SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING
UNIVERSITI SAINS MALAYSIA

EFFECTS OF GEOLOGICAL PROPERTIES OF LIMESTONE FORMATION IN BLASTING

by

MUHAMMAD AFIQ ARIFF BIN MOHD ARIFFIN

Supervisor : Major Assoc. Prof. Ir. Ts. 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)

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AUGUST 2022

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled 'Effects of Geological Properties of Limestone Formation in Blasting'. 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.

Name of Student: **Muhammad Afiq Ariff Bin Mohd Ariffin** Signature:

Date: 16/8/2022

Witness by

Supervisor: Major Assoc. Prof. Ir. Ts. Dr. Mohd Hazizan Mohd Hashim Signature:

Date: 16/6/2022

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LIST OF ABBREVIATIONS

PLT	Point Load Test
RMR	Rock Mass Rating
RQD	Rock Quality Design
UCS	Uniaxial Compressive Strength
XRF	X-ray Fluorescence

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ABSTRAK

Batu kapur ialah batu sedimen yang terdiri daripada kalsium karbonat (kalsit) atau kalsium dan magnesium karbonat berganda (dolomit). Ia biasanya terdiri daripada fosil kecil, serpihan cangkerang dan serpihan fosil lain. Pada pemeriksaan teliti permukaan batu, fosil ini kerap kelihatan dengan mata kasar. Butiran beberapa batu kapur sangat halus. Batu kapur biasanya berwarna kelabu, tetapi ia juga boleh berwarna putih, kuning atau coklat. Ia adalah batu lembut yang mudah tercalar. Ia akan mudah berbuih dalam mana-mana asid biasa. Matlamat projek ini adalah untuk menyiasat kesan faktor geologi terhadap pemecahan letupan di kuari batu kapur di Imerys Malaysia di Simpang Pulai, Perak, Malaysia.

Kerana pengetahuan yang tidak mencukupi tentang tenaga letupan sebenar yang dilepaskan dalam lubang gerudi, amalan permulaan yang berbeza-beza dalam reka bentuk letupan, dan kesannya terhadap ciri pelepasan tenaga letupan, kawalan pemecahan melalui reka bentuk letupan yang berkesan dan kesannya terhadap produktiviti adalah tugas yang sukar untuk berlatih jurutera letupan. Sistem Penilaian Jisim Batu (RMR) digunakan untuk memilih parameter seperti panjang ketakselanjaran, kekuatan bahan utuh, jarak, luluhawa, pemisahan dan pengisian. Sebelum operasi letupan bermula, pemetaan geologi dilakukan di tapak letupan bangku untuk menentukan nilai RMR struktur tapak yang dipilih, dan kekuatan bahan utuh ditentukan menggunakan Ujian Beban Titik (PLT). Sampel batuan dikumpul selepas diletupkan dan analisis pemecahan dilakukan menggunakan perisian pemprosesan imej WipFrag. Data penilaian pemecahan daripada beberapa siri peletupan kemudiannya dibandingkan dan dikorelasi dengan data PLT, XRF, dan struktur masing-masing untuk menilai kesan sifat ini pada saiz serpihan yang terhasil.

Didapati kekuatan jisim batuan, arah ketakselanjaran terhadap muka cerun dan sifat struktur jisim batu di lokasi letupan mempengaruhi saiz pemecahan.

Sebagai kesimpulan projek, RMR memainkan peranan penting dalam menentukan analisis pemecahan batuan berikutan letupan. Data pemetaan, seperti kehadiran keretakan, luluhawa, jarak, dan pengisian, adalah penting untuk melaksanakan analisis RMR. Analisis RMR ialah medium yang sangat baik untuk menyiasat keadaan lokasi dan menentukan jenis batuan yang ada.

EFFECTS OF GEOLOGICAL PROPERTIES OF LIMESTONE FORMATION IN BLASTING

ABSTRACT

Limestone is a sedimentary rock composed of calcium carbonate (calcite) or calcium and magnesium double carbonate (dolomite). It usually consists of small fossils, shell fragments and other fossil fragments. On careful examination of the rock surface, these fossils are often visible to the naked eye. The grains of some limestones are very fine. Limestone is usually gray, but it can also be white, yellow or brown. It is a soft stone that is easily scratched. It will easily foam in any common acid. The aim of this project is to investigate the effect of geological factors on explosive breakdown at a limestone quarry at Imerys Malaysia in Simpang Pulai, Perak, Malaysia.

