ROCK MASS SURFACE ROUGHNESS CHARACTERIZATION USING IMAGE ANALYSIS TECHNIQUE

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USING IMAGE ANALYSIS TECHNIQUE

by

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ABSTRAK

Pekali kekasaran ketidakselanjaran (JRC) sangat penting untuk menentukan kekuatan ricih batu, misalnya, sebagai salah satu input untuk model Barton-Bandis. Secara konvensional, profilometer sisir Barton banyak digunakan di lapangan tetapi beberapa masalah berkaitan dengan aksesibilitas, intensif buruh, dan memakan masa. Untuk mengatasi masalah ini, kajian ini bertujuan untuk menilai teknik fotogrametri dalam menghasilkan pengukuran JRC yang boleh dipercayai. Untuk mencapai ini, satu set replika JRC jisim batu dihasilkan untuk menentukan bacaan JRC. Sebagai tambahan, drone digunakan untuk mengambil gambar model JRC dengan kualiti tinggi sebagai kaedah fotogrametri Kenderaan Udara Tanpa pemandu (UAV). Kebolehpercayaan langkah-langkah tersebut bergantung pada beberapa parameter seperti jumlah gambar, kualiti gambar, dan jumlah awan titik. Digitalisasi model JRC akan dilakukan untuk membuat model 3D menggunakan fotogrametri. Hasil pengukuran JRC dibandingkan dengan kaedah profilometer sisir Barton manual. Kemudian, jisim batu sebenar digunakan untuk mengesahkan teknik fotogrametri. Hasilnya, JRC model 3D dapat dihasilkan dengan menggunakan teknik analisis gambar. Kualiti ultrahigh mempunyai ukuran yang paling tepat sebagai panjang sebenar dengan ralat sifar peratus dan hampir sama dari segi profil. Ia menghasilkan nombor JRC yang serupa dibandingkan dengan pengukuran sebenar menggunakan sisir Barton. Bagi kualiti rendah, sederhana, dan tinggi, kesalahan masing-masing adalah 15.54%, 9.46%, 2.7%. Walau bagaimanapun, kualiti sederhana adalah cara yang paling efisien kerana dapat menghasilkan pengukuran JRC yang boleh dipercayai dalam jangka waktu yang pendek dan praktikal dapat digunakan untuk kerja lapangan.

ABSTRACT

The joint roughness coefficient (JRC) is very important to determine the shear strength of the rock, for example, as one of the inputs for the Barton-Bandis model. Conventionally, the Barton comb profilometer is widely used in the field but some issues related to accessibility, labor-intensive, and time-consuming. To tackle these problems, this study aims to evaluate the photogrammetry technique in producing reliable JRC measurements. To achieve this, a set of JRC replica of the rock mass is produced to determine the JRC readings. In addition, a drone is used to take photos of the JRC model with high quality as Unmanned Aerial Vehicle (UAV) photogrammetry method. The reliability of such measures depends on some parameters such as the number of images, image quality, and the number of point clouds. The digitalization of the JRC model will take place to create a 3D model using photogrammetry. The JRC measurement results are compared with the manual Barton comb profilometer method. Then, an actual rock mass is used to verify the photogrammetry technique. As result, the JRC of the 3D model can be produced by using the image analysis technique. The ultra-high quality has the most accurate measurement as actual length with zero percent error compared to actual measurement using Barton comb. As for low, medium, and high quality, the error was 15.54%, 9.46%, 2.7% respectively to the actual. However, the medium quality is the most efficient way since it can produce the reliable JRC measurement within a short period and can practically use for fieldwork.

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LIST OF ABBREVIATIONS

DEM	Digital Elevation Model
DSLR	Digital Single-Lens Reflex
JRC	Joint Roughness Coeffiecint
TIN	Triangulated Irregular Networks
TLS	Terrestrial Laser Scanners
USM	Universiti Sains Malaysia
UAV	Unmanned Aerial Vehicle

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The joint roughness coefficients (JRC) are significant values to consider when evaluating rock mass stability difficulties. JRC is an important indicator that characterizes the surface and strength of a jointed rock mass (Bao et al., 2020). The comb profilometer reported by (Barton & Choubey, 1977) is useful for estimating initial shear strength. However, determining the surface roughness of rock joints in situ takes time and has a limitation on accessibility (Yong et al., 2018).

To improve accuracy and obtain more roughness data over larger and potentially inaccessible areas than can be obtained by manual measurements, remote sensing techniques such as terrestrial laser scanning (TLS) and close-range photogrammetry (CRP) are also used in both laboratory and field investigations, as well as in laboratory and field investigations (Dong Hyun Kim et al., 2015). It is difficult to ignore the significant advantages of photogrammetry, such as mobility, economic feasibility, interpretation of visual information, and efficiency, it is hard to ignore the limitations of photogrammetry (Mancini et al., 2017). Furthermore, it is also advantageous that photogrammetry can produce structured color images in which exposed discontinuity surfaces may be distinguished from excavated surfaces, which can be used to differentiate between the two types of surfaces (Yong et al., 2016).

Three-dimensional (3D) photos of rock faces can provide valuable information for the classification of different rock masses. Three-dimensional (3D) laser imaging was utilized to determine surface roughness in an underground field trial (Ünlüsoy & Süzen, 2020).

Besides, the surface roughness measured manually, and the surface roughness estimated from 3D data are compared. When utilizing principal component analysis, joint orientation is first determined using the 3D point cloud data, starting at the same location as the manual observations (D. Kim et al., 2013). The Joint Roughness Coefficient (JRC) is calculated using the profile length of the greatest asperity amplitude obtained from 3D data (Kumar & Ismail, 2020).

Furthermore, one of the main advantages of image analysis method is the level of accuracy and precision can get from 3D point cloud scan. Conventional methods can't guarantee such precision because they rely on the geologist's skill and knowledge, as well as the surveying equipment's quality (Asadollahi & Tonon, 2010). To generate a surface roughness map, surface roughness measurements can be taken across the entire image digitalization and other joint properties can be efficiently assessed (Mah et al., 2013). The goal of this study is to evaluate whether photogrammetry can produce reliable JRC readings that can be used to assess slope stability.

