SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING
UNIVERSITI SAINS MALAYSIA

APPLICATION OF UNMANNED AERIAL VEHICLE (UAV) PHOTOGRAMMETRY METHOD FOR ROCK MASS RATING ANALYSIS OF A ROCK SLOPE

by

NOR AFIQAH ADRIANA BINTI ROSLAN

Supervisor: Assoc. Prof. Dr. Hareyani Zabidi

Dissertation submitted in partial fulfillment
of the requirements for the degree of Bachelor of Engineering with Honours
(Materials Engineering)

Universiti Sains Malaysia

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "Application of Unmanned Aerial Vehicle (UAV) Photogrammetry Method for Rock Mass Rating Analysis of a Rock Slope". I also declared that it has not been previously submitted for reward for any degree or diploma or other similar title for any other examining body or university.

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Date: 19th August 2022

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Date: 19th August 2022

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LIST OF ABBREVIATIONS

3D	Three-Dimensional
RMR	Rock Mass Rating
DSE	Discontinuity Set Extractor
UAV	Unmanned Aerial Vehicle
GSD	Ground Sampling Distance
SfM	Structure from Motion
GCP	Ground Control Point
FoS	Factor of Safety

APLIKASI MENGGUNAKAN KAEDAH UAV FOTOGRAMETRI UNTUK ANALISIS KECERUNAN BATU MELALUI KAEDAH KUALITI JISIM BATUAN

ABSTRAK

Pencirian jisim batuan adalah langkah pertama dalam menentukan kualiti dan kestabilan jisim batuan. Terdapat banyak skim pengelasan jisim batuan yang kerap digunakan untuk tujuan berbeza seperti untuk menganggar kekuatan dan kebolehubah bentuk jisim batu, kestabilan cerun batuan dan perlombongan bawah tanah. Beberapa teknik telah digunakan dalam pemetaan ketakselanjaran penakrifan jisim batuan sesuatu cerun batuan dalam penyelidikan ini seperti pemetaan manual dan fotogrametri UAV. Matlamat projek ini adalah untuk mengkaji sifat geologi batu kapur, menganalisis sifat jisim batuan batu kapur menggunakan sistem kualiti jisim batuan (RMR) dan menyiasat ketepatan pemetaan antara UAV dan kaedah konvensional. Perisian yang digunakan dalam projek ini ialah Agisoft Metashape dan Discontinuity Set Extractor (DSE). Langkah seterusnya ialah pengumpulan data dari kawasan kajian yang kemudiannya diteruskan ke ujian makmal seperti indeks ujian beban titik. Berdasarkan penarafan jisim batu daripada pemetaan manual dan indeks kekuatan beban titik, batu kapur ini diklasifikasikan sebagai "batu yang baik". Daripada perbandingan ketepatan antara pemetaan manual dan analisis DSE menunjukkan bahawa pemetaan manual adalah lebih tepat. Ini disebabkan oleh ralat yang diperolehi dalam perisian itu sendiri dan terdapat beberapa titik yang tidak dapat ditangkap oleh perisian tersebut. Walau bagaimanapun, kelebihan menggunakan fotogrametri UAV dapat memperoleh ketepatan tinggi imej ketakselanjaran di cerun yang sukar dicapai dengan berjalan kaki dan berjaya mendapatkan lebih daripada empat (4) set sambungan.

APPLICATION OF UNMANNED AERIAL VEHICLE (UAV) PHOTOGRAMMETRY METHOD FOR ROCK MASS RATING ANALYSIS OF A ROCK SLOPE

ABSTRACT

Rock mass characterization is the first step in defining rock mass quality and stability. There are many rock mass classification schemes which are frequently used for different purposes such as for estimation of strength and deformability of rock masses, stability of rock slopes and underground mining. Several techniques have been used in mapping the discontinuities of rock mass rating of a rock slope in this research such as manual mapping and UAV photogrammetry. The aim of this project is to study the geological properties of limestone rock, to analyse the rock mass properties of limestone rock using Rock Mass Rating (RMR) system and to compare the mapping method between the Unmanned Aerial Vehicle (UAV) and the conventional method. The software used in this project are Agisoft Metashape and Discontinuity Set Extractor (DSE). Next step is collection of data from case study area which then will proceed to the laboratory test such as point load test index. Based on the rock mass rating from manual mapping and point load strength index, this limestone is classified as “good rock”. From the mapping method between manual mapping and DSE analysis it shows that UAV mapping validated to manual mapping. However, the advantages using the UAV photogrammetry was able to obtain high precision of image of the discontinuity on slopes that are difficult to access on foot and managed to get more than four (4) joint sets which cannot obtain by manual mapping.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Specific factors, including the rock mass's structure, the quality of its discontinuities, joint spacing, filling material, and other parameters, are quantified and characterized in the analysis of rock mass quality. The most often used rock mass classification systems is the rock mass rating (RMR) (George et al, 2020).

The slopes are typically exposed to instability problems because of the rock mass conditions as well as external environmental influences. The heavily joined granite mass that makes up the rock slopes has variable spacing, dips, and dip directions in different places. In South Africa, a geomechanics categorization system has been developed by (Bieniawski, 1976). The system assigns a general rock mass rating (RMR) rating from 0-100 as quality improves. Therefore, Bieniawski's method is based on six factors: the strength of the complete rock material, the designation of the rock quality (RQD), the distance between joints, the state of the joints, the condition of the groundwater, and the orientation of discontinuities. The rating system demonstrates that not all parameters have an identical impact on how the rock mass behaves.

