CORRELATION OF SCHMIDT HAMMER REBOUND NUMBERS AND KNOCKING BALL STIFFNESS PARAMETERS FOR SEDIMENTARY AND METASEDIMENTARY ROCKS

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by

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ABSTRAK

Salah satu sifat batu yang paling penting ialah kekuatan batu yang utuh. Kekuatan bahan blok batu utuh ditentukan oleh kekuatan batu utuh, yang mempengaruhi sebahagian kecil kekuatan jisim batu. Dalam konteks kajian untuk penilaian kestabilan cerun, kekuatan batu utuh jisim batu telah dinilai menggunakan pelbagai kaedah yang berbeza. Dalam kajian ini, korelasi ditubuhkan antara kaedah pemerolehan data sifat batu utuh. Pengambilalihan data dilakukan dengan melakukan dua ujian in-situ iaitu ujian Schmidt Hammer dan Knocking Ball. Ujian Schmidt Hammer adalah pendekatan standard yang digunakan dalam industri kerana ia adalah alat indeks yang berkesan yang mudah digunakan dan dikendalikan, bagaimanapun, ia mungkin menghadapi kesukaran apabila menilai pelbagai kekuatan batu terutamanya dalam julat yang lebih rendah. Sementara itu, ujian Knocking Ball yang berdasarkan teori Hertz boleh digunakan untuk pelbagai kekuatan batu yang lebih luas kerana ia adalah peralatan yang lebih sensitif. Kedua-dua kaedah ini berkorelasid menggunakan nombor pemulihan dan parameter kekakuan mereka. Di samping itu, UCS nombor pemulihan juga akan ditentukan untuk dikaitkan dengan modulus Young bagi parameter kekakuan. Semua korelasi yang ditubuhkan adalah baik dan positif kerana ia mencapai hasil yang diinginkan di mana pekali korelasi, R^2 lebih besar daripada 0.5. Kedua-dua analisis dibandingkan untuk menunjukkan kekuatan dan kelemahan setiap pendekatan yang digunakan dalam kajian ini untuk menilai sifat-sifat batu utuh.

ABSTRACT

One of the most important rock properties is intact rock strength. The strength of an intact rock block material is determined by intact rock strength, which influences a fraction of the strength of a rock mass. In the context of studies for slope stability assessment, the intact rock strength of a rock mass has been assessed using a variety of different methods. In this study, correlation is established between the methods of the data acquisition of the intact rock properties. The data acquisition is done by performing two in-situ tests which are Schmidt Hammer and Knocking Ball tests. The Schmidt Hammer test is the standardised approach used in the industry as it is an effective index apparatus which is easy to use and handle, however, it may encounter a difficulty when assessing a wide range of rock strength especially in the lower range. Meanwhile, the Knocking Ball test which is based on the Hertz theory can be applied to a wider range of rock strength as it is more sensitive equipment. These two methods are correlated using their rebound numbers and stiffness parameters. In addition, the UCS of the rebound number will also be determined to be correlated with the Young's modulus of the stiffness parameters. All the correlations established are good and positive as it achieved the desired results where the coefficient of the correlation, R^2 is greater than 0.5. The two analyses are compared to demonstrate the strengths and weaknesses of each approach employed in this study to assess the properties of intact rocks.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The main focus of this study is the intact rock properties. Intact rock is one of the components in the composition of rock mass, including discontinuities. An intact rock is an aggregate of minerals that is clear from minor and major structural defects. Intact rocks are treated as isotropic, homogeneous, and continuous. In rock engineering, the onset and distribution of failure in intact rock are critically important issues. Tensile fractures begin to form in samples at low confining pressures at a rate of 40% to 60% of the uniaxial compressive strength. As loading continues, these tensile fractures gain density and eventually consolidate, causing strain localization and macro-scale shear failure in the samples (Hoek and Martin, 2014).

Testing of intact rock specimens in the laboratory has been limited in practice due to the size and durability of structural flaws. The need of estimating important parameters for the design of civil and mining engineering operations is essential. Therefore, in situ evaluation of the behavior of intact rocks in the expected stress range and stress field is given a lot of attention. Comprehensive data collection, both in the field and in the laboratory, is sometimes performed with the aim of conducting a realistic study of the intact rock properties, such as predicting its deformational response and stability.

The conventional in situ method of evaluation is the Schmidt hammer test which was developed in the 1940s as an index apparatus for in situ non-destructive test of concrete. However, since the early 1960s, it has been used in rock mechanics practice mainly for estimating the uniaxial compressive strength (UCS) and Young’s modulus of rock materials. The standard methods for the Schmidt hammer test can be expected to ensure consistent and reliable values and reproducible correlations for a given rock type due to its long history and widespread usage.

1.2 Problem Statement

Intact rock properties are examined as it is usually affected by weathering. Weathering is strongly linked to rock slope erosion and evolution. Weathering has an impact on the strength of rocks as well as the forces that they experience. Weathering has often been portrayed in an over-simplified way, however, it actually consists of numerous processes acting on multiple spatial and temporal scales, with many complicated inter-linkages.

Rocks are prone to failure due to the obvious disruption to the original geometry and strength. Furthermore, natural pores that intensify the weathering impacts enlarge in engineering time because of these instabilities and stress reduction. In general, methods with significant engineering judgement are used to analyse slope stabilities. As a result of this, probability – based methods are gaining popularity. The fastest way to analyse the intact rock properties is by performing in-situ tests such as the standardised method which is the Schmidt hammer test.

However, there are a number of issues regarding the application of Schmidt hammer such as the normalization of rebound values, specimen dimensions, surface smoothness, weathering and moisture content. These issues continue to compromise the reliability of Schmidt hammer.