Because of insufficient knowledge of actual explosive energy released in the borehole, varying initiation practise in blast design, and its effect on explosive energy release characteristic, fragmentation control through effective blast design and its effect on productivity are difficult tasks for practising blasting engineers. The Rock Mass Rating System (RMR) is used to select parameters such as discontinuity length, intact material strength, spacing, weathering, separation and filling. Before the blasting operation began, geological mapping was performed at the bench blasting site to determine the RMR value of the selected site structure, and the strength of the intact material was determined using the Point Load Test (PLT). Rock samples were collected after blasting and fragmentation analysis was performed using WipFrag image processing software. Fraction evaluation data from several blasting series were then compared and correlated with PLT, XRF, and structure data respectively to evaluate the effect of these properties on the resulting fragment size. It was found that the strength of the

rock mass, the direction of discontinuity on the slope face and the structural properties of the rock mass at the blast site influence the size of the fracture.

As a conclusion of the project, RMR plays a significant role in determining the rock fragmentation analysis following the blast. The mapping data, such as the presence of cracks, weathering, spacing, and infilling, is critical for performing the RMR analysis. RMR analysis is an excellent medium for investigating the condition of a location and determining the type of rock present.

CHAPTER 1

INTRODUCTION

1.1 Introduction

In mining industry, blasting is a process of chemical and physical that happens through the detonation or firing of the explosives. During the process the mineral-bearing materials will break. The geological conditions of the blasted bench have a considerable impact on the blasting operation's success. Holes are been drilled into the rock, which later was partially filled with explosives. Stemming, inert material, is packed into the holes to direct the explosive force into the surrounding rock. Detonating the explosive causes the rock to collapse. During the blasting there are several factors that need to be consider and the single most essential geological factor among many characteristics is geological structure such as joints, bedding planes, and their direction in relation to the bench face.

1.2 Background Study

For centuries, explosives have been used in mining and quarrying industries, particularly those operating in hard rock areas, as a means of breaking rock masses and extracting desired materials because it is the most cost-effective method. When an explosive confined within a blasthole is detonated, a large amount of gases at extremely high temperatures and pressures are produced in a very short period of time. By subjecting the rock surrounding the blasthole to stresses and strains, this gas acts as the energy to break the rock (Bhandari, 1996). Using the energy released when explosives are detonated, rocks are broken and loosened from the wall face, forming a muckpile of rock fragments that are then loaded and hauled for further processing (Afeni et al., 2009).

Mining and mineral processing have traditionally been considered as two different processes in the mining industry. At the same time, they are both components of size reduction operations, which require a significant amount of energy. Drilling and blasting, as well as loading, transporting, and coarse crushing of broken rock, are common mining operations related to size reduction and fragment handling. Fine crushing and grinding are two milling processes.

The degree of rock fragmentation is a measurement used to evaluate the effectiveness of rock blasting. The resulting size distribution, fragmentation, is a critical issue in this process. A good fragmentation is achieved when the fragmented rock requires no further treatment, such as secondary breakage after the primary blast, and can be moved directly to the next stage of processing while containing the least amount of unsalable fraction: the fines. However, it is a subjective issue that is determined by the characteristics of the equipment used to handle the fragments in downstream operations, such as loading and hauling equipment, processing plants, and the end use of the rock (Chakraborty et al., 2004 & Cunningham, 2005).

The size of blasting fragments is determined by two factors: uncontrollable parameters (i.e., mine site geology) and controllable parameters (i.e., design of the blast). Mechanical (rock strength) properties and structural properties are the main geological features influencing fragmentation, with mechanical properties influencing the formation of initial cracks and structural properties influencing the propagation of shock wave and high pressure explosion gas throughout the rock mass. The geological conditions of the mine site should be considered when designing a blast because they affect the distribution of explosive energy in rock mass.

Existing discontinuities in a blast site, depending on their direction and other properties such as spacing, aperture and the condition of the aperture: tight, open, or filled, as well as overbreak cracks caused by previous blasts, all affect the size of fragments produced. Other geological factors that contribute to the boulder problem include rock strength and bedding thickness. Lyana and her co-researchers found that a more thorough inspection of the geological properties of the bench face can be used to improve future blasts at the quarry by tailoring blast design parameters to improve fragmentation while avoiding the need for secondary breakage (Lyana et al., 2016).

The main focus for this research is to obtain the relationship between the geological features of the blasting area and its effect towards the fragmentation of the rock after the blast. The geological features can be refer to the Rock Mass Rating system (RMR) where the geological features such as joints, crack, weathering of the face and also condition of discontinuity were taken into account in order to give the rating to the rock and determine the category of the rock.