Based on previous research, the data collection was used a conventional method. Subsequently, the orientation of the discontinuities was measured using a geological compass in terms of dip and dip direction, while the uniaxial compressive strength (UCS) of the intact rock and the joint compressive strength (JCS) were estimated using a Schmidt hammer. A profilometer was also used to check the roughness of the joints, while a surveyor's tape was used to measure the aperture and joint spacing. Finally, the filling material was evaluated, as well as the weathering conditions in the area. Scanline or window sampling are commonly used to collect data on discontinuities (George et al, 2020).

The Unmanned Aerial Vehicle (UAV) has been developed as a platform of useful source for efficient data collection and mapping in a low-cost system, as opposed to later digital mapping methods like LiDAR. A typical image-based field surveying with an unmanned aerial vehicles (UAV) system require a flight planning, ground control points (GCPs) for geo referencing, image acquisition, camera calibration and image orientation, image processing for 3D information extraction (Remondino, 2011). However, because it has been consistently improved into a device that can multitask and lower the payload for more technical jobs, UAV has evolved in recent years into a tool that is more valuable and worth the price.

Hence the aim of this research is to compare conventional method in geological mapping to the advanced method which is by using UAV Photogrammetry to becoming the standard for geoengineering and civil engineering site surveys, making data acquisition faster and safer on slopes that are difficult to access on foot. One of the main advantages of using UAVs for rock slope stability studies is able to record detailed images even on high and steep slopes. UAV photogrammetry allows you to create 3D data and orthophotos. These can be used to define some features of slope shape and discontinuity. The generated point cloud from Agisoft Metashape Software was analysed using the free source software Discontinuity Set Extractor (DSE) in the built 3D model to find discontinuity sets and assess their orientation at the researched area (George et al, 2020). On the other hand, point load index test is conducted in order to know the strength of the rock at the study area as it is one of the parameters in rock mass classification.

1.2 Study Area

The study area in this research was in Bercham, Ipoh, Perak. To be specific, the study area was at Huat Tian Keong Temple, Perak. The latitude and longitude for this temple were 4º37’26.70” N and 101º07’53.87” E, respectively. This latitude and longitude were obtained from the Google earth Software. The sample collected were divided into three (3) part which are A, B, and C. Each of these sample contain five (5) subsample which gave fifteen (15) in total. The location of Ipoh, Perak on the map of Peninsular Malaysia, was produced using ArcGIS software which is shown in Figure 1.0.

Figure 1.0. Location of Ipoh, Perak on the Map of Peninsular

1.3 Problem Statement

The stability analysis of rock slopes has proven to be a difficult issue for engineers and geologists since the rock mass that makes up the slope frequently contains discontinuities of various types, resulting in numerous types of slope failure. Faults, bedding, foliation, joint, cleavage, and schistosity are the most typical types of discontinuities in rock masses. The geologic and geotechnical properties of the bedrock and soil that make up the slopes play a big role in slope stability. When the shear strength and shear stress in the ground are out of equilibrium, these slopes crumble, causing catastrophic loss of life and property. Slope failure could be caused by heavy precipitation, extreme weather, seismic disturbances, and human activity (Mohammad Khalid et al, 2016).

Therefore, it is necessary for engineers or geologist to investigate the strength of the rock mass in order to evaluate the rockfall potential by assigning rock mass rating (RMR) and reduce the effect from slope failure. However, access to rock faces is frequently difficult or impossible. Taking into account the persons in charge safety during a slope stability inspection as well as the issues with direct access to slopes (Syaran et al, 2011).

Hence, in order to minimize the risk and safety during the investigation, unmanned aerial vehicles (UAVs) has identified as one of the methods that can record detailed images of faulting rock mass even on high and steep slopes. Using current common UAVs, the location and orientation of the implemented sensors can be registered and followed in a local or global coordinate system. UAV photogrammetry can be thought of as a novel photogrammetric measuring method as a conclusion. UAV photogrammetry opens up new applications in the close-range domain by combining airborne and terrestrial photogrammetry, in addition to bringing new (near) real-time applications and affordable alternatives to conventional human aerial photogrammetry. To do a manual or semi-automated structural analysis and to gather details about the discontinuity sets, such as joint spacing and orientation, by using the results from 3D point cloud. Once these data have been collected, a discontinuities analysis can be utilised to identify the probability of rockfall (George et al, 2020). Besides laboratory tests can also be used to give detailed information due to cost constraints and the fact that in-situ tests are quite expensive. For instance, point load test index testing is chosen as to determine the strength of rock.

1.4 Objectives

In this project, there are several objectives that are aimed to achieve. They are:

1. To study the geological properties of limestone rock.
2. To analyze the rock mass properties of limestone rock using Rock Mass Rating system
3. To compare the mapping method between UAV mapping and the conventional mapping.

1.5 Scope of Research

A detailed engineering geological field survey is the initial stage in determining the characteristics of a rock mass. More specifically, the author employed a geological compass to measure the orientation of the discontinuities in terms of dip and dip direction for the purposes of this study. The data is then recorded into a sheet that contains the rock mass rating parameters. Representative rock samples from the research area were obtained, and the samples were examined in the laboratory according to established standard procedures. The experiments were carried out in order to determine the essential input parameters for rock slope stability analysis (point load strength index).

Then, imagery was collected using a DJI Phantom 4 Pro. The survey photos were processed using the Agisoft Metashape software, which resulted in a dense point cloud. The generation of a detailed DEM was made possible by further processing of the point cloud data. After georeferencing the 3D point cloud, the orientation of individual joints was measured using a geological compass. The obtained point cloud was examined using the open source software Discontinuity Set Extractor (DSE) to detect discontinuity sets and measure their orientation at the study area. Combining the information collected during traditional field survey and the data extracted from the generated 3D model the strength and rock mass rating (RMR) of the research area can be predicted.

