrock. Dyno (2010) had stated that stemming columns are generally 0.7 to 1.2 times the burden as follows in Equation 2.7:

$$(0.7 - 1.2\ ) \times B \tag{2.7}$$

Sized crushed stone or chipping can be used as stemming. The type of stemming material and amount of stemming used definitely influence the degree of confinement and the efficiency of the blast**.** Dyno (2010) suggested that the stemming material size should be within D/10 to D/20. However, it has been studied that coarse angular material such as crushed rock is more effective and the resistance to ejection of stemming column also increases.

As eloquently stated by Rai and Yang (2010), stemming also gives a crucial role that need to be considered to promote the rock fracturing by transmitting shock waves and gas pressure through the burden rock mass. Improper stemming can lead to poor fragmentation. However, excessive stemming column length can generate over sizes within the muck piles. The study also mentioned that excessive over sizes within muck piles were reported due excessive stemming column lengths. Rajpot (2009) also stated that excessive stemming could generate large quantity of boulders, poor swelling of the muckpile and an elevated vibration level.

In conjunction to the problems, the blast hole plugging was introduced to overcome such problems without altering the stemming column lengths. Figure 2.5 shows the longitudinal section of the blast hole.

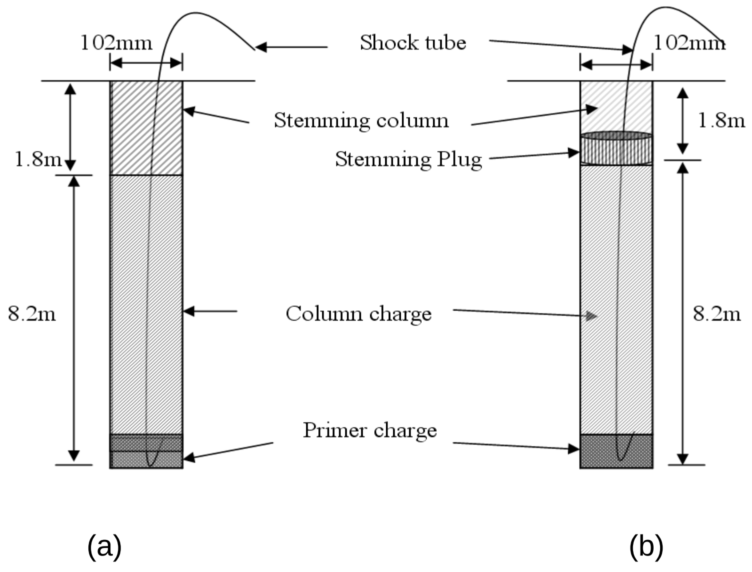

Figure 2.5: Longitudinal section of the blast hole (a) without stemming plug (b) with stemming length

In a limestone quarry, the blast holes were plugged to overcome excessive over sizes due to the presence of prominent fractures and weak planes. It was done by using a hollow cone shaped device constructed of high impact polystyrene. Therefore, it was expected that the plug would inflate due to the blast hole pressure generated after detonation. This technique can assist in gas and shock pressure retention inside the blast hole for extended duration. This study coincides with Lip (2016) which also mentioned stemming cap should be used to improve fragmentation.

2.4.4 Powder factor

Powder factor is expressed as the weight of explosives used to a given volume of rock. The formula is written as in Equation 2.8:

$$Powder\ factor = \frac{weight\ of\ explosives}{volume\ of\ rock} \tag{2.8}$$

According to Dyno (2010), the calculation of powder factor is based on rock hardness. Table 2.1 shows the classification of typical powder factors used in mass blasts.

Table 2.1: Typical powder factors used in mass blasts

Rock Type	**Powder Factor (kg/m^3)**
Hard	0.7 – 0.8
Medium	0.4 – 0.5
Soft	0.25 – 0.35
Very soft	0.15 – 0.25

Source: (Dyno Nobel, 2010)

Singh *et al* (2015) had studied that powder factor could give vital influence on the rock fragmentation. As stated in their study, lower powder factor could generate over size rock. They also concluded that the increase powder factor would decrease the mean fragment size. Prasad *et al (*2017) mentions that as the powder factor increases, the mean (X_{50}) and maximum fragment (X_{95}) size decrease. This study coincides with Kanchibotla *et al.* (1998) which also mentioned that an effect on the coarse end of the distribution and a large amount of fines were caused by high powder factor.

According to Parra, Onederra and Michaux (2014), high powder factor can cause a decay in the rock material work index. This implies that powder factor can be related to a reduction in the strength of fragments and potential reductions in energy consumption during grinding and crushing. This study coincides with Tosun and Konak (2015) which also asserted that energy consumption by crusher is dependent on powder factor. Higher powder factor causes micro fractures in the material formed from the blasting also increase. Thus, energy consumption by crushers while crushing the material will be minimized.