1.2 Problem Statement

The surface roughness of rock discontinuities is a significant element in determining the rock mass's strength characteristics. Joint roughness coefficient (JRC) is a widely used term to determine the parameter for discontinuities of the shear strength of the rock and it is commonly measured using Barton's combs in the field. This conventional method of assessment, however, is labour-intensive, limit of accessibility and time-consuming. In comparison, the photogrammetry technique may be used to get reliable measurements of the JRC. However, the reliability of such measures depends on some parameters such as the number of images, image quality, and the number of dense point cloud.

Besides that, manual measurements are prone to being subjective, resulting in overestimation. To address this issue, remote sensing techniques such as photogrammetry can be used to drastically reduce survey time while also lowering risk. Even though it is a relatively new technique, it has already been used to characterize slope geometry and provide partial information for slope stability assessments (Ferrero et al., 2011).

JRC values of slope discontinuities can be generated by high resolution 3D digital models developed from this method (Poropat, 2009). Using high-resolution digital photographs, photogrammetry can be map and characterize the kind and geometry of rock discontinuities (H. Guo, 2011). However, the accuracy of JRC values produced using photogrammetry can be a problem because they are highly dependent on image quality, and an error can develop owing to data spatial density (Haneberg, 2007). The photogrammetry technique was used to digitalize 3-D point clouds of the rock mass surface roughness replica, which is subsequently confirmed using Barton's comb method.

1.3 Objectives

The aim of this study is to evaluate the reliability of image processing technique in determining the joint roughness coefficient (JRC) by verifying with Barton Comb method manually. The objectives of the modelling study are as follows:

1. To develop a set of joint roughness coefficient (JRC) model of the rock mass using 3D printing technology.
2. To determine the joint roughness coefficient (JRC) rock mass replica using photogrammetry technique.

3. To compare the JRC measurement results using photogrammetry technique with manual Barton Comb method.
4. To verify the photogrammetry technique with actual rock mass.

1.4 Scope of Work

1. Determine the joint roughness coefficient (JRC) categorization from 2 to 20 using photogrammetry technique.
2. 3D printed models shall be within the dimension of 160mm x 60mm x 20mm by using Anycubic i3 Mega printer.
3. Digitalization using Agisoft Metashape analysing software to produce point clouds to generate 3D model.
4. Use of Barton Comb (profilometer) to measure joint roughness coefficient (JRC) manually.
5. Verification of photogrammetry technique using actual rock mass.

1.5 Dissertation Outline

The thesis paper has been categorized into several chapters for a better understanding of this study. Hence, this paper contains five chapters.

Chapter 1: This chapter explains the basic essence of the research and offer an outline of the contents of this study. This chapter outlines the philosophical context for what the researcher will study, including the scientific problems, theories, and basic research structure.

Chapter 2: This chapter establishes a well-documented review for the analysis of research topics, and to formulate a research methodology. This chapter sets out the theoretical context for the thesis and outlines the topic, the basic research problem, the question(s) and the design elements.

Chapter 3: This chapter contains the methodology framework of the study. In further depth, study technique, the data collection processes, the research procedure, the form of data analysis and the research constraints of the project are explained in this chapter.

Chapter 4: The aim of this chapter is to summarize the data obtained, interpret the data, and report the findings. This part of Chapter 4 determines the problem statement, analysis, discussion and the comparison of results then makes a statement as to what will be discussed in this chapter.

Chapter 5: This chapter concludes the study based on the objective specified. In this chapter, assumptions, connotations, and recommendations will be made.

1.6 Expected Outcome

The joint roughness coefficient (JRC) can be measured from Metashape analysis software and then compare with manually measurement using Barton's comb method to verify the image analysis method. By using the photogrammetry method, the discontinuity of the rock mass shall be digitalized from the 3D-printed model by designing the model based on JRC category.

1.7 Importance and Benefits

The benefit of the photogrammetry technique is the time taken to collect partial data of rock discontinuity can be reduced. Moreover, it guaranteed the safety of geologists in the field due to the limitation of accessibility of the dangerous area. Then, the cost for photogrammetry method is quite reasonable due to its efficiency in determining the joint roughness coefficient (JRC) measurements.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Chapter

Since the Joint Roughness Coefficient (JRC) was developed by Barton and Choubey, it has been widely used in the analysis of rock slope stability. The conventional method of calculating JRC has been to compare the surface of discontinuities to the roughness profiles (Barton & Choubey, 1977). Although time-consuming, this mapping process quite often involves significant risks during field work, which makes it an unfavourable option.

On top of all that, manual measurements have a high likelihood of being subjective, leading to an overestimation. As a solution to this problem, remote sensing techniques such as photogrammetry can be used to reduce survey time while also lowering risk (Cai et al., 2018). It has already been used to define slope geometry and provide important details for slope stability assessments despite the fact that it is a relatively new technique. High resolution 3D digital models derived from this method can be used to generate the JRC values of slope discontinuities (Ferrero et al., 2011). However, because JRC values obtained through photogrammetry are highly dependent on image quality, and an error can occur due to data spatial density, the accuracy of JRC values obtained through photogrammetry can be a problem.

2.2 Image Analysis

The process of obtaining useful data from photographs, mainly digital photos, using image processing techniques is known as image analysis. Reading barcoded tags to detecting a person based on their face are just a few examples of image analysis tasks (Solomon & Breckon, 2011).