Therefore, another method is used to complement the Schmidt hammer method which is the Knocking Ball method. The Knocking Ball test is a more sensitive in-situ test developed to quickly determine the deformation characteristics of rock materials and rock masses. This test's principle is based on the Hertz theory, which is a standard contact mechanics solution for non-adhesive contact problems between two elastic bodies. Hertz theory interprets the collision of metallic sphere against foundations, where it deforms differently based on its properties. The softer the foundation, the longer the contact time of the sphere and the foundation.

The Knocking Ball test is applied to determine the rock mass classification and to evaluate rock quality. The result of this test helps determine the rock mass classification instantly on site. The knocking ball test is useful and appropriate to be used to complement the standardised Schmidt rock hammer test to obtain reliable elastic moduli of rocks.

1.3 Objectives

There are three main objectives in this study:

1. To determine the intact rock properties using Schmidt hammer and Knocking Ball tests for sedimentary and metasedimentary rocks.
2. To establish the empirical correlation of the data obtained from Schmidt hammer and Knocking Ball tests.
3. To evaluate the intact rock properties obtained to the strength and weathering grade of rock.

1.4 Scope of Work

1. The research work and analysis will only be based on sedimentary and metasedimentary rocks.
2. There will be only two in-situ tests performed namely Schmidt Hammer and Knocking Ball tests.
3. The data acquired from each study area should be more than 50 data. More data acquired shall be better as it may increase the accuracy of the results.
4. The core samples which is used as a ‘control sample’ shall be right circular cylinders with a height to diameter ratio of 2:1, approximately 50 mm diameter with 100 mm height.

1.5 Dissertation Outline

The dissertation paper has been organized into multiple chapters for a better understanding of this study. As a result, the chapters are listed below.

Chapter 1: This chapter primarily covered the conceptual background of this study, including the statement of typical problem experienced, main objectives, and scope of work of this study.

Chapter 2: This chapter presents a well-supported justification for examining research issues and developing a research technique. This chapter provides some ideas regarding the underlying research problem and the design aspects, as well as the theoretical framework for the thesis.

Chapter 3: The research methodology for the study is explained in this chapter. This chapter covers the domain of the study technique, research methodology, methods of data collection, data acquisition tools, dataset preparation, research procedure, and project research restrictions.

Chapter 4: This chapter's goals are to assemble a review of the information gathered, analyse it, and report the findings. Typically, Chapter 4 section will reflect back on Chapter 3. All of the steps taken in Chapter 3 will produce results. The study results should be simply presented in Chapter 4 as an overview of the results should be saved for Chapter 5.

Chapter 5: The framework of the analysis is clearly reviewed in this chapter. In this chapter, assumptions, implications, and recommendations will be made.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will highlight the major parameters that have been examined in earlier studies, either often or rarely. A summary will be compiled that includes a descriptive comparison of the definitions, parameters, methods, results and discussions, conclusion, and limitations. The topics and parameters include the common tests performed on intact rocks, new methods of acquiring rock properties and the rock evaluation.

2.2 Intact rocks properties

Geotechnical properties such as rock mass and intact rock properties can be utilized in rock mass classification systems to classify rock masses based on their strength, weathering, seismic properties, and discontinuity characteristics. However, techniques for classifying rocks have mostly been designed to test the stability of exposed rock faces (Kramadibrata, 1996).

For rock mechanics in engineering work, there are a number of characteristics or properties that are seen to be particularly crucial for engineering applications (Deere and Miller, 1966). The following is a list of the characteristics that relate to the characteristics of the intact rock material:

a) The uniaxial compressive strength is a characteristic that can be used to determine right away whether a rock substance is too weak for a certain application to constitute a problem by itself.

b) According to the pre-failure information characteristics of the rock substance, creep of some kind may be anticipated in the material itself at stress levels below those needed to cause failure.

c) The safety factor that is employed in design as well as the precautions to be taken during construction should be influenced by the failure characteristics of the rock substance, i.e., brittle or plastic.

2.2.1 Factors affecting intact rock parameters

Intact rock parameters such as uniaxial compressive strength (UCS) and Young's modulus (E) are significantly influenced by factors such as rock class (igneous, sedimentary, and metamorphic), degree of weathering, and degree of foliation. However, it is critical to distinguish between factors that affect a single parameter, such as UCS, and factors that influence the relationship between the two parameters, such as UCS and E (Ching *et al.*, 2019).

For instance, it is well known that, generally speaking, UCS for sedimentary rocks is lower than that for igneous rocks. This might not indicate that there are three different relationships for igneous, sedimentary, and metamorphic rocks, rather, it just means that the relationship between UCS and E is distinct for different rock classes. For sedimentary rocks, a lower UCS is correlated with a lower E, whereas for igneous rocks, a higher UCS is correlated to a higher E. Therefore, there is no reason why the correlation cannot be the same for both rocks, with igneous rock data points occupying the higher portion of the relationship and sedimentary rock data points occupying the lower portion.

2.3 Uniaxial Compressive Strength (UCS) for Rock Testing

The parameter most frequently used to assess rock mass classifications and slope stability among the numerous strength characteristics of rocks is unconfined compressive strength (UCS), which is also useful for assessing the drillability and cuttability of rocks used for tunnelling (Thuro, 1997).

In the broad field of rock engineering, the UCS of rock is regarded as the most frequently utilised design parameter. For rock mass engineering stability and rock mass design, the UCS of a rock is a crucially important parameter, especially when the rocks are subjected to compressive loads with low confining pressure. Therefore, for rock mass engineering, it is crucial to properly and simply calculate the UCS (Wang and Wan, 2019). For determining the UCS, two different sorts of approaches are typically used:

a) Direct laboratory tests on rock samples.
b) Indirect analyses using related parameters that are significantly easier to get than the UCS itself.

