ASSESSMENT OF UAV-PHOTOGRAMMETRIC MAPPING ACCURACY BASED ON DISTANCE VARIATIONS

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UNIVERSITI SAINS MALAYSIA

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ASSESSMENT OF UAV-PHOTOGRAMMETRIC MAPPING ACCURACY
BASED ON DISTANCE VARIATIONS

By

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of the requirements for the degree of Bachelor of Engineering with Honours
(Mineral Resources 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 “Assessment of UAV-Photogrammetric Mapping Accuracy Based on Distance Variations”. I also declare that it has not been previously submitted for the award of any degree or diploma or another similar title for any other examining body or University.

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Date : 5/7/2019

Witness by

Supervisor : Dr Hareyani Binti Zabidi Signature:

Date : 5/7/2019
ACKNOWLEDGEMENT

Alhamdulillah to Allah the Almighty whom willing giving me opportunity to complete this Final Year Project entitled “Assessment of UAV-Photogrammetric Mapping Accuracy Based on Distance Variations” within the time. The final year project was prepared for this course requirement for the undergraduate programme.

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Furthermore, I would like to thank master and PhD students that helps us on guiding our project on quarry site and share their experience on manual mapping and photogrammetry mapping at the worksite. Besides, I also want to thank all my family and friends that never stop supporting me from earlier until the end of this project. Your prayer for me was what sustained me thus far. Finally, this thesis is dedicated to the my loving parents for the vision and determination to educate me. This piece of victory is dedicated to both of you. For those who contribute and share some ideas for my project, I really appreciate and may Allah bless on that kindness with His grace.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAV</td>
<td>Unmanned Aerial Vehicle</td>
</tr>
<tr>
<td>UAVDP</td>
<td>Unmanned Aerial Vehicle Digital Photogrammetry</td>
</tr>
<tr>
<td>2D</td>
<td>Two Dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>Three Dimensional</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>DSE</td>
<td>Discontinuity Set Extractor</td>
</tr>
<tr>
<td>GCP</td>
<td>Ground Control Point</td>
</tr>
<tr>
<td>txt</td>
<td>Text</td>
</tr>
</tbody>
</table>
ABSTRAK

ASSESSMENT OF UAV-PHOTOGRAMMETRIC MAPPING ACCURACY
BASED ON DISTANCE VARIATIONS

ABSTRACT

This project focuses to study the structural geology properties of limestone and to determine the most effective distance variations for UAV mapping. The study area are located at two (2) different quarries which are Hume Quarry and CIMA Quarry. One window for every quarry with difference distances of 10 and 15 meter. The most common technique used to generate highly detailed DOMs are laser scanning and digital photogrammetry. Digital photogrammetry enables high resolution acquisition data with lower cost and more user friendly survey planning. By using UAV photogrammetry, the appropriate distance for every data is between 5-15 meter. The great advantage of actual UAV systems is the ability to provide a detail information to allow 3D photogrammetry to be modelled as the photo contains a coordinate which increase the accuracy for data collected. To analyze the photogrammetry method and to understand the criteria needed for geological mapping, an Unnamed Aerial Vehicle (UAV) was used for geotechnical mapping while Agisoft Photoscan, Discontinuity Set Extractor (DSE) in MATLAB software and CloudCompare were used to analyze the photogrammetry method before compared with manual mapping. It is believed that the difference of dominant joint and orientations shown in both method is due to that the software used difficult to detect the joint because lot of disturbance. There are some slope face that covered by soil. Both result from UAVDP and manual mapping show in agreement with each other. In conclusion, data extracted from DSE at 10 meter distance is more accurate than 15 meter distance. If the distance of drone and quarry face is far, the resolution of images will become lower which can affect the selection of discontinuity joint sets.
1.1 Research Background

In the past twenty years, the remote sensing investigation applications for the construction of the Digital Outcrop Model (DOMs) (Powers et al., 1996) have rapidly increased (Tavani et al., 2016). Rock discontinuities mapping is not important only for geological studies such as geological structure and mechanical rocks but also for engineering and industrial applications such as slope stability, tunnels, quarries, CO\textsubscript{2} and nuclear waste storage, oil and gas exploitation. Therefore, the acquisition of accurate quantitative discontinuity data, which are not affected by biases and censoring is very important.