A new method is proposed for 3-D auto mapping of joints detected mostly as traces in a rock face rather than planar surfaces. The method is used to generate 3-D points in a photogrammetry or LiDAR-derived point cloud that meet the joint traces in image data. The 2-D trace texture is extracted from picture data using a combined global and local threshold approach, which is then integrated with a series of image-processing algorithms. Second, data matching links the image pixel positions that correspond to detected traces to the 3-D coordinates of the point cloud. A coordinate transformation between the image coordinates and the point cloud coordinates is used to achieve this matching. Finally, a 3-D discontinuity trace map is used to determine the traces' 3-D spatial properties (Zhang et al., 2019). When compared to previous methods that exclusively use point cloud data, the findings suggest that integrating image and point cloud data enhances the mapping of discontinuities that largely occur as traces in outcrops (Ge et al., 2015).

2.2.1 Photogrammetry

The advancement of computer vision technology, as well as the increased availability of new platforms with ultra-high-resolution sensors, has paved the way for research in engineering geology in general, and landslide identification and classification in particular (Karantanellis et al., 2020). They are recognised as leading platforms for site-specific 3D modelling because to their benefits of detailed data gathering at a cheap cost and effective performance. To fully use the generated data, a methodology based on Object-Based Image Analysis (OBIA) and the integration of multivariate data arising from UAV photogrammetry processing was generated.

Photogrammetric techniques correctly determine the geometric features of the Earth's surface from photographs obtained by remote sensing platforms. Objects' size, form, and location are all measured remotely, as are their colour or tone, texture, and spatial patterns and connections. As a result, geoscientific information and geometric structures can be used to interpret and analyse such observations. Photogrammetry techniques are used to produce maps and digital elevation models (DEM) using remote sensing data (Schmidt et al., 2007). Orthophotographs, photomosaics, site cross-sections and preparation of vector data are among the other responsibilities. For decades, most aerial photogrammetric products have been in use. These broad experience have led to standards and guidelines that ensure the quality and consistency of the mapping products (Dawson et al., 2017).

Three JRC measuring methods were used to assess the influence of surface roughness on slope stability.

- **Aerial Photogrammetry**: Imagery acquired by UAVs in the air is used to produce 2D and 3D computer generated models. These models are topographical in nature and accurately depict the size and physical aspects of the region. These models are rotatable and can be zoomed. Since they are entirely created from images from the real locations as recorded by a UAV, they show each last detail in the photographs. A machine is attached to the cameras, particularly an aircraft or a drone such as Unmanned Aerial Vehicle (UAV). It can thus capture pictures from the upper surface. The greater the number of images, the more accurate the statistics are. It also helps to compare the quality. The aircraft fly over the planned area with certain landmarks to be captured. The aircraft speed regulates the camera's capture speed.

They also know the height of the plane from the surface of the earth (Uysal et al., 2015).

- **Terrestrial Photogrammetry**: The word Terrestrial means Earth-related. It explains why the camera is in this 12-photogrammetry stationary position. The position of the camera is increased and the angle of tilt, the focal length of the lens is regulated (Uysal et al., 2015).

- **Close Range Photogrammetry**: CRP (closed range photogrammetry) is the collecting and processing of photogrammetric data from a distance of less than a million feet. Both ground and aerial methods may be collected and the final output can be rendered two or three-dimensional. New technical challenges are demanding innovative (Hybrid) sensor systems such as automated navigation or aerial vehicle, a wide range of imaging devices available for closest photogrammetry purposes (Ma et al., 2019).

2.2.2 Light Detection and Ranging (LiDAR)

Remote sensing technologies like as photogrammetry and digital image processing have been demonstrated to improve productivity and worker safety in rock engineering investigations. The effectiveness of terrestrial Light Detection and Ranging (LiDAR) for detecting fracture and bedding plane orientations is compared to conventional techniques (Jaboyedoff et al., 2012). A three-dimensional digital point cloud is created by the creation of tightly spaced data points over a surface using reflected laser pulses. A few of the benefits are simple operation, digital storage and extraction of site data, the capacity to gather data in difficult places, and the ability to scan in any lighting situation (Dove et al., 2008).

The Figure 2-1 shows the different sensors and scanning mechanisms involved in the collection of LiDAR data. The fundamentals of airborne LiDAR mapping are simple. A straight beam manager, which scans the laser pulses over a swath of terrain that is typically oriented on and co-linear with the flight path of the aircraft in which the system is installed, is attached to an optically pulsed laser (Muhadi et al., 2020). The round trip durations of the laser pulses from the plane to the ground are monitored using a precision interval timer, and the time intervals are translated into range measurements using the speed of light as a reference (Hu et al., 2012). The process of computation of ground coordinates is shown in the flow diagram in Figure 2-2.

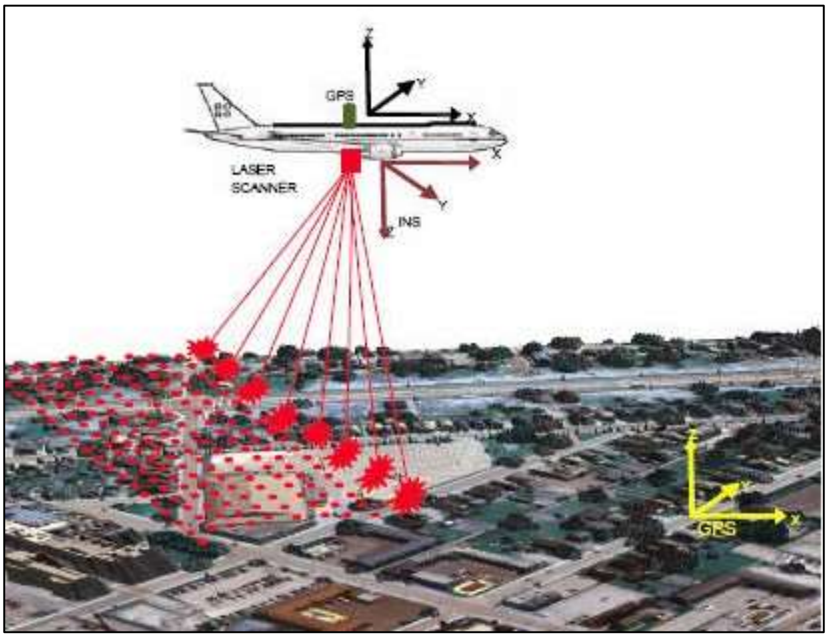

Figure 2-1 Principle of topographic LIDAR

(Source: Muhadi et al., 2020)