1.3 Study Area

The study is conduct at Imerys Mineral Malaysia Sdn Bhd which is located No. 104206, Kampung Keramat Pulai, Perak, 31300 Kampung Kepayang and the red box mark is an area of the focus as in Figure 1.1. The primary explosive used in this quarry is ANFO (ammonium nitrate with fuel oil), and the initiation system is NONEL (non-electric shock tube detonator). The primary jaw crusher opening at the quarry is 800 mm. As a result, blasted fragments larger than 800 mm are considered oversize. Table 1.1 displays typical blast parameters for quarry blasting operations.

Table 1.1 Typical blast parameters for quarry blasting operation

Parameters	Details
Diameter of holes (mm)	89.00
Average bench height (m)	11.20
Depth of holes (m)	12.20
Spacing (m)	4.27
Burden (m)	3.96
Stemming (m)	2.40
Sub-drill (m)	0.9

The company's primary activities are the manufacture and distribution of materials such as limestone powder, limestone chips and the slurry which are compatible with the company's core competencies of extracting, processing, and applying minerals for global industrial applications.

Figure 1.1 Location of Imerys Mineral Malaysia at Gunung Terendum, Simpang Pulai, Perak

1.4 Problem Statement

A poor blasting can cause failures, overbreak, and unstable ground could result from damage to the host rock caused by a production blast. Knowing how far the fractures created by a production blast will penetrate the host rock is a useful tool for engineers in designing a safe highwall while keeping the actual excavation close to the design. In order to prevent this problem to happen blasting must be conducted at specific and desired rock mass needed to be removed while leaving the host rock with minimal damage control of the rock damage due to blasting because it is very important when it comes to mine or construction design.

Fragmentation control through effective blast design and its effect on productivity are difficult tasks for practicing blasting engineers due to insufficient knowledge of actual explosive energy released in the borehole, varying initiation practice in blast design, and its effect on explosive energy release characteristic.

1.5 Objectives

- To investigate the relationship between blasting and geological properties of limestone formation.
- To examine the correlation between the Rock mass rating (RMR) system and its fragmentation performance after blast

1.6 Limitation of study

For this project, the authors are unable to conduct the mapping of the quarry face as it should be due to the safety reason of the working area which is the rock can easily fall and also due to the recent incident occur to the quarry near Imerys. The dip and dip direction of the face was measured from the safety distance away from the quarry face. Another limitation is time constraint which the author only have two weeks to conduct the site data collection. There is only four blasting operation that the author can attend in the two weeks period.

1.7 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 1 introduces the basic information about the geological features of the rock and its properties. The executive summary, background research, problem statement, objectives, expected outcome and thesis outline are also included in this chapter.

Chapter 2 discusses the literature review of the study. The Rock Mass Rating system (RMR), the rock fragmentation analysis, point load test are discussed in detailed in this chapter. Method of conducting the quarry mapping, type of data that need to obtain, the observation of the features of the blasting area and also the particle size analysis using Wipfrag are also discussed in this chapter.

Chapter 3 provides the information about the material and the procedure in this study. The general sample for this project is a limestone rock. Other procedure such as the point load test, rock fragmentation analysis using image analysis are also discuss in this chapter. Characterization techniques such as X-Ray Fluorescence (XRF), are included as well.

Chapter 4 discuss the experimental result, findings and discussion. A more detailed elaboration and explanation about the rating of the RMR and also the fragmentation analysis application are provided in this chapter.

Chapter 5 summarizes the significant findings in this study. Recommendations and suggestion for future study are also provided as well

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, it is important to understand and know the usage of the limestone in the modern world. In this study, Rock Mass Rating system (RMR) play an important role in order to obtain the relationship of the RMR and its effect towards the rock fragmentation after the blasting process.

The usage of limestone and its important in modern world is been discussed in Section 2.2. In 2.3 the rock blasting in aggregates production is briefly discuss which in this section discussed about the important of RMR and UCS as a geological factor that can affect the fragmentation. In Section 2.4, the rock classification is briefly talk which involving the process of RMR and RQD which is important when to give a rating to the rock. The physical testing of the samples or a rock is been discuss in Section 2.5 which in this project it is involving point load test (PLT). Point load test is a method to determine the strength of the rock and for this case which a limestone. Point load test also is needed when using RMR since it also useful to give the rating of the rock. In Section 2.6, the rock fragmentation system is been talk as mention in this section there are many techniques of rock fragmentation analysis such as sieving, visual and photography method. Section 2.7 discuss about the method of image analysis of rock fragmentation which in this project the software that been used is WipFrag. The reason of using WipFrag is because it is a reliable software, easy to use and many authors already publish their journal using WipFrag which make the software is trustable.