1.6 Thesis Outline

The five chapters of author research include introduction, literature review, methodology, results and discussion, and conclusion and recommendation. Chapter 1 covers the introduction, problem statement, objectives, and thesis statement in detail. The problem statement tells how the using of Unmanned Aerial Vehicle (UAV) Photogrammetry mapping can reduce the risk compared to the manual mapping.

The literature review for the research area was covered in chapter 2. This chapter will analyse how often Agisoft Metashape has been utilised in research and analyse how Discontinuity Set Extractor (DSE) relates to manual mapping. The research methodology that could be used was discussed in Chapter 3. The techniques employed in this study included manual mapping techniques, Point Load Index laboratory testing, 3D point cloud software like Agisoft Metashape, and DSE discontinuity analysis. This chapter also includes a flowchart on how to use the Agisoft Metashape software.

Chapter 4 covered the analysis of the research data. The research data will be discussed here, such as the class or rock mass rating acquired by manual mapping and the point load index, the discontinuities analysed by DSE, and a comparison between manual mapping and UAV photogrammetry. Chapter 5 concludes with a recommendation. It includes discussing about the overall finding of all the current investigations. Additionally, there are certain suggestions that are useful and can be applied to future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

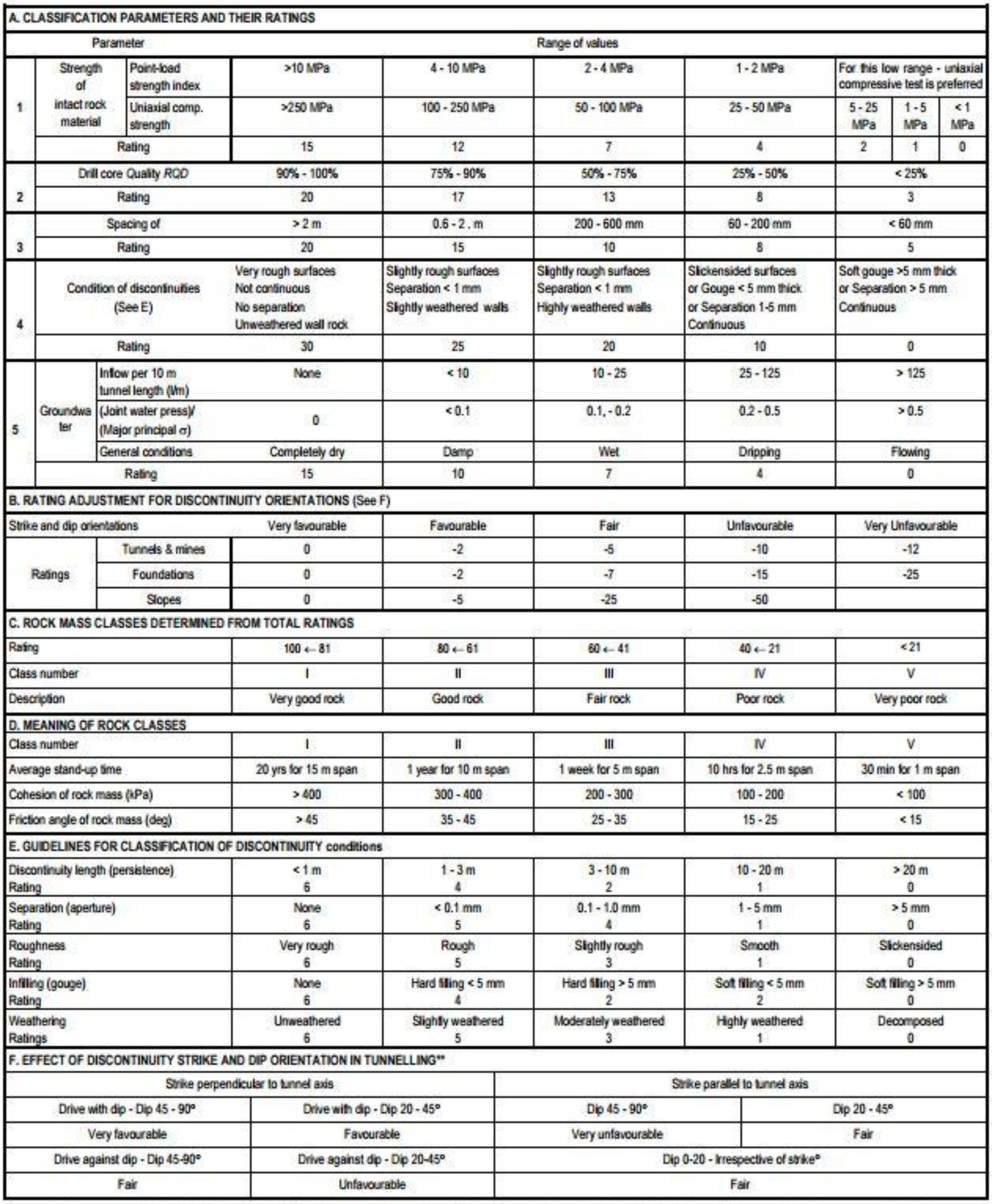
This chapter focuses on the literature review component of the research project. In this part, the author will discuss well about the geology of the study area, which includes rock formation and its history. The classification of rock masses is also discussed here as part of the research goal in determining the rock quality. The Rock Mass Rating (RMR) is the main classification systems that are used. There are several parameters for RMR. The primary goal of rock mass classification is to give quantitative data and guidelines for engineering reasons, which can help to improve geological formation descriptions.