In 2014, Tosun and Konak (2014) mentioned that when high powder factor is used in blasting process, the blasted fragments will have a finer dimension. The cost of explosives and drilling is increased due to high fuel consumption by drilling machines for drilling. However, higher powder factor will minimize total unit cost of the operations such as loading, hauling and boulder crushing. In hauling operation, finer blasted fragments can give high hauling efficiency and minimize cycle time. Besides that, only fewer boulders will be formed in the muck pile at high powder factor. Hence, it can reduce the fuel consumption of the hydraulic breaker which can absolutely minimize boulder crushing cost.

According to Mohamed *et al.* (2015), powder factor depends on rock structure, blast design and explosive parameters. High explosives energy contain large amounts of aluminium powder which have higher density charge that can break more rock per unit weight compared to low explosives energy. Hard, dense rock requires more explosive than soft, low density rock. Besides that, it also stated that a rock with numerous, closely spaced joints or fractures requires lower powder factor than massive rock with few existing planes of weakness. Moreover, powder factor is also highly related with the free faces. A blast with many free faces only requires low powder factor to fracture the rock.

2.4.5 Blast Pattern

According to Murr *et al.* (2015), the degree of blasting conditions of ore for crushing and grinding is not based only on the powder factor. The distribution also depends blast design. In their study, they also stated that adjustments to the blast design parameters can provide a solution to acquire different fragmentation distributions that appropriate for crushing and grinding in quarrying operation. The common blast patterns used are the square pattern, the rectangular pattern and the staggered pattern. From their study, they had discovered that the distribution of energy throughout the blast differs for each of these blast patterns.

a) Square pattern

A square blast pattern has drilled spacings that are equal to drilled burdens. Figure 2.6 shows the arrangements of blast hole in square pattern.

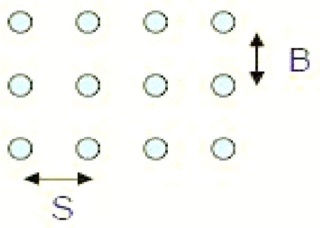

Figure 2.6: Square Blast Pattern

b) Staggered pattern

In staggered pattern, spacings are larger than the burdens. The spacings of each row are offset such that the holes in one row are positioned in the middle of the spacings of the holes in the preceding row. This blast pattern is usually used for row firing, where the holes in one row are fired before the holes in the row immediately behind them. Figure 2.7 shows the arrangements of blast hole in staggered pattern.

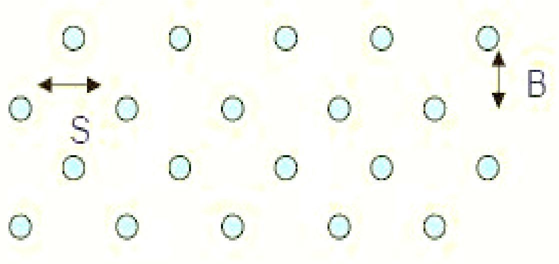

Figure 2.7: Staggered Blast Pattern

c) Rectangular pattern

A rectangular blast pattern has drilled spacings that are larger than drilled burdens. Figure 2.8 shows the arrangements of blast hole in rectangular pattern.

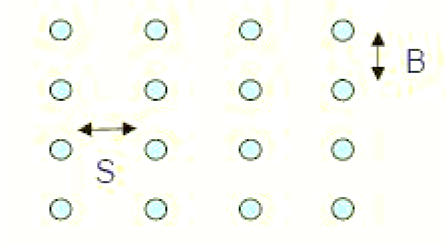

Figure 2.8: Rectangular Blast Pattern

Based on Murr *et al.* (2015) research, fragmentation for staggered pattern is finer than square pattern. In the study, they had considered that a square pattern and a staggered pattern having the same area of influence around a blast hole. The square pattern with 7.6 by 7.6 meters and staggered pattern with 7.2 by 8.2 meters had been studied. The arrangements of blast holes of each patterns are shown in Figure 2.9 and Figure 2.10.

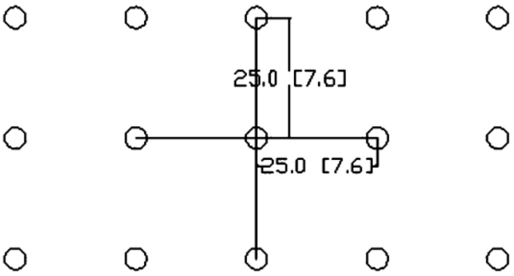

Figure 2.9: Arrangement of blast holes for square pattern of

7.6 by 7.6 meters

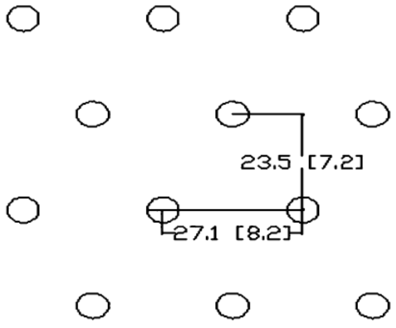

Figure 2.10: Arrangement of blast holes for staggered pattern

7.2 by 8.2 meters

From this study, comparisons between the two blast patterns show that there is 21% difference in the energy density at the furthest distance from a blasthole. Therefore, the lowest energy density for the square pattern will be approximately 21% lower than for the equivalent equilateral pattern. Thus, it can be concluded that fragmentation will be finer for the staggered pattern and individual fragments may be less resistant to crushing and grinding due to increases in internal micro cracking.