The most common technique used to generate highly detailed DOMs are laser scanning and digital photogrammetry. While laser scanning can be very expensive and requires complex survey planning (heavy and bulky equipment), digital photogrammetry enables high resolution acquisition data with lower cost and more user friendly survey planning (Westoby et al., 2012). Developments in RGB cameras and Unmanned Aerial Vehicle (UAV) technologies have increased the applications for UAV-based Digital Photogrammetry (UAVDP) (Torok et al., 2017).

UAVDP can be used in various of scenarios (Nex and Remondino, 2014) as shown in Figure 1.1, from meter scale to kilometer scale and from simple geometries to complex geometries. Moreover, UAVDP can also overcome the blockage effects that often affect because the UAV platform can remotely move the camera to more optimum inaccessible positions. The use of different points of view is important for the reduction
of blockage or areas that cannot be measured using UAV that are restricted to data collection from the ground.

![Diagram of different mapping techniques](image)

Figure 1.1 Applicability of different mapping techniques in relation to the outcrop dimensions and geometry complexity (modified after Nex and Remondino, 2014)

The horizontal surface adjacent to them might be as narrower than 10 meter in length, which means the camera must be placed at a very short distance from the object (Thoeni et al, 2014; Kim et al, 2016). In addition, the type of rock studied requires high resolution because of its discontinuity properties.

1.2 Problem Statement

Nowadays, high technology approach has improved the acquisition of geotechnical data to access and capture a high resolution images of rock face by means of Unmanned Aerial Vehicle (UAV) based photogrammetry. There are several techniques has been used in the mapping the distance variations of rock mass by manually. In contrast, assessment and monitoring by using UAV photogrammetry more
difficult and complicated as the information obtain needed to process by using several software before it can be completely modelled.

To get the best result from this method, usually the recommended distance between drone and rock about 10-50 meter. If the drone is too high and far from the rock, the data quality will become low resolution. Moreover, it will be difficult to get the best mapping accuracy such as crack, joint, fault and orientation (strike & dip). It will impact several data when using software.

By using UAV photogrammetry, the appropriate distance for every data is between 5-15 meter. The great advantage of actual UAV systems is the ability to acquire a high resolution image and providing a detail information to allow 3D photogrammetry to be modelled as the photo contains a coordinate which increase the accuracy for data collected. This study is to determine the most effective distance variations in UAV mapping between 10 meter and 15 meter from the rock surface. In photogrammetry, accuracy is always relative to positional accuracy, which is defined as the degree to which the information on the map created from the data captured matches the actual real world.

1.3 Study Area

The study area are located at two different quarries which are Hume Quarry Gopeng, Perak and CIMA Quarry Bukit Keteri, Perlis. Generally, the geology of the study area at Hume Quarry is predominantly underlain by the Khantan Limestone Formation. The Khantan Limestone formed during the Sillurian-Denovian age and part of the Kinta Valley Limestone bedrock. Khantan formation is generally made up of phyllite, slate, shale and sandstone.
The distance of Hume Quarry is 1.94 km away from Hume Cement Plant and main office as Figure 1.2 and topography map as Figure 1.3. Figure 1.4 shows the specific study area at Hume Quarry which label as Window A for this research. The Hume Quarry also have two more quarries which are located in Kampar and Kinta District which have limestone and granite deposit at some of the places. This company has been operating almost seven years since 2012 with integrated cement plant that utilizes ground-breaking technology. In the past few years, this quarry has stated as the ex-pond of the tin mining operation.

![Figure 1.2 Location of the study area and the distance between the main office to the quarry site](image_url)
Figure 1.3 Location of study area by topography map

Second quarry is Cement Industries of Malaysia Berhad (CIMA) at Bukit Keteri, Perlis that owned by UEM Group Berhad. CIMA is one of the leading cement
manufactures in Malaysia. Figure 1.5 shows the location of study area, Figure 1.6 shows the topography map while Figure 1.7 shows the specific study area at CIMA Quarry.