The geomechanical investigations were designed to separate the rock masses under investigation into sub-groups based on rock strength, geological structure, and rock mass categorization in order to fully understand the changing nature of the rock. These included scanline mapping of rock faces and laboratory studies on rock samples collected along the sides of the benches extracted by continuous miners. Rock mass rating (RMR) systems are often used in the early stages of mining and civil projects. It is possible to estimate other rock mass features, such as geomechanical parameters, by specifying these values. Therefore, many researchers established experimental models to derive the RMR.

In order to determine the length of discontinuities, separation, roughness, infilling, and weathering of rock layers, quantitative data was acquired. For instance, geologists (a) measured the distance between each discontinuity, (b) measured the width of individual rock face discontinuities, (c) measured surface discontinuity roughness, (d) analysed the material that the discontinuities were filled with, and (e) recorded the appearance of discontinuity weathering. The goal was to see if the rock layers were breaking and worn down or if they were still intact and smooth (Beemer & Worrells, 2017). Later, this data was utilised to calculate the entire discontinuity condition.

The rock mass could be sorted into five classes: very good (RMR 100–81), good (80–61), fair (60–41), poor (40–21), and very poor (<20). The list of parameters and assigned value in the rating is given in Figure 2.1 (Salmanfarsi, 2020). Perhaps more pressing in the context of Malaysia is that in most rock classification systems, the role of water movement which is one of the parameters, has not been given significant proportion in the parameters (Pantelidis, 2009). This is especially significant for local climate, with water movement being the largest contribution factors for landslide, making up to 58% of landslide cases.

For all but very weak rock materials, the analysis of rock slope stability is fundamentally a two-part process. The first step is to analyse the structural fabric of the site to determine if the orientation of the discontinuities could result in instability of the slope under consideration (Wylie, 2015). This is normally achieved through a stereographic analysis of the structural fabric, which is also known as kinematic analysis (Piteau, 1978). The second stage needs a limit-equilibrium stability analysis to compare the forces preventing failure with the forces causing failure after it has been determined that a kinematically possible failure mode exists. The factor of safety, or FOS, is the ratio of these two sets of forces. The orientation of the line of intersection of the wedge-forming planes governs a kinematic analysis for wedge failure. Kinematic analyses determine whether sliding is possible. If so, whether it will occur on only one plane or on both planes at the same time, with movement in the direction of the intersection line. (Wyllie, 2015).



A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values				
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa 1 - 5 MPa < 1 MPa
	Rating		15	12	7	4	2 1 0
2	Drill core Quality *RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%
	Rating		20	17	13	8	3
3	Spacing of		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm
	Rating		20	15	10	8	5
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous
	Rating		30	25	20	10	0
5	Groundwater	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing
	Rating		15	10	7	4	0

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.

** Modified after Wickham et al (1972).

Figure 2.1: Rock Mass Rating System (RMR) (Bieniawski, 1989)

2.2 Site Geology

The Huat Tian Keong Temple, which is situated in Ipoh, Perak, at latitude 4°37' North and longitude 101°08' East, is chosen as the research area. Figure 2.2 displays lithology map of area in Perak include the study area which was in Ipoh, Perak. The geological formation of the temple's land is a representation of several kinds of limestone formation. In Malaysia, karstification forms a major part of the limestone formation, producing a complex tectonic structure (Zabidi et al, 2016). Phyllite, slate, shale, and sandstone are some of the locally significant host rocks that make up this limestone.

Locally, the study area's limestone is composed mainly of massive and thin-bedded types with patches and/or spots of greyish white and black carbonaceous rock. Additionally, fine-grained limestone can be found everywhere and it is sometimes intercalated or linked to carbonaceous (fissile) phyllite/schist (Syaran, 2011). According to observation, the limestone rock strata that make up Huat Tian Keong Temple are often huge to densely bedded, white, brownish, and black, and have many strong joints.