2.4.6 Delay Time

Sharma (2011) had mentioned that short delay blasting was usually practiced for bench blasting. In order to create space for the blasted rock from the succeeding rows, the delay time between blastholes and rows should be long enough. Some studies have been made to determine the effect of the delay time on multiple row blastings. One of them is the rock must be allowed to move 1/3 of the burden distance before the next row is allowed to detonate. Based on the study, the rock hardness should be taken into account to determine the suitable delay time between rows. The delay time is usually between 10 ms/m (hard rock) to 30 ms/m (soft rock).

The perfect delay time between the rows is usually 15 ms/m of the burden distance. This length of delay generates good fragmentation and minimize flyrock. It also allows the burden from the previously fired holes enough time to move the broken rock forward from the subsequent rows. Proper delay time is essential for systematic release of explosives energy and proper burden relief (Rai and Yang, 2010). Figure 2.11 shows an illustration of perfect delay time between rows.

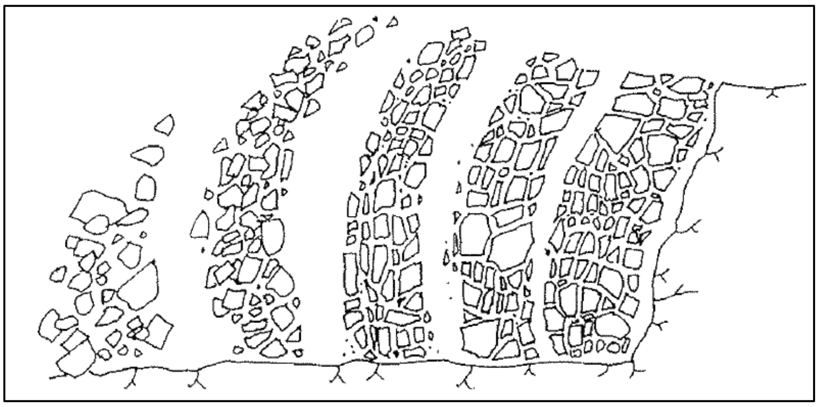

Figure 2.11: Perfect delay time between rows

In contrast with that, too short delay time may cause the direction of the rock from the back rows to move upward instead of to the horizontal direction. Figure 2.12 shows an illustration of short delay between rows.

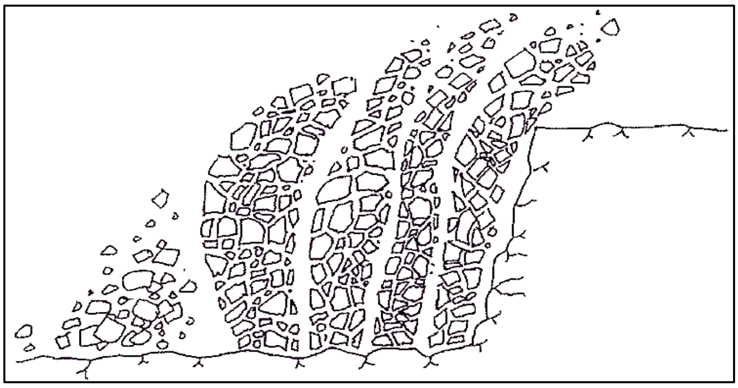

Figure 2.12: Short delay time between rows

On the other hand, too long delay time can cause excessive flyrock, airblast and formation of boulders. This is because long short delay creates greater rock movement between detonations.

2.4.7 Blast Hole Diameter

In 2009, Rajpot (2009) studied on the effect of fragmentation specification on blasting cost mentioned that the distribution of explosives in a blast depends on drillhole diameter. According to Dyno (2010), the calculation of powder factor is based on bench height. The formula is expressed as in Equation 9:

$$Blast\ hole\ diameter\ (mm) = 15\ \times Bench\ Height\ (m) \tag{2.9}$$

A small blast hole diameter can generate good blast fragmentation. This is due to a better distribution of energy in blasting by having lower powder factor. However, the costs of drilling, priming and initiation are quite high. It also requires a lot of time for charging and stemming of drillholes.

According to Austin Powder Company (2002), large blasthole diameter has high drilling and blasting costs. It also allows large burden and spacing which can give coaser fragmentation. Theoretically, drillhole diameter is calculated based on:

i. Degree of fragmentation required
ii. Bench height
iii. Properties of rock mass to be blasted
iv. Drilling and blasting cost