2.2 Limestone and its usage

Humans have been using limestone for thousands of years, and the possibilities for processing and using this raw material continue to expand. Limestone evolved primarily as sedimentary rocks (Těhník and Nečas, 2010). The majority of limestones formed in the seas and were formed by rock-forming organisms. Limestones were also formed in freshwater bodies such as lakes, rivers, and caves. The absence of clay or sandy material, as well as the climate, were the primary conditions for the formation of limestone (Těhník and Nečas , 2010). Calcium carbonate undergoes a number of polymorphic modifications. It is found in nature primarily as the minerals calcite and aragonite. Calcite is typically organic sediment. At higher temperatures or in the presence of sulphates, aragonite is secreted from solutions. It could also have a biogenic origin from the shells of certain mollusks (Těhník and Nečas , 2010).

They are usually made up of small fossils, shell fragments, and other fossilised debris. Further examination of the stone surface reveals these fossils frequently to the unaided eye, but this is not always the case. Some of the limestones have a very fine grain. Limestone is typically grey, but it can also be white, yellow, or brown in colour. It is a soft rock that scratches easily. It will easily effervesce in any common acid. Limestone is a naturally occurring mineral that can be found all over the world. It is primarily used in road construction, concrete production, and as a structural fill. It is also the primary raw material used in the manufacture of cement, quicklime, and a variety of other products (Kenny and Oates, 2000).

Limestone is also known as a source of lime, which is used in the production of steel, mining, paper, water treatment and purification, and plastics. Lime is also used extensively in the production of glass and agriculture. Lime products are the most widely available and least expensive alkaline chemicals, and they are used in a wide range of industrial processes. Iron and steel production is the most common use in many countries, followed by building and construction, environmental protection, and the chemical industry. Hydraulic lime is a traditional building material, particularly as a binder in mortars. The primary environmental concerns associated with the production of lime and limestone products are air emissions and energy consumption (Kenny and Oates, 2000).

Limestone is primarily composed of calcium carbonate (at least 50% $CaCO_3$) in the form of the mineral calcite. Limestone is also referred to as sedimentary rock because it is formed by the sedimentation of mineral calcite, minerals, and other non-carbonate impurities in an appropriate environment (Kiattikomol et al, 2000; Bouazza et al, 2016). Limestone is an important raw material in the cement industry because of its chemical properties. Portland cement is made by calcining a finely ground raw limestone and clay mixture (Bouazza et al, 2016).

2.3 Rock Blasting in Aggregates Production

Because of its cost-effectiveness and efficiency, rock blasting is the most commonly used rock excavation technique in the mining and construction industries. The primary goal of surface mines and quarries is to extract the greatest amount of material at the lowest possible cost. The material may include ore, coal, construction aggregates, and for this case also including limestone. Blasting operations must be carried out in order to meet the quantity and quality requirements of production while maximizing the overall profits of the mining or quarrying operation. Blasting and crushing reduce in-situ rock to the required size, or additional grinding reduces it to a fine powder suitable for mineral processing.

The frequency and scale of blasting events are increasing in order to increase limestone production. Geological and geotechnical data, such as rock quality designation (RQD), unconfined compressive strength (UCS), and joint setting, primarily govern blast performance. Joints are critical components of any blasting operation because they determine both safety and performance. Joints are natural planes of weakness that offer almost no resistance to splitting. Because joints are zones of discontinuity and weakness, they are affected first during blasting, rather than the stable homogeneous regions. As a result, they exert control over the rock breakage process by determining which area is affected first. The joint sets have an effect on rock fragmentation and overbreak. The blast design can be improved by reviewing and analyzing previous data from mine blasts (Bhandari, 2011; Parihar and Bhandari, 2012). Fly rock caused by blasting in opencast mines is a complex phenomenon because it is a random occurrence. According to Raina et al., (2007) and Raina et al., (2011) attempted to devise a criterion for prediction of blast-induced fly rock distances and focused on the factors on which the phenomenon of fly rock depends.

Rock formations as they occur are not homogeneous or isotropic, and the homogeneity varies even on a small scale (Božić & Braun, 1991). The structural control has a significant impact on the geomechanical and dynamic properties of rock formations. The strength of rock mass decreases as the frequency of joints increases, and the deformability of rocks depends on their orientation. The interaction between the rock mass and the stresses generated by explosive detonation can produce beneficial or harmful blasting results. Joint planes can sometimes improve the performance of the explosive induced fragmentation mechanism (Gama, 1977). Over the last four decades, blasting technology has advanced significantly. (Scott et al., (1993) stated that the principal changes of relevance to the fragmentation of rock using explosives have been:

- The creation of dependable bulk explosives. The use of ANFO as a bulk explosive revolutionised blasting. Pumpable water gel and emulsion explosives now offer a variety of explosive properties, giving the blasting engineer more control over the type and distribution of explosive energy within the rock mass.