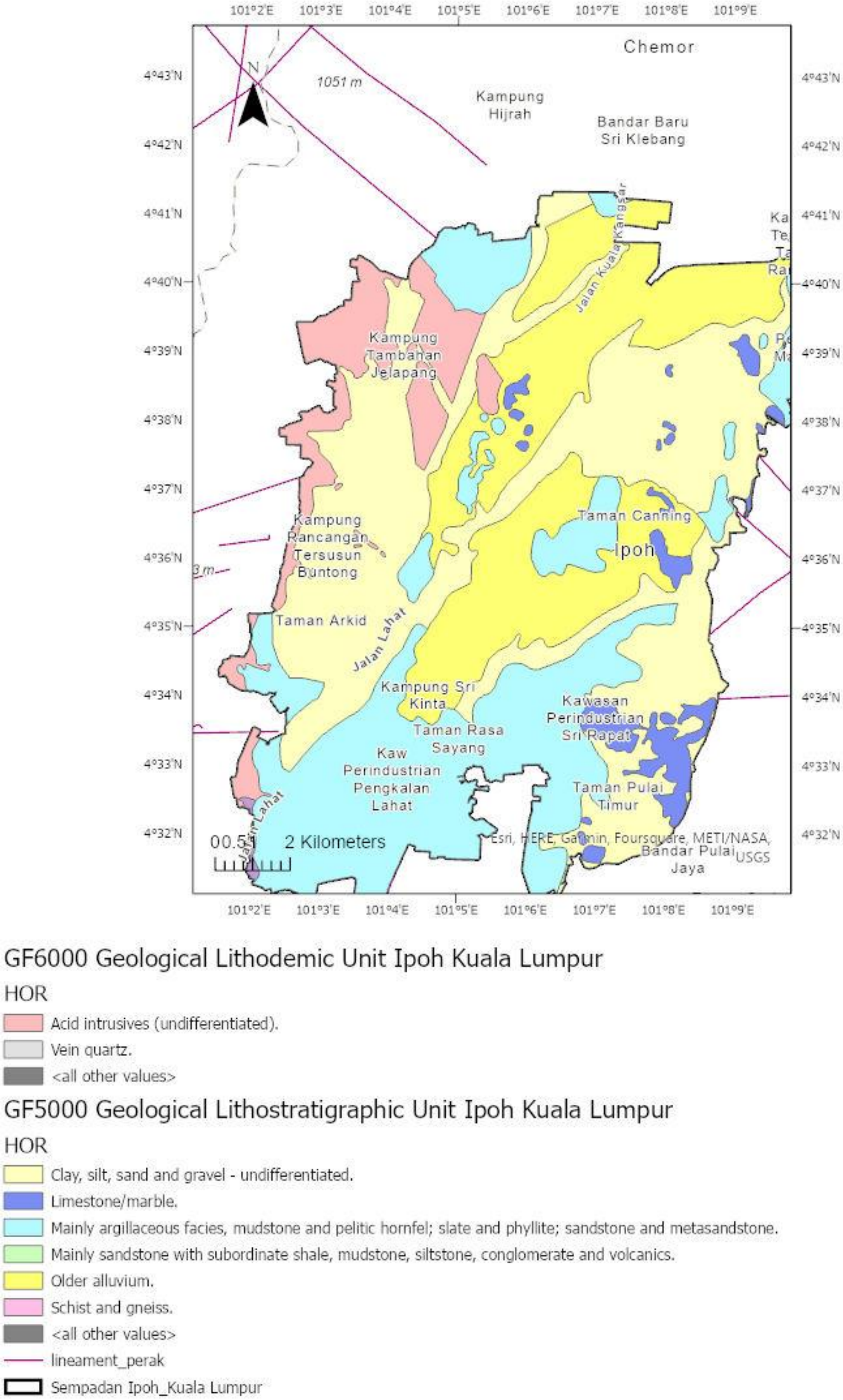


Figure 2.2: The Lithology Map of Perak

2.3 Rock Mass Classification System

The use of a rock mass classification scheme can be very helpful during the feasibility and initial design stages of a project when there is very little detailed information available on the rock mass and its stress and hydrologic properties. To sum it up, this can involve using the classification scheme as a checklist to make sure all-important info has been taken into account. On the other hand, one or more rock mass classification methods can be used to create a picture of a rock mass's composition and characteristics in order to provide and to estimate the parameters of support requirements and estimates of the rock mass's strength and deformation properties (Anon., n.d.).Besides, it will provides better communication between the engineer and geologist. It is recommended that at least two methods be used at any site during the early stages of a project.

Terzaghi became the earliest reference on the rock mass classification for the design of tunnel support in which the rock loads, carried by steel sets, are estimated on the basis of a descriptive classification. Terzaghi highlights the characteristics that govern the behaviour of rock masses, especially when gravity constitutes the dominant driving force. Based on his 25 years of experienced in tunnel construction in Swiss Alps at that time. Terzaghi managed to come out with definitions, practical comments on the geology information which is useful for engineering design. Below is the example of Terzaghi definition or description about geology information.

1. Neither joints nor hair cracks can be found in intact rock. As a result, if it breaks, it breaks across sound rock. Spalls may fall off the roof hours or days after blasting due to the damage caused by blasting. This is a condition known as spalling. Hard, undamaged rock can also be found when there is a situation known as popping, where rock slabs suddenly and unexpectedly separate from the sides or roof.

2. Individual strata with little to no resistance for separation at the boundaries between the strata make up stratified rock. Transverse joints might or might not weaken the strata. Spalling is a rather common condition in such rock.
3. Rock that is moderately jointed has hair cracks and joints, but the blocks between the joints are so closely interlocked or locally grown together so vertical walls will not need lateral support. Both spalling and popping conditions may occur in rocks of this type.
4. Chemically intact or almost chemically intact rock fragments that are completely separated from one another and inadequately connected make up blocky and seamy rock. Vertical walls may need lateral support in such rock.
5. Crusher run is a type of rock that has been crushed yet is chemically unaffected. Crushed rock below the water table shows the characteristics of a water-bearing sand if the majority or all of the fragments are as small as fine sand grains and no recementation occurred.
6. Rock is being squeezed into the tunnel slowly; without perceptible volume increase. A large proportion of microscopic and submicroscopic clay minerals or micaceous minerals with a poor swelling capacity is a need for squeezing.
7. Swelling rock moves into the tunnel in large quantities. Only rocks with clay minerals, such as montmorillonite, that have a high swelling capacity appear to have the ability to swell.

After rock mass classification has been introduced by Terzaghi, since then many researchers tried to modify this rock mass system for better used. One of it was (Deere, 1988). These systems tackled various engineering projects such tunnels, chambers, mines, slopes, and foundations while taking into account recent developments in rock support technology, especially rockbolts and shotcrete.