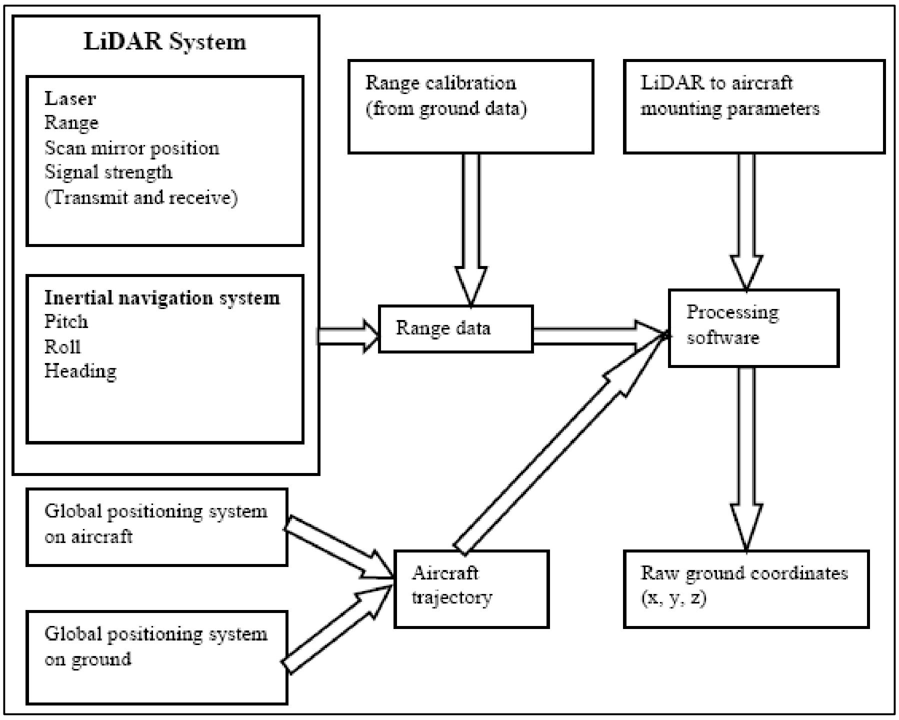

Figure 2-2 Flow diagram showing various sensors employed in LiDAR instrument and the computation steps

(Source: Muhadi et al., 2020)

Since LIDAR is a sensing system, data collection is significantly quicker and more precise. This is because of the position benefit. LIDAR has the lead when compared with other methods used in data collecting when it comes to higher sample density. This can improve the results of some applications. LIDAR technology also has high penetration capabilities. It can therefore easily map and collect the required elevation data from densely forested areas (Zhang et al., 2019). LIDAR technology includes an active lighting sensor. For this reason, the light variation of day and night cannot be affected. That's how it works. Lidar also did not suffer from extreme weather conditions. The working of LIDAR technology does not interfere with extreme weather conditions. Data may still be collected and returned for analysis under the sunlight. Last but not least, additional data are available which can be useful. In fact, the amplitude of the return energy can be observed by LIDAR. In this scenario, a data point's reflection value is recorded (Guyot et al., 2018).

On the opposite. It's costly. LIDAR is needed if data needs to be collected in large regions of land. It may not be worth it if it's just a minor job. In weather condition like heavy rain, LIDAR pulses may not be effective. This is because the whole process is affected by refraction (Bandini et al., 2020). In addition, LIDAR technology usually collects too many data types that require competition processing and analysis. It could therefore take a while before all the data are analysed. LIDAR generally collects large and complex data sets. This is why the analysis of data requires skilled techniques, which can make the costs even reasonable. This method works only at elevations below 2000 m and the pulses in higher level do not work (Dawson et al., 2017).

2.2.3 Laser Scanner

Over the last 10 years the dominant technique for obtaining 3 D data on complex vintage monuments is terrestrial laser scanners (TLS). The technology provides high rates of capture and geographical data density. As a graphic representation of the object 3D scanners produce a point cloud, determined by the instrument's distance from the thing (Alshawabkeh et al., 2020). Even though many 3D coordinates on the surface of an object are measured quickly, 3D scanners are also known to produce edge errors. Varied 3D scanners have various angles and size increases and are therefore not able to work out small details of objects. Additionally, the range scanner's achievable accuracy is limited by the acquisition distance and occlusions (Pagano et al., 2020).

Images can be read simply from different angles, unlike terrestrial laser scanning, which requires relatively high technology installation. Photogrammetry Image-based modelling has evolved into an effective and precise method in collecting data without contact in applications of culture and heritage. Compared to discrete measuring techniques, photogrammetry has many advantages (Ge et al., 2015).

2.3 Constitutive Model

For numerical modelling of the behaviour of joint rocks, the building models for joined rock masses are important. Many models are founded on empirical and theoretical approaches for rock joints (Xu et al., 2015). Depending on their size, the behaviour of the joints is based on the roughness of the surface.

2.3.1 Mohr-Coulomb Model

A number of linear equations are used for the Mohr-Coulomb (MC) failure criterion in the main stress zone. It defines conditions under which an isotropic material fails and neglects any effect of intermediate principal stress σII. MC can be expressed as a function of the failure plane's major σI and minor σIII principal stresses, or normal stress r and shear stress s. The condition of Mohr is premised on the idea that failure is mostly determined by σI and σIII. The shape of a failure envelope might be linear or nonlinear, as it occurred on a failure plane (Labuz & Zang, 2012).