For the prediction of the unconfined compressive strength of rock samples, the Miller's correlation, one of the most common Schmidt hammer correlations in Malaysia, was tested, and it was shown that the correlation's grade of accuracy is acceptable. However, similar to other Schmidt hammer correlations, if a new developed correlation is established, the usage of the of new developed correlation for UCS prediction in the case of highly weathered rock is not recommended due to improper UCS prediction (Nazir *et al.*, 2013).

2.3.1 Limitations of Uniaxial Compressive Strength testing

The preparation of the rock specimens for the direct laboratory tests must comply to very strict requirements, which might be challenging or even impossible for fractured rocks. Additionally, getting core samples costs money and takes time because a highly qualified operator is needed. Due to their simplicity and non-destructive character, indirect measurement methods of the UCS of rocks have thus been frequently used (Wang and Wan, 2019).

2.4 Seismic Methods for Sedimentary Rocks Strength Test

Seismic techniques are commonly used to characterise and determine the dynamic properties of rocks on-site and in the laboratory. These methods are being utilised more frequently in geotechnical engineering since they are non-destructive and reasonably simple to use (Kahraman, 2001). Seismic method such as Schmidt Hammer test has been widely utilised to quantify the characteristics of intact rock properties in term of strength. This technique is a form of manual data acquisition methods.

2.4.1 Schmidt Hammer test

Due to their ease of use and non-destructive nature, various indirect estimation methods of the UCS of rocks have been established. The Schmidt hammer test, one of these methods, is more efficient and practical for determining the UCS of rock. The Schmidt hammer is portable and useful in both the lab and field. The Schmidt hammer is frequently used to acquire an indirect measurement of UCS because it is a non-destructive, affordable, and portable hardness testing tool (Wang and Wan, 2019).

The Schmidt hammer test method is now commonly used to determine the strength and quality of rock. For determining the mechanical properties of rock material, the Schmidt hammer offers a rapid and affordable assessment of surface hardness (Sharma, Khandelwal and Singh, 2011).

The UCS estimated using the Schmidt hammer test can be divided into two types which are by using the empirical formulas and using soft computation techniques. In the past, empirical formulas were frequently used to calculate the UCS using rebound value (N). Significant work has been put into developing empirical formulas to estimate the UCS for different rock types using linear regression analysis, multiple regression, and nonlinear regression models in order to achieve more accurate UCS (Wang and Wan, 2019).

It is well known that R-value for different rock types varies to a great extent. For instance, there are significant variations between the R-values measured on freshly formed natural surfaces and those that have been crushed, as well as between freshly formed surfaces and various types of weathered surfaces. It has also been found that treated surfaces exhibit a higher relation between the R-value and the UCS than those that do freshly exposed natural rock surfaces. Additionally, as weathering progresses, the R-values' variability rises. This is mostly due to the importance of surface roughness in Schmidt hammer testing, where the existence of microcracks and visible micrograins affect the R-values (Gupta, Sharma and Sah, 2009).

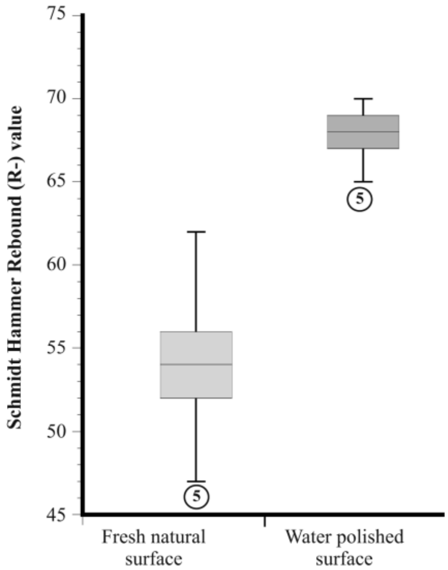

Figure 2.1: Box plot exhibiting Schmidt hammer rebound (R) values for the fresh natural weathered surface and the water-polished surface (Gupta et al., 2009).

By employing basic mathematical relationships, the Schmidt Hammer rebound values can also be used to calculate the Impact Strength Index (ISI), Slake Durability

Index (SDI), and P-wave velocity of various igneous, sedimentary, and metamorphic rock types. While P-wave velocity exhibited an exponential correlation with the Schmidt hammer rebound number, ISI and SDI exhibited a linear relationship.

$$ISI = 0.4388RR + 69.916 , R^2 = 0.9589 \tag{2.1}$$

$$SDI = 0.0491RR + 95.6 , R^2 = 0.7891 \tag{2.2}$$

$$P_v = 966.22e^{0.0262RR} , R^2 = 0.9584 \tag{2.3}$$

Between the Schmidt hammer rebound number, ISI, SDI, and P-wave velocity of the various rocks studied, a strong coefficient of determination was discovered as shown in Figure 2.2 to Figure 2.4 below. As a result, they are all highly correlated with one another, and the proposed correlation equations can be used to calculate the P-wave velocity, ISI, and SDI using just the Schmidt hammer rebound number (Sharma, Khandelwal and Singh, 2011).