Initially, Bieniawski's Rock Mass Rating (RMR) modification for mining approach was based on case studies mostly from the civil engineering field. As a result, numerous changes have been suggested to make the classification more applicable to mining applications because the mining industry has a tendency to view it as being relatively conservative. A modified rock mass rating system for mining has also been proposed by (Laubscher, (1977, 1984)), (Laubscher & Taylor,1976), and (Laubscher & Page, 1990).

This MRMR system modifies Bieniawski's basic RMR value to take into consideration in situ and generated stresses, stress variations, as well as the impacts of blasting and weathering. The resulting MRMR value is accompanied by a set of recommendations for additional study. It is important to keep in mind when using Laubscher's MRMR approach that many of the case histories it is based on caving operations. Block caving in African asbestos mines served as the inspiration for the adjustments at first, but later, the database also included case studies from other parts of the world. The Bieniawski RMR classification has also been updated by (Cummings et al, 1982) and (Kendorski et al, 1983) to create the MBR (modified basic RMR) system for mining.

The Rock Mass Rating (RMR) method, also known as the Geomechanics Classification, was described in detail by (Bieniawski, 1976). The reader should be aware that Bieniawski has significantly changed the ratings given to many parameters, as this method has been improved over time as more case records have been analysed. The discussion that follows is based on the classification's 1989 version (Bieniawski, 1989). Estimating the strength of rock masses is a topic covered in both this version and the version from 1976. The RMR system classifies a rock mass based on the following six factors:

1. Uniaxial Compressive Strength of Rock Material.

2. Rock Quality Designation (RQD).
3. Spacing of Discontinuities.
4. Conditions of Discontinuities.
5. Groundwater Conditions.
6. Orientation of Discontinuities.

The rock mass is separated into a number of structural regions when using this categorization technique, and each structural region is classed independently. In most cases, a major structural feature, like a fault or a change in rock type, marks the boundaries of the structural zones. Within the same rock type, there may be cases where significant variations in discontinuity spacing or characteristics require for the division of the rock mass into a number of small structural regions.

2.3.1 Uniaxial Compressive Strength of Rock Material.

The strength of intact rock must be known in order to classify a rock mass, it is generally agreed by most of the researcher. It's clear that there is currently a lack of certainty on the topic of strength classification as a whole. However, it should be acknowledged in all fairness that different divisions into classes of strength and their designations are mainly arbitrary and that all categories may be suitable for the particular use for which they were developed. To allow proper communication among individuals interested in rock strength data, some standard of terminology is required, even though no classification should be rejected (Bieniawski, 1973). Determining a rock's uniaxial compressive strength is a quick and inexpensive method. For the purpose of determining the point load strength index, which is related to the uniaxial compressive strength, tests may be performed on prepared rock specimens in the laboratory or on unprepared rock cores in the field using portable equipment. The core sample cracks when strains are too great compared to the bearing limit. These cracks form in the weaker areas. The author can observe the clock reading as fractures appear. The greatest compressive strength of rock is shown at that point.

2.3.2 Rock Quality Designation (RQD)

The presence of discontinuities in a rock mass has a negative impact on its mechanical characteristics. Hence, the amount of their presence must be determined before any excavation assessment. Deere developed the Rock Quality Designation (RQD), which is a widely used indicator of the quality of a rock mass. Following that, Deere proposed that a scan-line, which can be used to assess discontinuity intensity at a face, may be considered directly similar to a drill core because the RQD can be detected in both. The RQD can thus be derived from the percentage recovery of sound pieces of core of 0.10 m or higher in length, based on rock cored samples, i.e.,

$$\mathrm{RQD} = \frac{\text{Total length of all pieces exceeding 0.10 m}}{\text{Total length of core run (m)}} \text{ x } 100$$

The International Society of Mechanics (ISRM, 1981) recommends a core size of at least NX diameter (54.7 mm) drilled with double barrel diamond drilling equipment for RQD assessment using rock cored sample. It is not necessary to count cores that are not firm and sound. As a result, extremely weathered rock will receive an RQD of zero. Furthermore, Coats stated that inclined drilling gives more information on the characteristics of the rock mass than vertical drilling.

Fracture Frequency (FF), defined as the number of fractures per meter, has recently been used to apply RQD information. Some researchers (Fowell & Johnson, 1991) argue that the RQD can lead to misinterpretation and that FF is preferable. (Priest & Hudson, 1976) developed a formula to determine RQD, assuming joint mapping measurements are available, because core drilling data is not always available. A negative exponential distribution can be used to approximate the frequency of discontinuities, according to their findings.