Coulomb, in his investigations, proposed the relationship where S_o is the inherent shear strength as cohesion c, and Φ is the internal friction angle with internal friction l = tan Φ. The equation (1) on the Mohr graph is represented by a line inclined to the r-axis with angle Φ as shown in Figure 2-3 (Labuz & Zang, 2012).

$$\lfloor \tau \rfloor = S_o + \sigma \tan \Phi \quad (1)$$

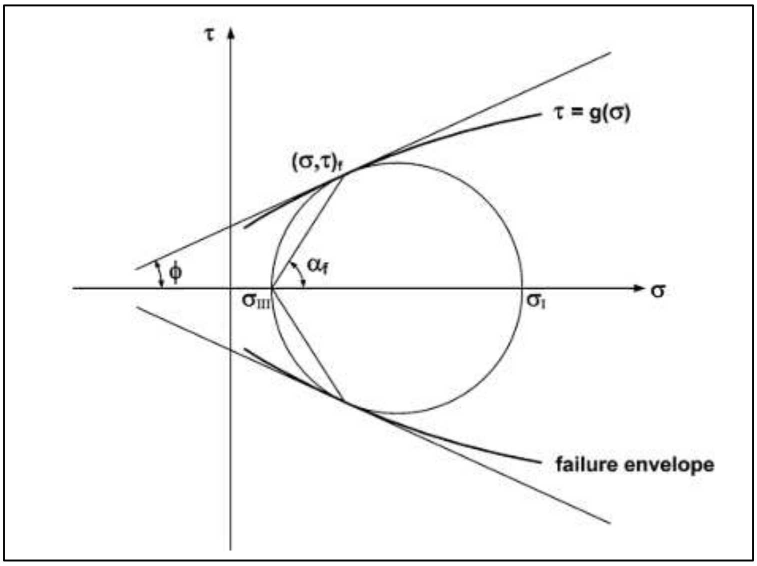

Figure 2-3 Mohr diagram and failure envelopes

(Source: Labuz & Zang, 2012)

This model type is suitable for jointed rocks comprising up to three arbitrary joints, especially with a usually large geographical distribution. The equivalent compliance matrix of the rock mass mostly is established. The Mohr-Coulomb is especially utilised to test the failure properties of an entire rock and the joints for all uses and purposes. It indicates mainly that the rock mass' corresponding matrix of compliance is established. The specific yield criterion Mohr-Coulomb is normally employed to control the failures of the complete rock and joints that are actually important. (Chang & Konietzky, 2018).

Many applications require knowledge of failure or frictional sliding under various conditions of stress. These include reservoir modelling or rock behaviour and assessing distant loads from the geometry of borehole breakdown. However, applying a Mohr–Coulomb failure criterion based solely on uniaxial symmetric shortening studies can result in considerable inaccuracies (Hackston & Rutter, 2016).

2.3.2 Barton-Bandis Model

$$\tau = \sigma_n \tan\left[\emptyset_b + JRC\ \log_{10}\frac{JCS}{\sigma_n}\right] \qquad (2)$$

The equation (2) provides the basic Barton equation for a rock joint shear strength where $\emptyset_b$ is the basic friction angle of the failure surface, JRC is the joint roughness coefficient, and JCS is the joint wall compressive strength. The Barton Bandis failure criterion is a frequently used empirical formula for modeling the shear strength of rock discontinuities. It is quite useful for assessing a strength model in the field or laboratory to test discontinuities. Barton-Bandis is a non-linear criterion that connects shear strength to normal stress (*Barton-Bandis Criterion*, n.d.).

2.4 Shear Strength of Discontinuities

It is of considerable relevance to analyse the stability of rock mass engineering, which is greatly influenced by the scale effects caused by the length and the ondulate amplitude of discontinuities. An enhanced shear strength criterion with simultaneous size and shear rate was proposed. There is a benefit of dimensional unity in the new shear strength criteria compared to prior empirical equations (Zheng et al., 2020).

2.4.1 Barton's Estimation of Shear Strength

$$\tau = \sigma_n \tan[\emptyset_b + i] \qquad (3)$$

Equation (3) applies for small normal loads and shear displacement caused by sliding along sloped surfaces. At larger normal loads, the strength of the intact material is exceeded, and the teeth start to break off, resulting in shear strength behaviour. It is closer to the intact strength of the material than to the frictional properties of the surfaces (Hoek, 2007).

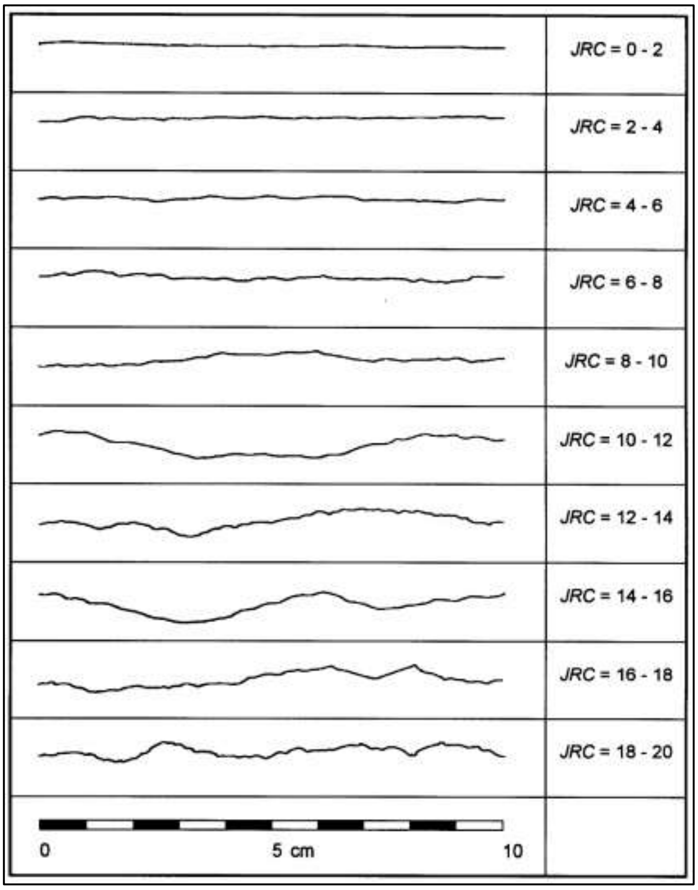

Figure 2-4 Roughness profiles and corresponding JRC values

(Source: Barton & Choubey, 1977)

2.4.1(a) Joint Roughness Coefficient (JRC)

The joint roughness coefficient (JRC) is a value that can be measured by comparing the surface of a discontinuity with Barton standard profiles. Figure 2-4 shows the profile sets that released by Barton and Choubey. The surface of discontinuity is visually compared with the standard profiles given and the JRC value corresponding to the profile that best resembles that of the discontinuity surface. For small-size laboratory specimens, the surface roughness scale is generally the same as the profiles displayed (Barton & Choubey, 1977).