CIMA Quarry is made up of fine grained limestone. Fresh rock are light grey in colour, weathering to reddish white. Large, black coloured mottles in the rock may be impurities of either carbonaceous or intraclastic material. However, in Perlis it forms a series of karst hills aligned in two parallel belts in North-South direction stretching from Southern Thailand where the limestone is known as Ratburi Limestone (Fontaine et al. 1994) until Beseri area (Azimah 1998).
Figure 1.6 Location of study area by topography map

Figure 1.7 Specific study area at CIMA Quarry
1.4 Objectives

The following are the objectives of this research:

1) To study the structural geology properties of limestone at Hume Quarry and CIMA Quarry.

2) To determine the most effective distance variations in UAV mapping.

1.5 Research Method

In this project, high resolution images taken from the drone either automated or manually fly will be the source data for the geological mapping. This research starts with locating the interest study area and design the flight route.

Process of taking picture can be done in such manual and automatic to provide higher accuracy on multiple angle and elevation. Configuration of ground control network been marked thoroughly covering the whole study area. An absolute reference system were collected by using global positioning system (GPS-Garmin Montana 680).

Next step is the extraction of acquisition data into Agisoft 3D photoscan for the 3-D mapping and the use of MATLAB,Mathworks® for the determination of the properties of the rock joint formation. Data from the point cloud (Photogrammetry) will provide such information in scalar vector form to calculate the discontinuity set using Discontinuity Set Extractor (DSE). From the calculation of the analyses data, a lot of information on discontinuities relations from DIPS software can be detailed recorded and modeled in 3D.
1.6 Thesis Outline

This thesis is presented by five chapters. First chapter of introduction will be introduce on the background of the project, problem statement, geology of the study area, objective and research method. Chapter two will be focused more on the relevance literature reviews link-related to this research project. In Chapter three, methodology of how the research project to be conducted is explained thoroughly. All steps and recommendations will be provided in order to obtain high accuracy of promising results. Next, in Chapter four, the evaluation and discussion of that analysis were explained based on data output and result. In the last chapter, there are conclusion and some recommendation for future research have been presented.
CHAPTER 2
LITERATURE REVIEW

2.1 Geology of Study Area

The geology of the Hume Quarry site is located at the north part of the Kinta Valley which represents various form of shaped and most of the limestone formation in Malaysia has undergone the process of karstification having a complex tectonic structure (Zabidi et al., 2016). These variation might cause from the development and deposition of the process of the sedimentation itself where the formation of the tectonic structure may vary in their discontinuities such (bedding plane, foliation-cleavage, fractures, joints, faults and shear zones) during the lithification process. Kinta limestone formation was believed had formed during (Sillurian-Devonian) which subdivided into calcareous facies which interbedded with the argillaceous rock facies include shale, schist, phyllite and rare quartzite. Some of the interbeds are conglomerate, chert, and sparse volcanic in place. Hume Quarry rock faces generally made up of yellow to yellowish brown, massive to highly bedded, heavily jointed of limestone rock strata.

Locally, the Kinta Limestones at the Gopeng is generally a white, pale grey and slightly yellowish rock. A hematitic inclusion were found at the quarry site which limestone in red colour are a rare event in several location. It is a secondary iron minerals, hematite covering the limestone surface which have been formed by the action of furregnous solutions on the limestone. According to the Annual Report of the Geological Survey for 1926, Gopeng posed a small lenticular beds of shale interbedded with the limestone though cannot visibly in the quarry face (Ingham and Bradford, 1960). The grain size of the limestone may vary from fine-grained to coarse-grained but it generally metamorphosed by the adjacent granite. However, according to (Rastall, 1927) a finer-grained saccharoidal type is more common in this quarry site. Meanwhile,
there are several classification system of intact rock that usually based on the strength and/or deformation properties (Unconfined Compressive Strength) where (ISRM, 1978c), (Canadian Geotechnical Society, 1985) adopted. The Table 2.1 shows the classification system of sedimentary rocks according to their formation process.