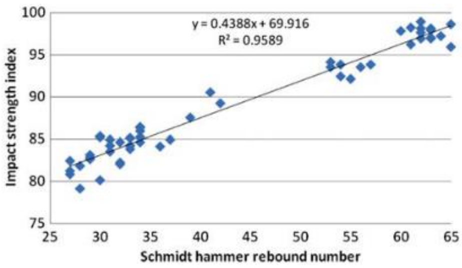

Figure 2.2: Correlation between ISI v. N

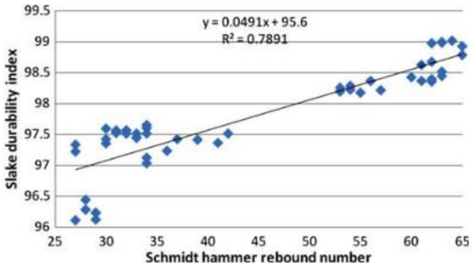

Figure 2.3: Correlation between SDI vs. N

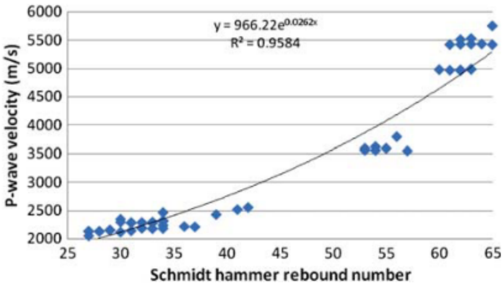

Figure 2.4: Correlation between P-wave vs. N

Schmidt hammer repeated blows at a single representative point produced rebound values that performed better than averages for single impact rebound values, P-wave velocities, and densities in forecasting weathering grades (Basu, Celestino and Bortolucci, 2009).

In the Grade I category, where weathering does not appear to have played any part, a wide range of uniaxial compressive strength (214–153 MPa) was found via uniaxial compression tests. The failure processes of the Grade I specimens may have been sped up or slowed down by variations in biotite percentage, distribution, and orientation, as well as in the frequency of quartz intragranular cracks. Mineral alteration, disturbance of the rock skeleton, and microcrack augmentation may be responsible for the decline in uniaxial compressive strength and elastic modulus as well as the increase in Poisson's ratio with increasing weathering intensity. Additionally, a basic correlation between weathering grades and failure types was found (Basu, Celestino and Bortolucci, 2009).

2.4.2 Coefficient and equation of correlation

By taking into account linear, logarithmic, power, and exponential functions, simple regression studies were undertaken to determine the type of relationship between dependent and independent variables. A useful indicator to evaluate the effectiveness of the proposed relationship is the coefficient of correlation between the measured and anticipated values (Minaeian, B., & Ahangari, K, 2011).

Table 2.1: Equations correlating the UCS to P-wave velocity (Minaeian, B., & Ahangari, K, 2011).

Reference	Equation	R^2
Entwisle et al. (2005)	$UCS = 0.78e^{0.88Vp}$	0.533
	$UCS = 0.78Vp^{0.88}$	0.531
Cobanglu and Celik (2008)	$UCS = 56.71Vp - 192.93$	0.67
Moradian and Behnia (2009)	$UCS = 165.05\exp(-\frac{4.452}{Vp})$	0.7
Diamantis et al. (2009)	$UCS = 0.14Vs - 336.05$	0.8
Khandelwal and Singh (2009)	$UCS = 0.133Vp - 227.19$	0.94

2.5 Knocking Ball method for Sedimentary Rocks Strength Test

A quick, easy, and reliable in-situ approach for analysing soil properties is needed for construction operations. In this case, the Hertz theory is used to apply a collision between a metallic sphere attached with an accelerometer and an assessment item to design a method for measuring deformation features (elastic collision theory). The deformation modulus of a soil material can be determined by applying the Hertz theory to an elastic collision based on the response properties when a metallic sphere with an accelerometer collides with an evaluation item (Kawano *et al.*, 2019).

2.5.1 Falling Ball test

The Falling Ball Test is a technique used to test soil properties including embankments and grounds by allowing a metallic sphere to fall freely. A metallic sphere fitted with an accelerometer collides with an evaluation object, which serves as the device's main working principle similar to Knocking Ball. Using the response characteristics, the elastic modulus of soil materials may then be quickly determined using the Hertz theory. Figure 2.5 below illustrates the concept used for both Knocking Ball and Falling Ball tests.

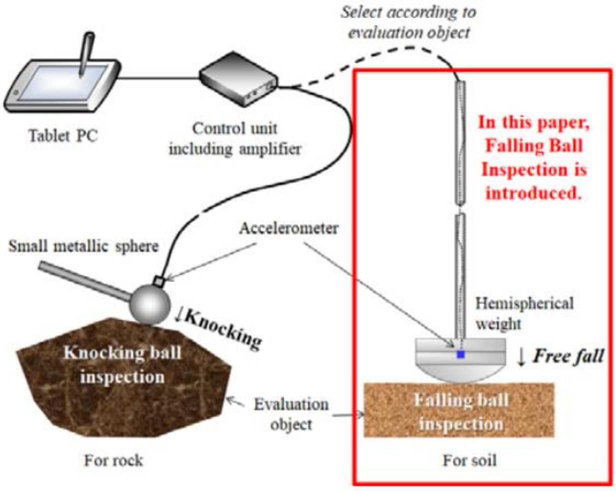

Figure 2.5: Device system and configurations (Kawano et al., 2019).

A metallic sphere falling freely can be used as the actual approach to assess the soil's qualities. Compared to conventional approaches, the method is faster and more applicable to a larger range of soil types. It has been confirmed that this method works well as a construction control method and that it can be used to assess the subgrade reaction modulus of foundation grounds and embankments as well as to regulate compaction of embankments (Kawano *et al.*, 2019). Figure 2.6 below displays the implementation of Falling Ball test.

Figure 2.6: Implementation status of Falling Ball Inspection (Kawano et al., 2019).