In the field, however, the relevant surface length may be several meters or tens of meters, and throughout the entire surface area the JRC value should be approximated. Figure 2-5 presents an alternative approach for determining JRC.

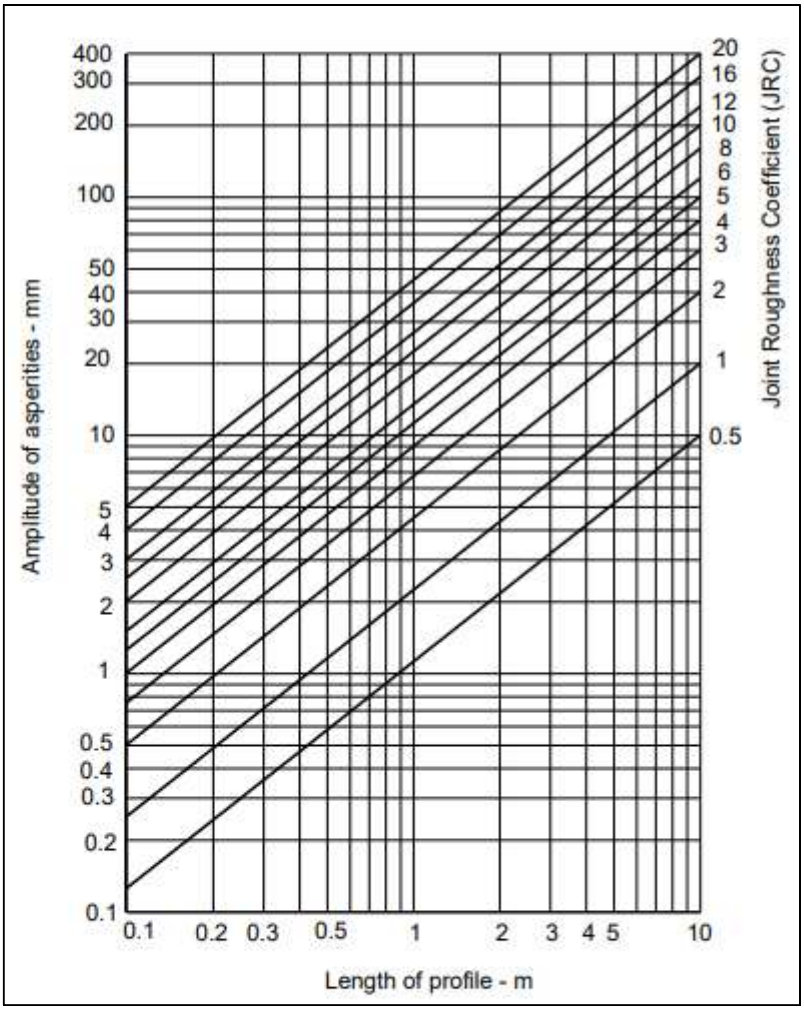

Figure 2-5 Alternative JRC Estimation

(Source: Barton & Choubey, 1977)

Besides, the shear strength of the surface will be improved by the surface roughness. The strength of the stability of excavation in rock mass will be increase significantly. The joint roughness coefficient (JRC) is the value measured by comparing the presence of the discontinuity surface with standard profiles provided by Barton and others. The deformational behaviour of rock systems is significantly influenced by the presence of rock joints. The features of joints, such as their direction, extent, planarity, roughness, and the strength of wall rock asperities, all have an impact on the behaviour of rock systems in a variety of ways. Roughness affects the friction angle, dilatancy, and peak shear strength at both small and large scales (Malik & Abdullah, 2016). Other than that, roughness is influenced either directly using the JRC in the Q system or indirectly roughness as part of the joint condition evaluation in rock mass rating (RMR) system (D. H. Kim et al., 2018).

Roughness of the rock surface can be measured in a practical way. The conventional way of taking measures has been to make direct contact with the rock, as described above. Direct approaches can give reliable and valuable data, but they are not without limitations. The use of a mechanical profilometer, often called profile comb, is one approach for assessing surface roughness. The tool consists of a line of pins that correspond to the joint face and can be traced to achieve a 2D surface profile. The 2D surface profile is often visually compared to the Barton referred roughness profiles in order to estimate JRC to define surface roughness (Mah et al., 2013).

To characterise the surface roughness of rock joints, a variety of approaches have been developed, including joint roughness coefficients (JRC), root mean square (RMS) values, structure-function (SF), and others. It is possible to determine the JRC value by performing tilt, push, and pull tests on rock samples, which scale the joint roughness range from 20 (rough) to 0 (smooth) (Li et al., 2019).

Moreover, this research is related to a computerized method for JRC quantitative evaluation. The relationship between the roughness amplitude/joint and the joint roughness coefficient was an effective method for estimating the JRC values of the different joints of a sized rock (Yong et al., 2018). Several new methods for measuring surface roughness are being developed using image analysis to replace the conventional approaches. Surface roughness of the rock mass is studied using computed tomography. Most of this study is done in the lab, allowing for controlled rock sample validation. Several outdoor field studies to quantify surface roughness have been carried out analysing image processing systems (Ge et al., 2015).