Table 2.1 Classification of Sedimentary Rocks (Zhang, 2006)

<table>
<thead>
<tr>
<th>Method of Formation</th>
<th>Classification</th>
<th>Rock</th>
<th>Description</th>
<th>Major Mineral Constituent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>Rudaceous</td>
<td>Breccia</td>
<td>Large grain in matrix</td>
<td>Various</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conglomerate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Argillaceous</td>
<td>Claystone</td>
<td>Micro-fine-grained plastic texture</td>
<td>Kaolinite, quartz, mica</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shale</td>
<td>Harder laminated compacted clay</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mudstone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arenaceous</td>
<td>Sandstone</td>
<td>Medium, round grains in silica matrix</td>
<td>Quartz, calcite (sometimes feldspar, mica)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quartzite</td>
<td>Medium, angular grains in matrix</td>
<td>Quartz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gritstone</td>
<td></td>
<td>Quartz, calcite, various</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Breccia</td>
<td>Coarse, angular grains in matrix</td>
<td></td>
</tr>
<tr>
<td>Organic</td>
<td>Carbonaceous</td>
<td>Limestone</td>
<td>Fossiliferous, coarse or fined grained</td>
<td>Calcite</td>
</tr>
<tr>
<td></td>
<td>(siliceous, furriginous, phosphatic)</td>
<td>Coal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Furrigenous</td>
<td>Ironstone</td>
<td>Impregnated limestone or claystone (or precipitated)</td>
<td>Calcite, iron oxide</td>
</tr>
<tr>
<td></td>
<td>Calcareous (siliceous, saline)</td>
<td>Dolomite, Limestone</td>
<td>Precipitated or replaced limestone, fine grained</td>
<td>Dolomite, calcite</td>
</tr>
</tbody>
</table>
2.2 Discontinuities

Generally, discontinuity is a term for most type of joints, weakness zone, weak bedding planes, fault and weak schistocity planes of a rock mass which having a low or zero tensile strength (ISRM, 1978). Fractures and discontinuities is the amongst the most important in geological structures from the hydrological view which allows storage and movement of fluid through them. The discontinuity itself makes the difference on the rock mass properties, therefore, it is crucial to understand the engineering properties of the rocks and characterize the discontinuities in details.

2.2.1 Description of Discontinuities

From an engineering point of view, the type of rock involved are the basic information need to be gather. The type and frequency of the joints are the most important to be studied. Figure 2.1 shows the schematic of primary geometrical properties of discontinuities in rock. The characteristic of the discontinuities can be describe under 10 parameter based on (ISRM, 1978):

1) Orientation: Discontinuity attitude in space. Can be describe by the dip direction (azimuth) and dip of the line of steepest declination in the plane of discontinuity.

2) Spacing: The perpendicular distance between adjacent discontinuities where normally refers to the mean or modal spacing of a set of discontinuities.

3) Persistence: The discontinuity trace length as observed in an exposure that may give a crude measure of the areal extent or penetration length of a
discontinuity. Termination in solid rock or against other discontinuities reduces the persistence.

4) Roughness: The inherent surface roughness and waviness which relates to the plane of a discontinuity. Both of the roughness and waviness contribute to the shear strength. If the waviness is in large-scale may also alter the dip locally.

5) Aperture: The perpendicular distance between adjacent rock walls of a discontinuity, in which the intervening space is air of filled with water.

6) Filling: Material that usually weaker than the parent rock and separates the adjacent walls rock of a discontinuity. Typical filling materials are sand, silt, clay, breccia, gouge, and mylonite. Thin mineral coatings and healed discontinuities such as quartz and calcite veins also includes.

7) Seepage: The water flow and free moisture that visible in the rock mass as a whole or individually in the discontinuities.

8) Wall strength: The equivalent compressive strength of the adjacent rock walls of discontinuity. It may be lower than the rock block strength that due to weathering or alteration of the walls. Wall strength is an important component of shear strength if rock walls are in contact.

9) Number of sets: The number of discontinuity set comprising the intersecting in discontinuity system. It may be further devided by individual discontinuities.
10) Block size: Dimension of the rock block from the same orientation discontinuity sets that intersect and resulting from the spacing of the individual sets. The block size and shape may further influence from the different individual discontinuities.