The falling-ball instrument's detection techniques can be utilised to quickly discover the subgrade's clay, silt, or sandstone's rebound modulus. The test depth should not be larger than 25cm, and the maximum particle size of the test material should be less than 10cm (Zhang *et al.*, 2020).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will explain the methods and procedures required to achieve the desired objectives of this study as mentioned in Chapter 1. Figure 3.1 below shows the procedure in performing this study which are particularly divided into 3 major stages namely the data acquisition, data correlation and data evaluation. The steps and flow of each stage are discussed further in detail in this chapter.

3.2 Overview of the Research Methodology

The main subject in this research will be based on the type of rocks, which are sedimentary and metasedimentary rocks. Several study areas have been selected which possess these types of rocks.

Then, in each of the study area, data acquisition was done by performing in-situ tests such as Schmidt Hammer test and Knocking Ball test. In addition, few rock samples were collected from each study area and brought back to be tested in the laboratory as a 'control specimen'. The samples will undergo coring process, cutting, and grinding to obtain the required specifications of core samples before testing.

After successfully performing the data acquisition, all the data acquired will be analyse before proceeding with correlation between the two methods of in-situ tests. Then, all the empirical data will be evaluated based on the rock and weathering grade, and the core samples produced will be tested through compression test to obtain a correlative value which can relate to the evaluation. All the steps and process will be described further in detail in this chapter.

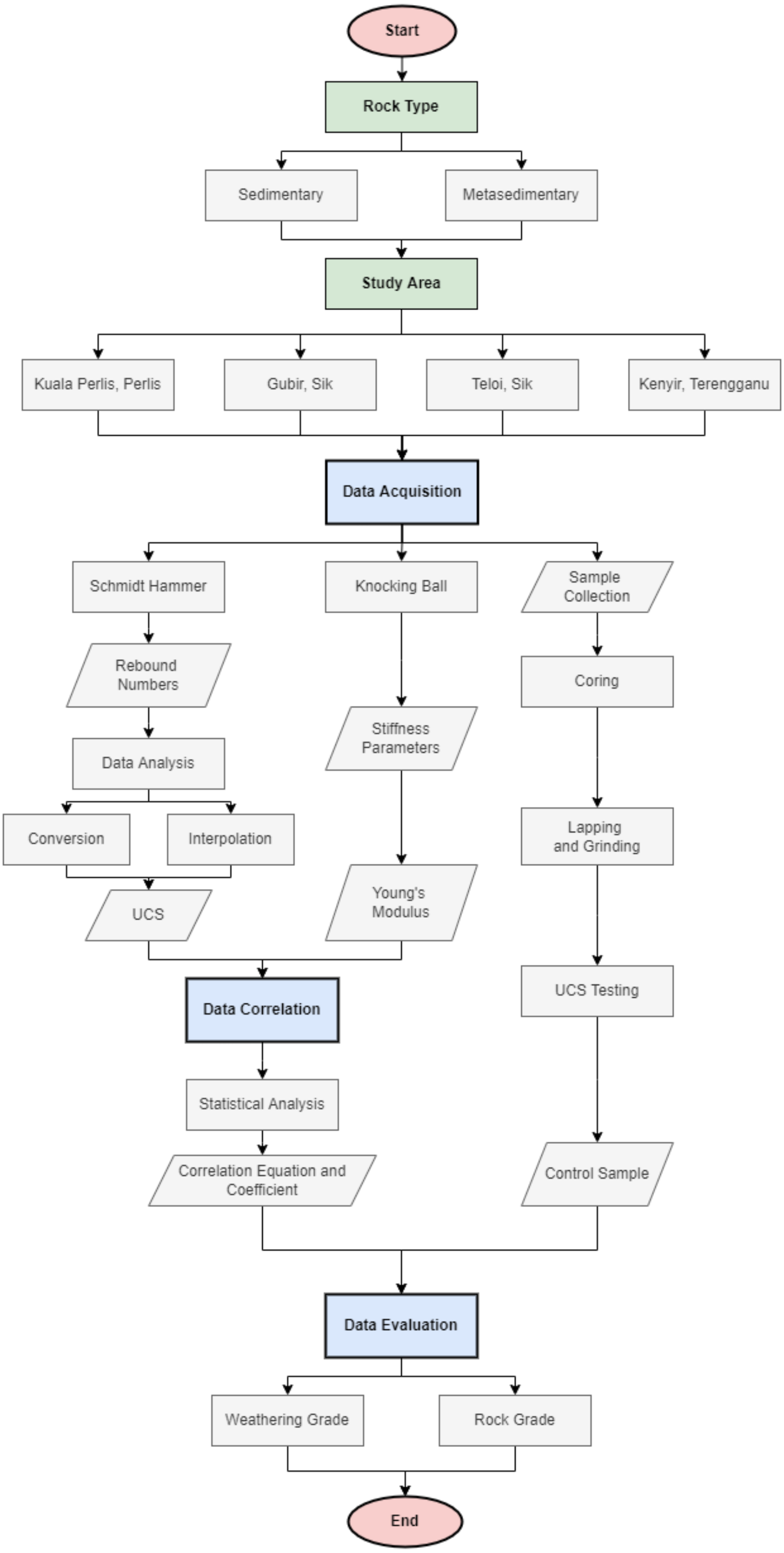

Figure 3.1: Flowchart of the Research Methodology

3.3 Types of Rock within the Study Area

The scope of rock types considered in this research are sedimentary and metasedimentary rocks. The formation of sedimentary rocks involves the accumulation or deposition of mineral or organic particles at the Earth's surface. The mechanisms that lead to the accumulation of these particles are collectively referred to as sedimentation. Sedimentary rocks are made up of a combination of detrital and chemical substances. Detrital material is specified for megascope use as being composed of clastic silicates (Krynine, 1948).