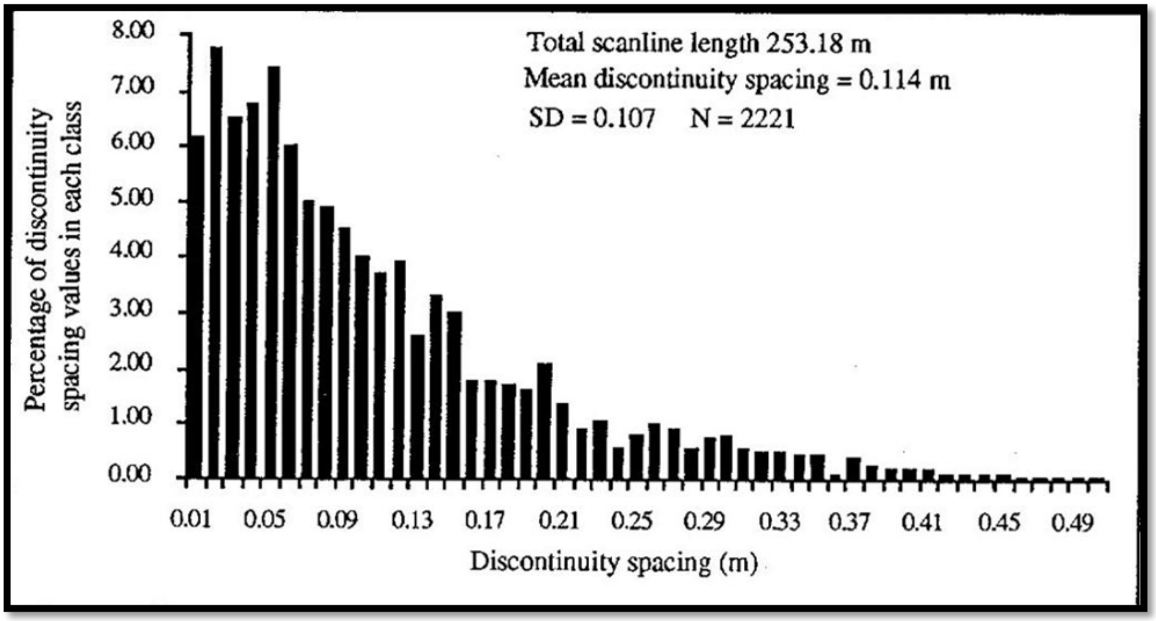


Figure 2.3: Discontinuity Spacing Histogram (Priest & Hudson, 1976)

A relationship was developed between the theoretical RQD and the average number of discontinuities per meter using the negative exponential distribution of discontinuity spacing values, such that:

$$\text{RQD} = 100\, e^{0.12ƛ} \ (0.1ƛ + 1) \qquad [2\text{-}3]$$

Where:

RQD = Rock Quality Designation

ƛ = Mean discontinuity frequency per meter.

The RQD values acquired using both approaches are typically in good agreement. This good agreement, according to (Priest & Hudson,1976), is a measure of how closely the discontinuity spacing values follow a negative exponential distribution in each site, not a validation of equation [2-3]. The lack of attention paid to such aspects as joint tightness, orientation of discontinuity, continuity of discontinuity, and nature gouge material, according to (Coon, R.F and Merrit, A.H, 1970), is one of the limitations of utilizing RQD as a rock mass measure.

2.3.3 Spacing of Discontinuities

Discontinuity spacing is defined as "the perpendicular distance between two successive discontinuities along an arbitrary sampling line, called scanline, and is sometimes referred to as the intact length," according to (Priest & Hudson, 1976) and (Eissa and Sen, 1991). (Priest & Hudson,1976) stated that a scanline of at least fifty times the mean discontinuity spacing is required to estimate the number of discontinuities per meter with reasonable precision, whereas (ISRM, 1981) stated that the scanline should preferably be greater than ten times the estimated spacing depending on the main goal of the mapping.

It is critical to recognize, according to (Pries, 1993) that there is no commonly accepted standard for scanline sampling. As a result, it's important to modify the details technique to suit local rock conditions and the objective of the work. (Attewell, 1993) recommends that discontinuity spacing data be given in a standard classification format, as shown in Table 2.1 which is comparable to the guidelines of (ISRM, 1981).

Table 2.1: Classification for Joint Spacing (Attewell, 1993)

Description	Planar structures	Spacing
Very wide spaced	Very thickly bedded	> 2 m
Widely spaced	Thickly bedded	600 mm - 2 m
Moderately widely spaced	Medium bedded	200 mm - 600 mm
Closely spaced	Thinly bedded	60 mm - 200 mm
Very closely spaced	Very thinly bedded	20 mm - 60 mm
	Thickly laminated (sedimentary)	6 mm - 20 mm
	Narrow (metamorphic and igneous)	6 mm - 20 mm
	Foliated, cleaved, flow-banded, etc. Metamorphic	6 mm - 20 mm
Extremely closely spaced		<20 mm
	Thinly laminated (sedimentary)	<6 mm
	Very closely foliated, cleaved flow-bended, etc. (metamorphic and igneous)	<6 mm

According to (Fowell & Johnson, 1991), in strong strata, allowing blocks to drop from the face can double excavation rates, and discontinuity spacings of less than 300 mm are required to make excavation rates independent of intact rock properties. In strong strata, allowing blocks to drop off the face can double excavation speeds. Additionally,Gehring asserted that cutting in highly jointed rock mass can yield three times the output of solid rock and that only discontinuity spacings of less than 100 mm had a major impact on the performance of road headers (F-6A, AM-50, AM-100). However, Braybrooke, concluded that the average peak cutting force rapidly decreases as joint frequency increases when excavating in a jointed rock mass.

2.3.4 Condition of Discontinuities

The orientation, spacing, surface roughness, infilling, and weathering of joints and/or cracks, are widely acknowledged as being among the parameters for the classification of rock masses. Faults and fractured zones, which generally comprise joints and cracks, are distributed throughout the rock mass. However, the distribution of joints and cracks within the rock mass is generally uniform, and the characteristics of the rock mass rely heavily on discontinuities like joints ((JICA), 2018).

2.3.5 Groundwater Condition

The inflow of groundwater into tunnels is a massive problem in engineering design. In fact, groundwater inflows are a common problem for tunnels, especially those constructed below the groundwater table, both during construction and occasionally even after. These inflows, which are typically viewed as unusual geological dangers, generate instability in the rocks that surrounding tunnels and cause significant harm, including injuries, fatalities, and huge economic costs. The operation and design of tunnels are said to be significantly influenced by groundwater conditions. Therefore, it is crucial to accurately estimate or evaluate groundwater inflows (Wadslin et al, 2021).