- Large diameter long hole drills are being developed. This technology enabled the design of long hole stopes containing large tonnages of ore per metre of development, allowing for significant economies of scale in terms of drilling and blasting costs.

- The creation of a flexible initiation system. Modern development systems enable greater confidence in controlling the initiation sequence of a large number of holes than was previously possible (Gama & Jimeno, 1993). Non-electric detonators with less than 3% precision are now widely available in most countries, and electronic detonators with exceptional accuracy and a wider range of delay times are being tested in full-scale mine blasts.

Blasting results are accessed based on the mining system's ability to handle the resulting muck. As fragmentation alone demonstrates, the effective cost of poor blasting can be several times that of the blast itself. Implications of poor fragmentation include:

- Secondary blasting has been increased. Secondary blasting of oversize is required to reduce it to a size that excavation machinery can handle (Persson et al.,1994)

- Mucking rates have been reduced. The size and looseness of the muck directly control the rate of loading from a draw point (Bhandari ,1996). The excavator must manoeuvre extensively to load large rocks, and bucket loads are typically reduced when working with coarse muck.

- Difficulties with handling and transportation. Poor fragmentation can reduce the efficiency of internal mine transport, crushing, and transport from the mine.
- Poor milling performance. The development and widespread use of semi autogenous grinding mills and fully autogenous mills places an increasing emphasis on the size distribution of ore delivered from mines. Problems arise when the size distribution varies over time and the proportion of fines exceeds what is desirable (Winzer et al., 1983).

Blasting designs in mines are still optimized through trial and error over months or years. As a result, a series of blasting tests were carried out in various mines, locations, and rock mass conditions using a borehole camera and fragmentation analysis software. The effects of rock mass conditions like fracture, discontinuity, mechanical properties of rocks, and blasting standard on the size of fragmented rocks were then discussed in order to develop guidelines for designing optimal blasting standards based on rock mass condition.

2.4 Rock classification system

When very little detailed information on the rock mass and its stress and hydrologic characteristics is available during the feasibility and preliminary design stages of a project, the use of a rock mass classification scheme can be extremely beneficial. At its most basic, this may entail using the classification scheme as a check-list to ensure that all relevant information has been taken into account. On the other end of the spectrum, one or more rock mass classification schemes can be used to create a picture of the composition and characteristics of a rock mass in order to provide initial estimates of support requirements as well as estimates of the rock mass's strength and deformation properties.

2.4.1 RMR

For geomechanics classifications, Bieniawski (1976) detailed a rock mass classification system known as the Geomechanics Classification or the Rock Mass Rating (RMR) system. As more case records have been examined over the years, this system has been successively refined, and the reader should be aware that Bieniawski has made significant changes in the ratings assigned to different parameters. The discussion that follows is based on the classification's 1989 version (Bieniawski, 1989). The RMR system classifies a rock mass based on the six parameters listed below:

1. Uniaxial compressive strength of rock material.
2. Rock Quality Designation (RQD).
3. Spacing of discontinuities.
4. Condition of discontinuities.
5. Groundwater conditions.
6. Orientation of discontinuities

On the basis of RMR values for a given engineering structure, the rock mass is sorted into five classes: very good (RMR 100–81), good (80–61), fair (60–41), poor (40–21), and very poor (<20). It must be ensured that double accounting for a parameter is not done in the analysis of rock structures or in estimating the rating of a rock mass.

Bieniawski (1976) proposed an additional parameter to account for the effect of discontinuity orientation on the stability condition (correction factor). This parameter, however, is introduced for tunnel and dam foundations but not for slopes (Aksoy, 2008). As a result, Bieniawski (1989) added more descriptive information to the fourth parameter of the basic RMR (the condition of discontinuities). In addition, when considering the effect of discontinuity orientation on the slope stability of a rock slope, he suggested using Romana's SMR system (1985)

Bieniawski (1989) modified the RMR system by applying a set of discrete functions, resulting in the so-called discrete RMR (DRMR). As a result, different users may obtain different RMR scores based on their own experience and selection of the discrete values. Sen and Sadagah (2003) modified the RMR system to address this issue by converting the classical discrete functions into continuous rating functions, resulting in the continuous RMR (CRMR). The difference between RMR values estimated by different users can be controlled to within 10% with this modification (Sen and Sadagah, 2003). The DRMR and CRMR were applied to structurally controlled road cuts in this study, and the resulting scores were compared. It should be noted that only the five parameters presented by the basic RMR (UCS, RQD, spacing of discontinuities, condition of discontinuities, and groundwater) are used for rock mass classification of road cuts in the study area in both DRMR and CRMR. Romana (1985) developed Slopes mass rating (SMR), a traditional lump-rating classification system for rock slopes. The SMR system is derived from the RMR system, in which adjustment parameters representing discontinuity orientations in relation to slope attitude are added to the basic RMR, as well as the effect of the excavation method. The SMR score is calculated by subtracting a factor from RMR based on the joint-slope relationship and adding a factor based on the excavation method.