Figure 2.1 Schematic of the primary geometrical properties of discontinuities in rock (Hudson et al, 1997b)

2.2.2 Types of Discontinuities

Discontinuities and their origins formed from the deformation of rocks where crustal plates collide or shear past each other. It is where the plutonic intrusions are emplaced, where the regional subsidence or uplift occurs, and other mean of stress in the earth occurring long time ago. Mechanism of deformation include also bending of strata that creates a fold structures, extensile cracking causing joints and so do shear rupture yield faults.
1) Faults: The term along which dragging of abrasive rock has an imprinted scratches and grooves and deposited rock powder or angular fragments which often altered to clay so called fault gouge (clay) and fault breccia (recemented).

2) Bedding planes/ strata: Most sedimentary strata were deposited initially planar surface that was horizontally or nearly horizontal (Goodman, 1993). It is generally high persistence features, although sediments laid down rapidly from water currents or heavily laden wind that may contain cross or discordant bedding.

3) Joints: Joints are the ordinary citizen of rock mass because they are the most common and most geotechnically significant discontinuities in rocks. It refers for the regularly recurring fracture surfaces that usually planar, cutting across the rock with constant orientation and having a mean spacings up to several meters. Joint sets are known for the group of roughly parallel or sub-parallel to a single plane until they intersect to form a joint system.

4) Cleavage: Discontinuities often frequently form parallel to bedding planes, foliations or slaty cleavage that may be term as bedding joints, foliation joints or cleavage joints. Fracture cleavage also known as false cleavage and strain slip cleavage that describe a welded parallel discontinuities dependent of any parallel alignment of minerals (Zhang, 2006).

**2.2.3 Orientation of Discontinuity**

Orientation is usually measured from true north and there are several ways of recording the information on strike of the discontinuity (most preferable) and dip
direction. Most of the engineering practices quote the orientation data in form of dip direction /dip (dip angle). Orientation from engineering point of view provides an importance as the presence of other deformation condition. It can be measured on site scanline and plotted on stereonets to measure the pole contour concentration and various discontinuity sets present. Figure 2.2 shows the orientation of plane (Price and Juan, 2013).

A number of algorithms based on statistical or fuzzy-set approaches are available for numerically a difficult clustering orientation data (Einstein and Baecher, 1982). Mean orientation of a number of the discontinuities can be calculated from the direction cosines. Sampling bias on orientation can also be considered.

![Figure 2.2 Orientation of Plane (Price and Juan, 2013)](image)

**Figure 2.2 Orientation of Plane (Price and Juan, 2013)**

Description of each term for the orientation of Figure 2.2:

i. *Dip*: The direction in which the steepest angle is formed between the plane of the rock bed and the horizontal surface.
ii.  *Dip direction:* The direction toward which the plane is inclined.

iii. *Strike:* The direction of the imaginary line which would represent the intersection between the plane and a horizontal surface.

iv.  *Trend:* The horizontal projection of the line’s horizontal which is clockwise from north.

v.  *Plunge:* The dip’s line where positive when it above horizontal but negative if it is below horizontal.

### 2.2.4 Intensity of Discontinuity

It can be described in different term in measures in one, two or three dimension, including discontinuity spacing, linear, areal and volumetric frequency, Rock Quality Designation (RQD), discontinuity trace length per unit area of rock exposure, and discontinuity area per unit volume of rock mass.

#### 2.2.4.1 Spacing and Linear Spacing

Discontinuity spacing is a distance between the adjacent discontinuities measured along a manual sampling line mapping (scanline). If the sampling line is normal to the discontinuity planes, the set spacing then called the normal set spacing (Priest, 1993). The terminology used by (ISRM, 1978) for describing the magnitude of discontinuity spacing as shown in Table 2.2 below.
Table 2.2 Classification of discontinuity spacing (Zhang, 2006)

<table>
<thead>
<tr>
<th>Description</th>
<th>Spacing (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely close spacing</td>
<td>&lt;20</td>
</tr>
<tr>
<td>Very close spacing</td>
<td>20-60</td>
</tr>
<tr>
<td>Close spacing</td>
<td>60-200</td>
</tr>
<tr>
<td>Moderate spacing</td>
<td>200-600</td>
</tr>
<tr>
<td>Wide spacing</td>
<td>600-2000</td>
</tr>
<tr>
<td>Very Wide spacing</td>
<td>2000-6000</td>
</tr>
<tr>
<td>Extremely Wide spacing</td>
<td>&gt;6000</td>
</tr>
</tbody>
</table>