Meanwhile, metasedimentary rock is a class of metamorphic rock in geology. Such a rock was initially created through sediment deposition and solidification. The rock recrystallized as a result of being exposed to extreme pressures and temperatures while being buried beneath other rock. Even after high-grade metamorphism and significant deformation, the general composition of a metasedimentary rock can be utilised to identify the original sedimentary rock. Each study area represents different rock types, either sedimentary or metasedimentary, based on their lithology. Figure 3.2 below displays the distribution of all the study area’s location and Table 3.1 below concludes the coordinates of the exact location for all study areas.

Figure 3.2: Overview of all the study areas in this research

Table 3.1: Location coordinates of all study areas

Study Area	Latitude	Longitude
Kg. Wai, Kuala Perlis, Perlis	6°25'44.78"N	100° 8'41.91"E
Gubir, Sik, Kedah	6° 6'45.17"N	100°51'4.60"E
Teloi, Sik, Kedah	5°44'39.44"N	100°40'47.32"E
Bukit Kawah, Kenyir, Terengganu	5° 5'24.71"N	102°36'48.07"E

Figure 3.3 below shows the geological map of the first study area which is located in Kuala Perlis, Perlis where the lithology shown is mostly limestone, marble, marine clay and silt. All these rock types are classified under sedimentary rocks.

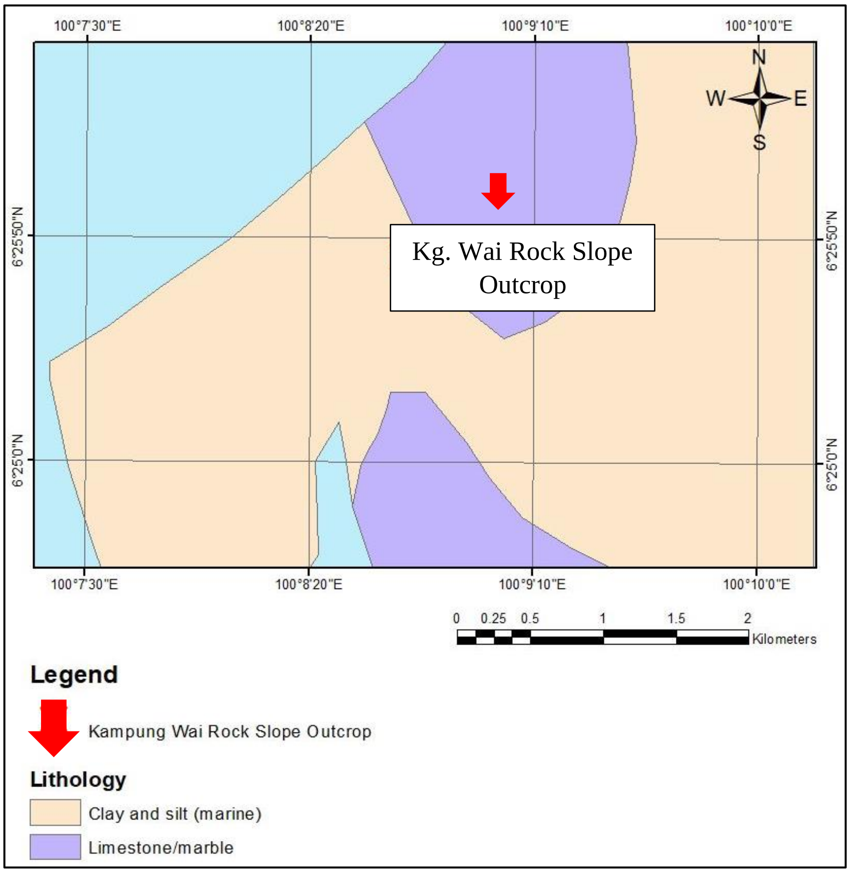

Figure 3.3: Geological map of Kampung Wai, Kuala Perlis, Perlis

Figure 3.4 below shows the outcrop of the rock mass in the study area. Some of the area on the rock mass have been highly weathered and moderately weathered which can be observed in Figure 3.4 below. There are some accumulation of highly and completely weathered rocks at the bottom of the slope. There are total of 52 points of intact rock taken on the rock mass. All these data taken will then believed to represent the rock properties of this study area.

Figure 3.4: Rock outcrop of Study Area 1 - Kampung Wai, Kuala Perlis, Perlis.

The next study area, which is located in Gubir, Sik, Kedah possess several types of rocks such as interbedded sandstone, siltstone and shale. However, all these rocks are still classified as sedimentary rocks. There are also several other rock types such as mudstone, phyllite, slate, conglomerate and acid intrusive. Figure 3.5 below shows the geological map of the study area where the lithology observed is mainly sandstone, siltstone, shale and slate. Based on Figure 3.5 below, the study area is located on the region of interbedded sandstone, siltstone and shale, hence, the major properties of the rock type taken is believed to be sandstone’s properties.