2.4.2 RQD

Deere (Deere et al 1967) created the Rock Quality Designation index (RQD) to provide a quantitative estimate of rock mass quality from drill core logs. The percentage of intact core pieces longer than 100 mm (4 inches) in the total length of core is defined as RQD. The core must be at least NW size (54.7 mm or 2.15 inches in diameter) and drilled using a double-tube core barrel. The correct procedures for measurement of the length of core pieces and the calculation of RQD are summarised in Figure 2.1

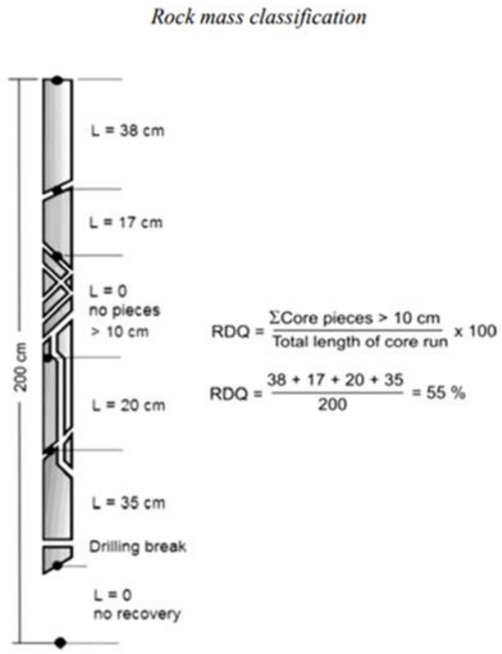

Figure 2.1 Procedure for measurement and calculation of RQD (Deere, 1989).

Palmström (1982) proposed estimating the RQD from the number of discontinuities per unit volume when no core is available but discontinuity traces are visible in surface exposures or exploration adits. For clay-free rock masses, the suggested relationship is:

$$RQD = 115 - 3.3\ Jv \qquad \text{(Equation 2.1)}$$

Where Jv is the volumetric joint count, which is the sum of the number of joints per unit length for all joint (discontinuity) sets.

Rock Quality Designation (RQD) core indices have been proposed for logging rock not only from borehole cores but also from exposure mapping to provide a ready indicator of rock quality. Several indices and definitions have been proposed, with little in common (D Norbury, 2005).It was a directionally dependent parameter, and its value can vary greatly depending on the borehole orientation. The volumetric joint count can be very helpful in reducing this directional dependence. RQD is intended to represent the quality of the rock mass in situ. When determining the value of RQD using diamond drill core, care must be taken to ensure that fractures caused by handling or the drilling process are identified and ignored. When estimating Jv using Palmström's relationship for exposure mapping, blast-induced fractures should be excluded.

This classification system divides the rock mass into a number of structural regions, and each region is classified separately. The boundaries of structural regions are typically defined by a major structural feature, such as a fault or a change in rock type. Significant differences in discontinuity spacing or characteristics within the same rock type may necessitate the division of the rock mass into a number of small structural regions in some cases. Bieniawski's Rock Mass Rating (RMR) system was originally based on civil engineering case studies. As a result, the mining industry viewed the classification as somewhat conservative, and several changes were proposed to make the classification more relevant to mining applications. Bieniawski compiled a comprehensive summary of these changes (Bieniawski , 1989).

A Modified Rock Mass Rating system for mining has been described by Laubscher (1977, 1984), Laubscher and Taylor (1976), and Laubscher and Page (1990). This MRMR system takes Bieniawski's basic RMR value and adjusts it to account for in situ and induced stresses, stress changes, and the effects of blasting and weathering. The resulting MRMR value is associated with a set of support recommendations. When using Laubscher's MRMR system, keep in mind that many of the case histories on which it is based are from caving operations. Initially, block caving in asbestos mines in Africa served as the foundation for the changes, but other case histories from around the world have since been added to the database.

2.4.3 Rock Tunneling Quality Index

For Rock Tunnelling Quality Index, Barton et al (1974) of the Norwegian Geotechnical Institute proposed a Tunnelling Quality Index (Q) for determining rock mass characteristics and tunnel support requirements based on an evaluation of a large number of case histories of underground excavations. The numerical value of the index Q ranges from 0.001 to 1,000 on a logarithmic scale and is defined by:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

(Equation 2.2)

Where,

- RQD = Rock Quality Designation
- Jn = joint set number
- Jr = is the joint roughness number
- Ja =is the joint alteration number
- Jw = is the joint water reduction factor
- SRF = is the stress reduction factor

Bieniawski's RMR (1976, 1989) and Barton et al (1974) are the two most widely used rock mass classifications. In order to arrive at a quantitative value for their rock mass quality, both methods incorporate geological, geometric, and design/engineering parameters. The RMR and Q similarities stem from the use of identical or very similar parameters in calculating the final rock mass quality rating. The differences between the systems are due to the different weightings assigned to similar parameters and the use of distinct parameters in one or both schemes.