2.4.1(b) Joint Wall Compressive Strength (JCS)

Suggested methods for estimating the joint wall compressive strength were published by the ISRM (1978). The use of the Schmidt rebound hammer for estimating joint wall compressive strength was proposed by Deere and Miller (1966), as illustrated in Figure 2-6.

2.5 3D Point Cloud Model

A point cloud consists of large numbers of three-dimensional data points (with X, Y and Z coordinates). The output frequently consists of a 3D point cloud for the collection of built-in data from existing structures. A laser or sonar scanner for example can be used to collect point clouds (J. Guo et al., 2017).

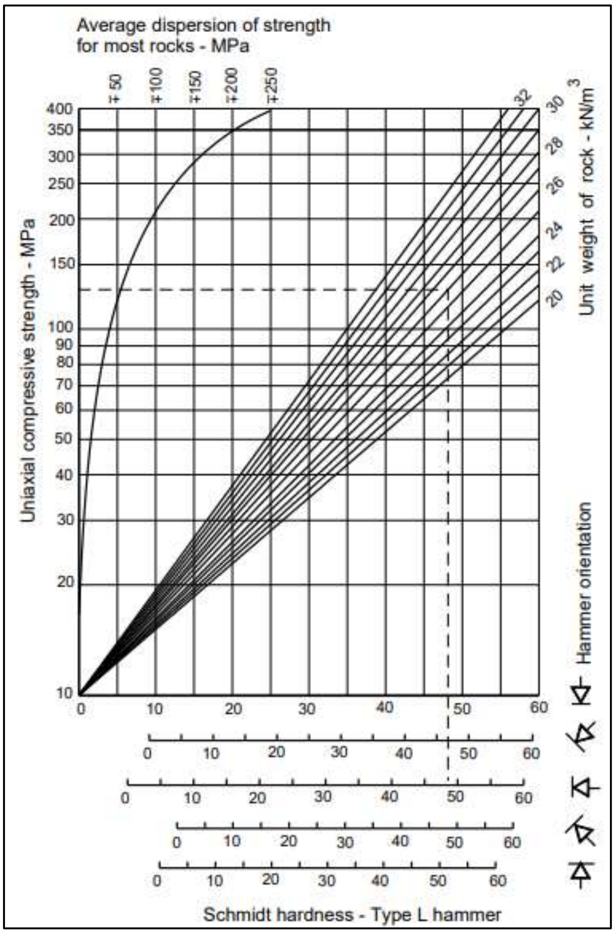

Figure 2-6 Estimate of joint wall compressive strength
from Schmidt hardness
(Source: Deere and Miller, 1966)

The use of 3D point clouds for structural analysis has become increasingly popular in the last decade, with particular growth occurring in the last decades. Using this method, you can cover surfaces that would otherwise be inaccessible using conventional methods. It is possible to analyze the global surface of a rock mass despite the limitations imposed by vegetation, humidity, or the intensity of natural light. When it comes to creating 3D point clouds, the most common techniques are light detection and ranging (LiDAR) and photogrammetry (Kong et al., 2021). Additionally, the utilization of remote sensing data to represent the surface of the rock mass using 3D point clouds is transforming conventional measuring methodologies in a variety of rock slope engineering applications (Riquelme et al., 2016).

With regards to UAV photogrammetry, while the point cloud from the UAV system provides precise geometric information, there are still a few inaccuracies in the cloud dataset. To generate continuous surface models, it takes some necessary processing. Point cloud splitting is the most critical stage in the 3D model reconstruction of point cloud pre-processing. The build-up of spliced errors and time consuming and inefficient real-time performance pose issues during point cloud splicing (Liu et al., 2019).

However, 2-dimensional photographs lose details and relative positions between two or more real-world objects. These features make 2D images less appropriate for applications that require input on depth and positioning, such as drones, autonomously driving, and virtual reality (Caudal et al., 2020). The employment of stereo vision to capture the 3D environment with detailed information, where two or more calibrated digital cameras are used to gain 3D information (Bello et al., 2020).

CHAPTER 3

METHODOLOGY

3.1 Overview of Chapter

This chapter explains the process of research and the methodologies used during the period of this research. Additionally, all techniques were chosen considering the detailed literature study, recommendations, and critical thinking mentioned in Chapter 2. The methodologies for this study are separated into four sections. The first stage of the study focuses on producing a set of JRC synthetic replication models of the rock mass using 3D printing technology. The second stage of this study taking the image of the synthetic models using the UAV photogrammetry technique. The Phantom 4 Pro was used to capture a large number of high-resolution photos of the JRC models. These images overlap such that the same point of the models is visible in multiple photos and from different points. The actual rock is used as the object for photogrammetry to determine the reliability of this method in the rock engineering field. Next, the third stage of the study was the surface analysis of the JRC models by producing a 3D model generated by vast amounts of data points in three dimensions (with X, Y, and Z coordinates) called point clouds. In addition, to build a three-dimensional map, photogrammetry uses various perspective points from multiple images, much like the human brain does to perceive depth using input from both eyes. Finally, the fourth stage was verifying the JRC measurement results using the photogrammetry technique with the manual Barton's comb method. Figure 3-1 outlines the overall methodology used in this study.