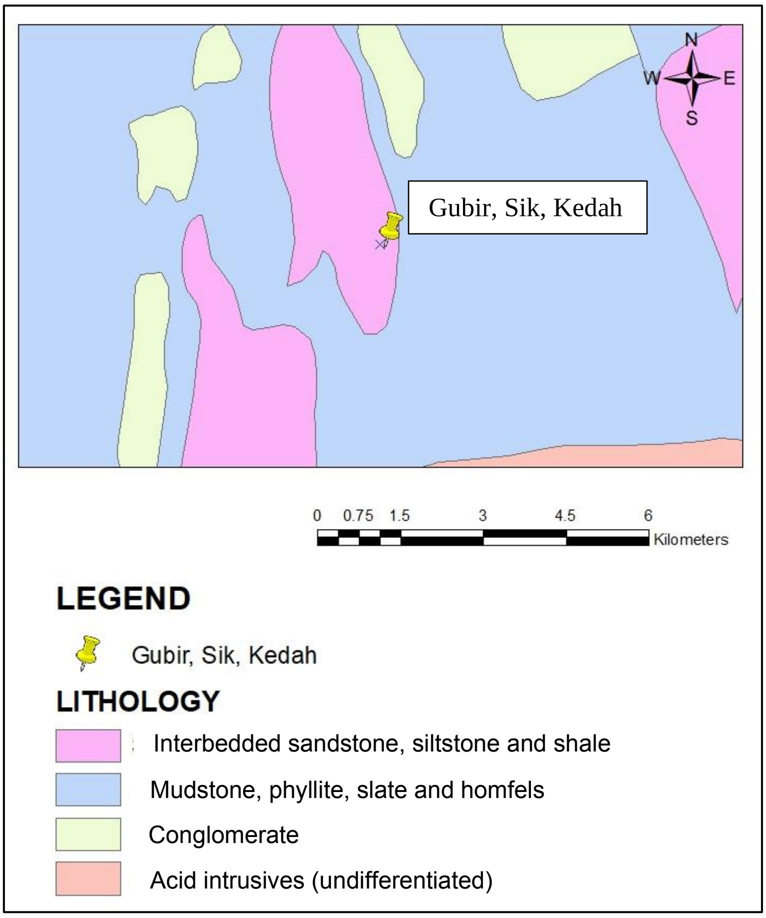

Figure 3.5: Geological map of Gubir, Sik, Kedah

From Figure 3.6 below, it can be observed that the outcrop of the rock mass of the study area has been slightly or moderately weathered. Therefore, there are rocks which can be seen at the bottom of the slope assumably have been weathered or fractured. The number of points tested on the intact rock taken on this study area’s rock mass is 56 points as planned. These data from the points taken will be used to analyse the rock properties of this study area.

Figure 3.6: Rock outcrop of Study Area 2 - Gubir, Sik, Kedah

Then, the next study area is located in Teloi, Sik, Kedah where it comprises of interbedded sandstone, siltstone and slate. Slate is a fine-grained, foliated, homogeneous metamorphic rock formed from a shale-type sedimentary rock. Therefore, these rocks are considered metasedimentary rocks. Figure 3.7 below shows the lithology of the study area where it is mostly siltstone, slate, limestone, and shale.

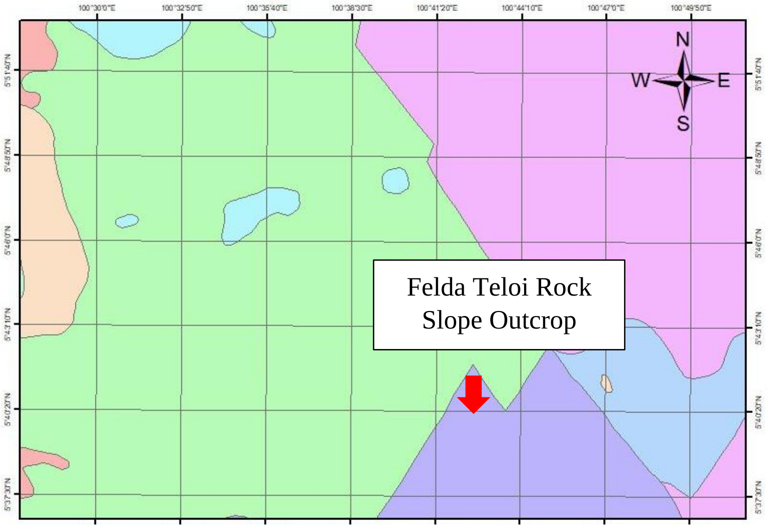

Figure 3.7: Geological map of Teloi, Sik, Kedah

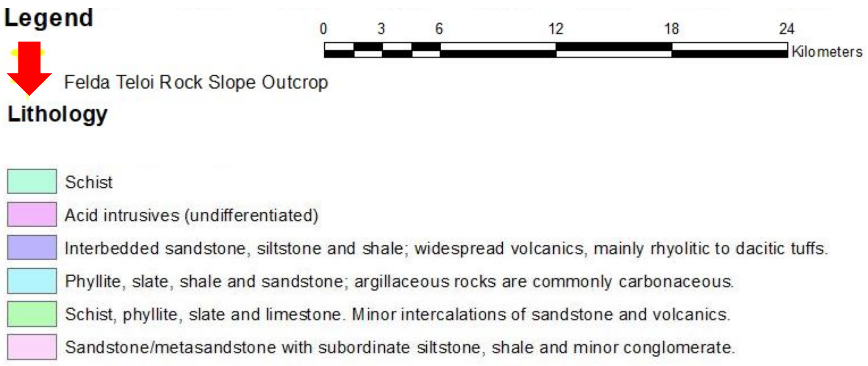

Figure 3.8: Legend for the Teloi geological map

Based on Figure 3.9 below, it can be observed that, the outcrop provides the visualisation of the rock condition which is interbedded sandstone, siltstone and slate. It can also be seen a faultline existed on the rock mass. There are 54 points of intact rock taken at this site to be used to study the rock condition of the site.