RMR directly considers compressive strength, whereas Q only considers strength as it relates to in situ stress in competent rock. Both schemes, though in slightly different ways, deal with the geology and geometry of the rock mass. Both take into account groundwater and include some component of rock material strength. Using a guideline presented by Barton et al (1974), some estimate of orientation can be incorporated into Q: 'the parameters Jr and Ja should relate to the surface most likely to allow failure to initiate.' The RMR system lacks a stress parameter, which is the most significant difference between the two systems. There are two approaches that can be taken when using either of these methods. The first is to evaluate the rock mass specifically for the parameters included in the classification methods; the second is to accurately characterise the rock mass and then attribute parameter ratings later. The latter method is preferred because it provides a comprehensive description of the rock mass that can be easily translated into either classification index. It would be nearly impossible to conduct verification studies if only rating values were recorded during mapping.

2.5 Physical Testing

Because it can provide comparable data at a lower cost, the PLT is an appealing alternative to the UCS. For over thirty years, the PLT has been used in geotechnical analysis (ISRM, 1985). A rock sample is compressed between conical steel plates until failure occurs in the PLT. A rigid frame, two point load platens, a hydraulically activated ram with pressure gauge, and a device for measuring the distance between the loading points comprise the apparatus for this test. The pressure gauge should be of the type that can record the failure pressure.

The uncorrected point load strength index can be calculated using the point load test (Is). It needs to be adjusted to the standard equivalent diameter (De) of 50 mm. If the core being tested has a diameter of less than 50 mm, the correction is not required. The size correction procedure, as outlined by the ISRM procedures, can be obtained graphically or mathematically. The following equation is used to calculate the Is50 (in psi) :

$$Is_{50} = P/De^2$$

(Equation 2.3)

P = Failure Load in lbf (pressure x piston area).

De = Equivalent core diameter (in)

For this project, type of point load test used is irregular lump test. Point load tests can also be performed in irregular blocks with the geometry of a rectangular prism. In this case, a cross-section of a specific block is considered a trapezoid with parallel top and bottom bases (W1 and W2) and constant height (D). The loading process is similar to that of the Block Lump Test, with an average width calculated (W=(W1+W2)/2). Figure 2.2 depicts a schematic of the specimen's geometric properties and the loading forces applied during the Point Load Test..

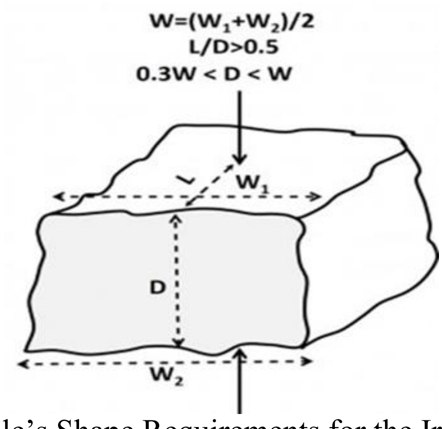

Figure 2.2 Sample’s Shape Requirements for the Irregular Lump PL Test and loading forces applied by the apparatus platens

The point-load test is especially useful for determining the strength of rock materials. Although many classifications have been proposed, it is believed that one based on a proposal by Deere and Miller (1966) is particularly realistic and practical for use in geomechanics. The point load test applies a concentrated load at the tip of the rock specimen until it is destroyed, and the specimen's point load strength can be calculated. The greater the concentrated load on the specimen, the greater the obtained point load strength. Concentrated loading methods primarily include diametral and axial, from which the diametral point load strength (DPLS) and axial point load strength (APLS) are derived, both of which have comparable reliability and are applied in the same way.

For the chemical composition of the rock, the samples need to be prepared in a powder form in order to perform the XRF analysis. Powder samples were placed in special containers supplied by the manufacturers of measuring instruments on these instruments. They were overlaid with the polyethylene film over which the measurements were made for measurements on the air atmosphere with a handheld XRF spectrometer. In the case of vacuum measurements, the samples were outfitted with a special vacuum foil.