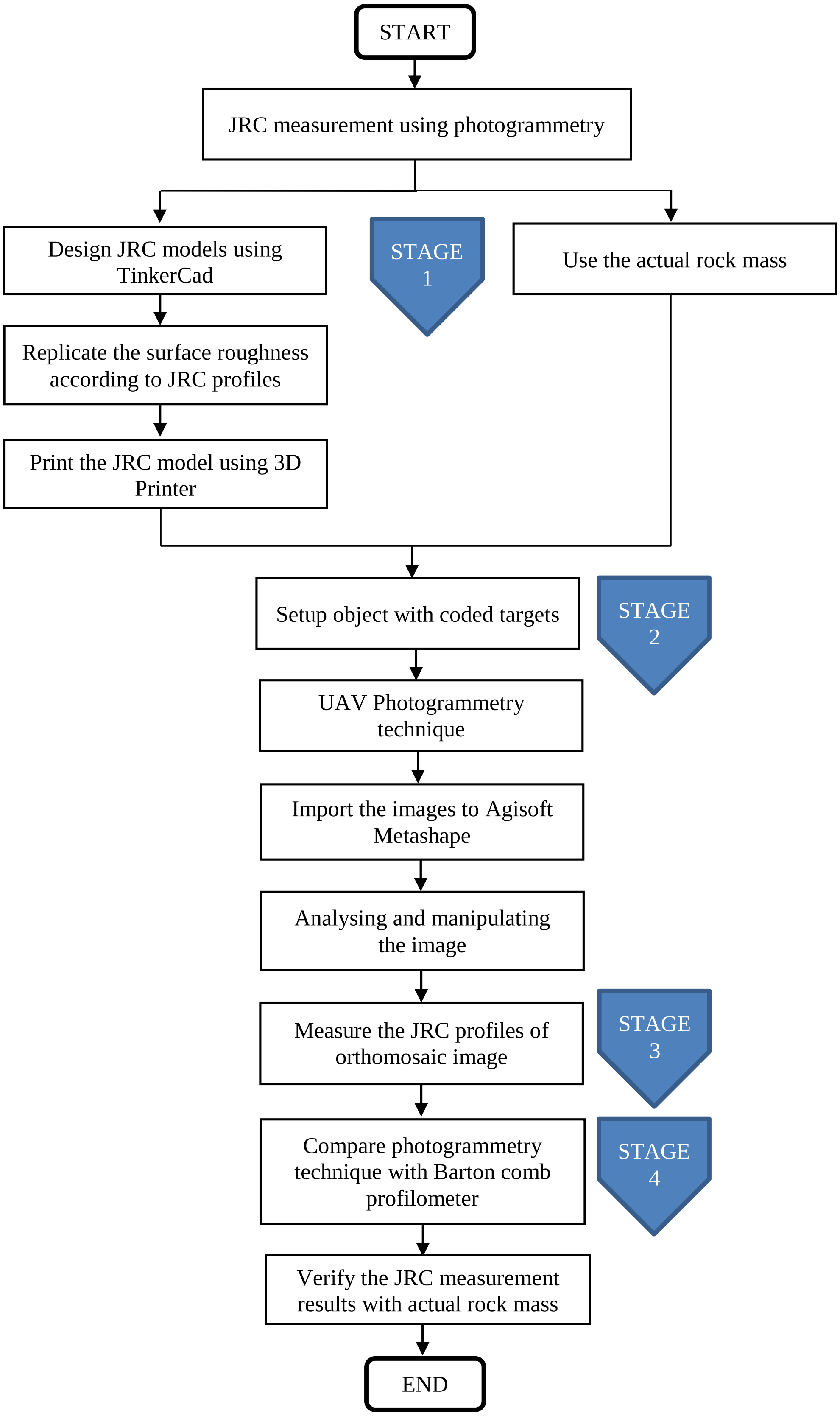

Figure 3-1 Methodology flowchart of the research

3.2 Production of the JRC Model

An actual physical representation of the 3D model can be made by using 3D printing equipment(Uysal et al., 2015), which constructs two-dimensional layers of the model with three-dimensional material one layer at a time. It is possible to create 3D Models either automatically or manually. A process similar to plastic arts such as sculpting, the manual modelling process of preparing geometric data for 3D computer graphics is similar to sculpting.

3D models are now being used in a wide variety of fields, including architecture and engineering (Jaboyedoff et al., 2012). For example, detailed rock models are used in the geotechnical field, and these models are created using multiple 2-D image slices. It can be obtained from a digital single-lens reflex (DSLR) camera, a light detection and ranging (LiDAR) scanner or an unmanned aerial vehicle (UAV) photogrammetry system. The process of creating a 3D model is depicted in Figure 3-2.

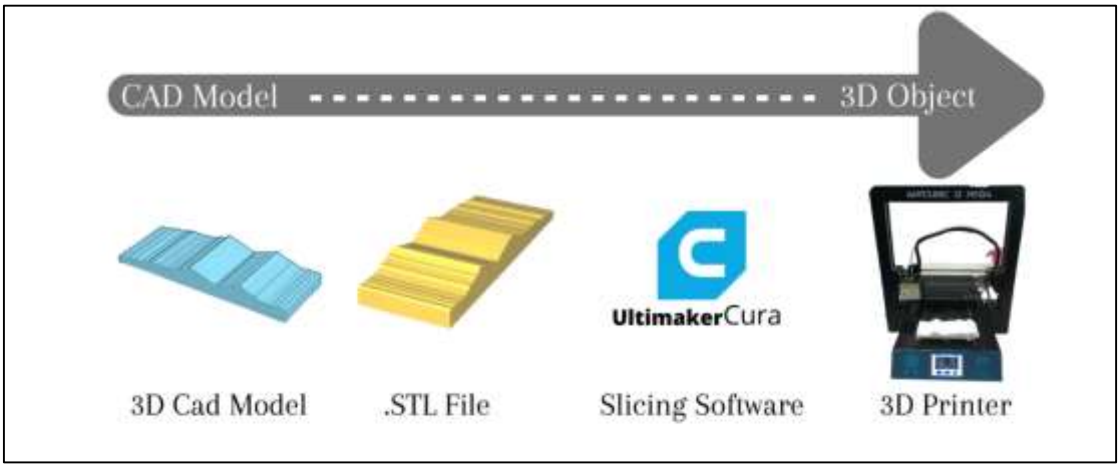

Figure 3-2 Process to create 3D model

3D Cad Model: TinkerCad is an online set of Autodesk software tools that allow full setup to construct 3D models. Users can make complicated models by merging simple components using constructive solid geometry (CSG).