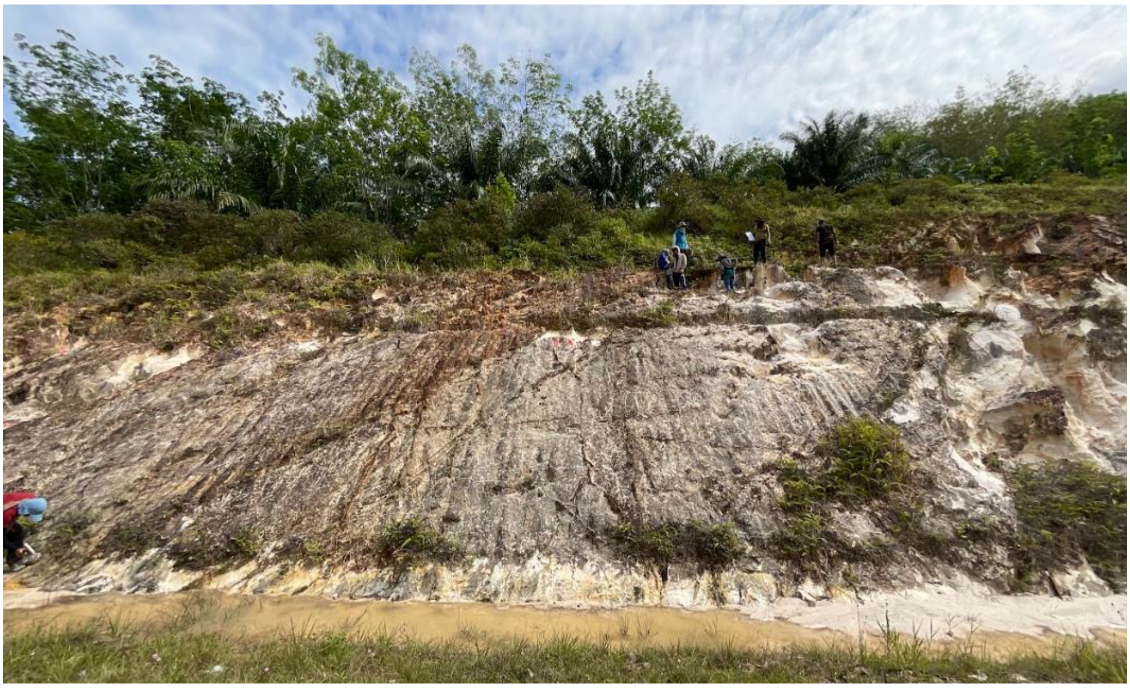

Figure 3.9: Study Area 3 - Felda Teloi, Sik, Kedah.

Next, the last study area in this research, which is located at Bukit Kawah, Kenyir, Terengganu consists of slate with subordinate sandstone. They are considered metasedimentary rocks. Figure 3.10 below shows the lithology of the study area which can be observed that it is conquered by sandstone or metasandstone. There is also the presence of phyllite, slate and shale with subordinate sandstone.

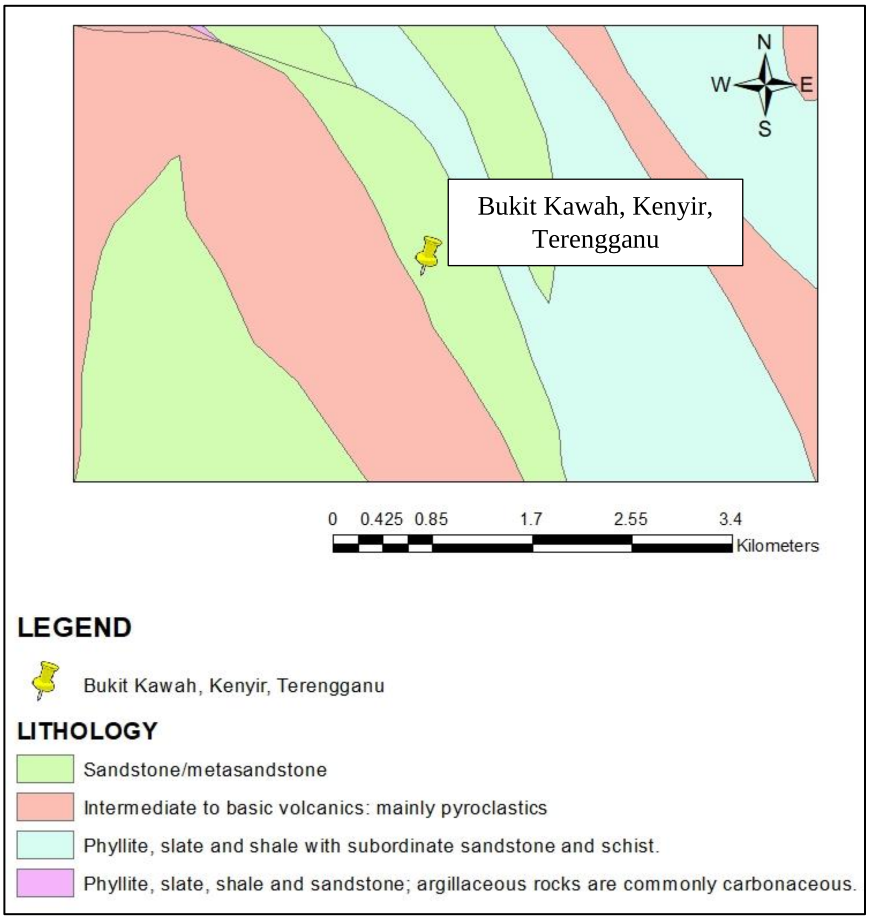

Figure 3.10: Geological map of Bukit Kawah, Kenyir, Terengganu

Figure 3.11 below provides the visualization of the outcrop of the study area. It can be observed that some points on the rock mass have been weathered. 130 points were successfully taken on the rock mass due to the large outcrop of the site.