2.6 Rock Fragmentation System

In hard rock mining, the particle size distribution of blasted rocks has a significant impact on the subsequent mine-to-mill process. Fines and oversized rock regions, for example, will significantly reduce loading and hauling productivity (Hustrulid, 1999). Given that material transportation costs can account for up to 60% of total operating costs, maintaining proper rock fragment particle size distribution is critical to mine productivity optimization. Furthermore, by feeding rock fragments within the optimal particle size ranges, the total milling process energy can be reduced. As a result, mining engineers regard fragmentation management as a critical task (Thurley, 2011).

In hard rock mining, the particle size distribution (PSD) of blasted rocks has a significant impact on the subsequent mine-to-mill process. Fines and oversize rock regions, for example, will be used more frequently for loading and hauling productivity. Given that material transportation costs can rise to a high percentage of total operating costs, maintaining proper rock fragment PSD is the bottom line of mine productivity optimization. Furthermore, by feeding rock fragments within the optimal particle size ranges, the total milling process energy can be reduced. As a result, mining engineers regard fragmentation management as a critical task (Hustrulid, 1999 & Thurley, 2011)

2.6.1 Method for the Rock Fragmentation Analysis

There is several methods for the rock fragmentation analysis, Sieving or screening is a simple and accurate method of determining particle or fragment size distribution. This method is practical for small-scale blasts or operations, but it is costly and time consuming. Rock fragments are screened through different sieves with varying mesh numbers for different fragment sizes, and the screened out fragments are sorted by size. By counting the number of fragments of each size, the nature of the blast can be predicted (Singh et al., 2013)

An Oversize index is calculated based on oversize boulders that cannot be hauled or processed by shovels or other mine machinery. The index is calculated in relation to the total mass of blasted in-situ material (Pradhan et al., 1996). The shovel loading rate method is more accurate for determining the nature of fragmentation in a group of blasts. This method is based on the assumption that the faster the mucking, the better the fragmentation. The loading rate of a shovel is taken into account. This method is ineffective when there is no uniform fragment distribution with a high percentage of undersize fragments.

For the visual analysis method, mining professionals inspect the post-blast muck immediately after blasting and decide whether to proceed with secondary blasting or change the parameters to optimize rock fragmentation. This is a subjective assessment method that cannot be completely trusted because the surface view of the fragments does not reveal information about the hidden portion (Maerz et al., 1996). For photogrammetric method, this method is more reliable and accurate because it can calculate the fragmentation volume in three dimensions (Singh et al., 2012). Digital image processing systems are increasingly being used in industrial applications other than research. Material sizing is now becoming routine due to the advancement of inexpensive fast computing power, improved image processing techniques and algorithms, and the availability of inexpensive, portable, and light-sensitive video cameras (Maerz et al., 1996).

2.7 Image analysis of Rock Fragmentation

For this project, the method that is been used is image analysis method. Where a photo of muck pile of blasted limestone were captured by using a smartphone camera and transferred it into a software called Wipfrag. With Wipfrag software it help to obtain the fragmentation analysis of the blasting process and its efficiency. From the software we are able to gain an information such as the mean particle size, minimum and the maximum fragment size, the standard deviation and also the percentage of fragment in particular size.

Wipfrag Software was used to perform fragmentation analysis in many of the previous study. The results obtained from the individual analysis of the rock pile samples cannot be considered perfect because the digital images used for the analysis cannot reveal the conditions of fragmentation behind the muckpile surface. The calculation of the uniformity coefficient and the coefficient of gradation is simple and effective for the appraisal of blast fragments. As a result, the obtained results were much more precise in predicting the optimal blast parameters. Wipfrag software was discovered to be very good for fragmentation analysis, as it allows for the measurement of blast fragment sizes in very short intervals of time. This software can generate the desired blast fragment sizes. Industry and researchers can utilise a variety of fragmentation measurement techniques, although the majority of them are time consuming and inaccurate. WipFrag is an image-based granulometry system that determines grain size distributions using digital image analysis of rock pictures and video tape images.

The WipFrag image analysis software predicts the grain size distribution in the muck pile by analysing a digital image of the blasted rock with a granulometry system. Camcorder images of the muck pile are typically captured in the field. In each view, a scale device is used to reference the sizing. The muck heap is photographed or videotaped, and the image is uploaded to the WipFrag system (Maerz et al., 1996). The image of the broken rock is converted into a particle map or network. The network areas are converted into volumes and weights, and the resulting data is graphed. Because of the fidelity and speed of fragment edge detection, fully automatic remote monitoring is possible at a rate of one image every 3 to 5 seconds. More fragments of varying sizes are resolved (Maerz et al., 1996).

WipFrag allows you to compare the automatically generated net to the rock image. Edge Detection Variables are used to efficiently analyse fragment boundaries (EDV). To improve edge detection, any inaccuracies can be corrected manually with a