2.3.6 Orientation of Discontinuities

A measurement convention for describing the orientation, or attitude, of a planar geologic structure is strike and dip. The direction of the line created by the intersection of a fault, bed, or other planar feature and a horizontal plane in geology is called strike. Strike indicates the attitude or position of linear structural features such as faults, beds, joints, and folds. However, dip defined as the steepest angle of descent of a tilted bed or feature relative to the horizontal plane, and is represented by a number of degrees (0° - 90°) and a letter (N, S, E, W) indicating the rough direction of descent. Another method is to take a strike that dips 90 degrees to the right of the strike. According to the right-hand rule of geology, the redundant letter that follows the dip angle is deleted when this approach is employed for depiction. The sign is a short line that is tied to the strike symbol and points in the direction where the flat surface is sinking down on the map.

2.4 Point Load Test Index

In terms of project planning and designing, the classification of rock masses is crucial. The feasibility and initial design stages of a project provide minimal information about the rock mass. There were attempts to use empirical, observational, and experimental techniques to learn more about the rock mass. Experimental method which are the most popular and reliable ways to characterize the rock mass inexpensive and used for tested strength of rock are the point load index (PLI) and uniaxial compressive strength (UCS) (Akbay & Altindag, 2020).

This study's objective is to figure out a rock's strength index. This method worked well and efficiently, according to (Broch, 1972). Broch adds that, prior to the common point load test, numerous other test types had been rejected for technical reasons, such as the inability of some test types to correctly identify the factors that determine a material's strength. Broch added that compared to earlier types of tests, point load tests are more tolerant of abnormalities in core sampling. He claims that the specimen's shape affects the strength values. Point load tests can therefore be adapted to fit the shapes of samples that are typically accessible, such as core samples or irregular lumps.

PLI is most commonly used in the indirect estimation of UCS. The indirect estimation of UCS is where PLI is most frequently used. In order to predict UCS as a function of PLI, a number of researchers have conducted investigations, and more than 100 equations connecting two factors have been developed (Akbay, 2018). To predict the UCS values, the PLI values of the rock must be multiplied by a wide range of coefficients, from 3 to 71. Bieniawski, Broch and Franklin study about the relationship of UCS and point load strength which can be expressed as:

$$\text{UCS} = (K)\ Is_{(50)} = 24\ Is_{(50)}.$$

Where K is the "conversion factor"

The advantages of this tests are it only need small machine because it uses small forces or loads that need to applied to the specimen. Besides, more tests can be made using the same cost although the specimen conditions are diverse. The only drawback of this method is that it requires machining of the core samples to be performed. Broch further argues that the point load test is influenced by the samples' geometrical measurements or qualities. He states that a point load test can be performed in four (4) different ways which are:

a) Diametral test
b) Axial test
c) Block lump test
d) Irregular lump test

2.4.1 Diametral test

The failure load P is independent of core length in the Diametrical point load test if the distance L is sufficiently large (Broch, 1972). He further claims that if this requirement is met, the strength index is unaffected by the end faces' uneven geometry. This means that the end faces of the Diametral point load test do not need to be cut as indicated in Figure 2.4 below.

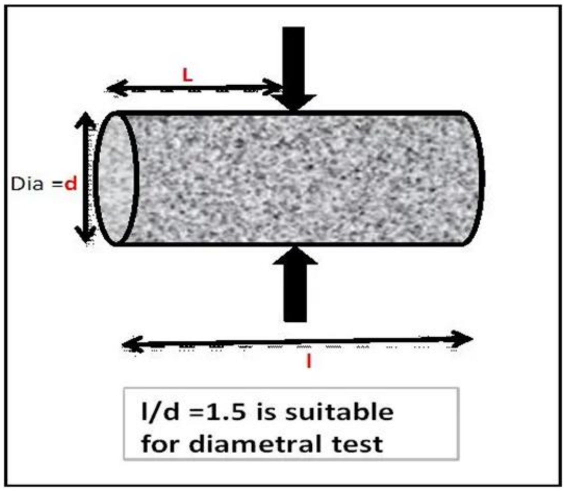


Figure 2.4: Diametral Test Specimen after (Suryakanta, 2014)

2.4.2 Axial Point Load

The cylindrical samples used in the axial point load test have a relatively short length. The specimen must have a length and diameter ratio that falls between 0.3 and 1.0. The specimen is placed so that its core axis and loading platens are parallel. Before starting the test, the distance between the contact sites is measured. Figure 2.5 shows the general arrangement of an axial PL test.

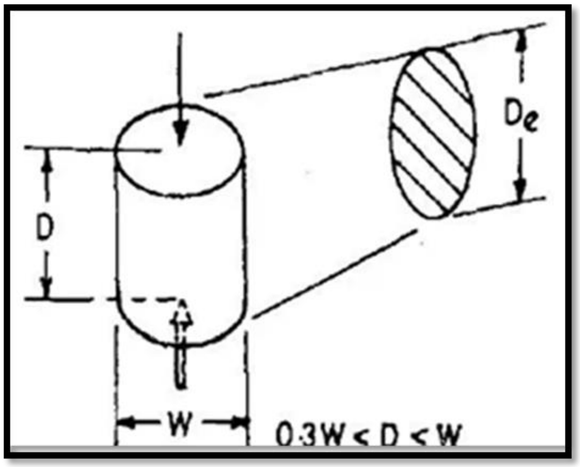


Figure 2.5: Axial Test Specimen after (Suryakanta, 2014)