2.2.5 Causes of Discontinuities

Engineering properties of type of discontinuity plays a major role in rock behaviour where they are related to the geological history. They are faults, bedding planes, joints and cleavage. They appeared in difference type of engineering structure usually patternly in group. Discontinuity are created due to stresses which may have a diverse origin such as:

i. The tectonic stresses that related to the deformations of rocks.

ii. The residual stresses cause by event that long happened before the fracturing.

iii. The cooling of magma or dessication of sediments causing contraction due to shrinkage.

iv. The surficial movements of landslides or glaciers.
v. The erosional unloading of deep-seated rocks.

vi. The weathering process such as dilation and dissolution.

There are many factors that can caused by a different types of discontinuities formation in the rock mass.

2.3 Photogrammetry

Photogrammetry is science based innovation with mathematical principal remain unchange over a time of history and improvement. The application for production purposes have drastically move forward along with the development of the technology (Linder, 2016). The principal of the photogrammetry is about the acquisition of data for 3D results such DSM/DTM, contour lines, textured 3D models, vector data and to extract the redundant set of tie points with a geo-referenced images captured. Recently, there are several open-source software which helped the automated identification such as PhotoModeller Scanner, MeshLab, CloudCompare and Agisoft Photoscan 3D had been commercially used with sufficient amount of sensitively data to be prepared.

Photogrammetry also is a great tools to provides a quantitative data from a single photo, 2D into 3D coordinates. Each image taken can give a different position in different perspective which can tells us the previous and future information regarding the type of problems to work on so-called stereoscopic viewing in photogrammetry (Linder, 2016).
2.3.1 Distance Variations in UAV Mapping

To get the best result from this method, usually the recommended distance between drone and rock about 10-50 meter. If the drone is too high and far from the rock face, the image resolution will be lower. Moreover, it will be difficult to get the best mapping accuracy such as crack, joint, fault and orientation (strike & dip). It will impact several data when using software.

By using UAV photogrammetry, the appropriate distance for every data is between 5-15 meter. The great advantage of actual UAV systems is the ability to acquire a high resolution image and providing a detail information to allow 3D photogrammetry to be modelled as the photo contains a coordinate which increase the accuracy for data collected. The extracted original number of points of the point cloud in short distance is more than the extracted points for long distance. This study is to determine the most effective distance variations in UAV mapping between 10 meter and 15 meter from the rock surface. In photogrammetry, accuracy is always relative to positional accuracy, which is defined as the degree to which the information on the map created from the data captured matches the actual real world. In conclusion, the research about the distance in UAV mapping is still new and not much related.

2.3.2 Agisoft PhotoScan

Agisoft PhotoScan is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales (Agisoft LLC, 2016). It also a solution of photogrammetry software where it can automatically generate the
dense point clouds, models, textured polygonal models, georeferenced true orthomosaics and DSMs / DTMs from still images.

It also allows very fast processes, providing the highly accurate results and capable to process thousands of the photos, yet all the processing is performed locally, without the need to transmitting the data from outside the company. So it provides for processing a sensitive data as an ideal solution.

2.3.3 CloudCompare

CloudCompare is a 3D point cloud (and triangular mesh) processing software. It has been originally designed to perform a comparison between two dense 3D points clouds (such as the ones acquired with a laser scanner) or between a point cloud and a triangular mesh. It relies on a specific octree structure dedicated to this task.

Afterwards, it has been extended to a more generic point cloud processing software, including many advanced algorithms (registration, resampling, colour/normal/scalar fields handling, statistics computation, sensor management, interactive or automatic segmentation, display enhancement, etc) (Riquelme et al., 2014).

2.3.4 Discontinuity Set Extractor (DSE) in MatLab Software

Discontinuity Set Extractor is one of open sources software programming in MatLab which programmed by Adrian Riquelme. The function of this programme is to extract as much as possible discontinuity sets from rock mass by digital photogrammetry or 3D laser scanner such as LiDAR or TLS and also synthetic data. It
also semi automatically identify points as members of an unorganised 3D point cloud that arranged in 3D space by planes (Riquelme, Abellán and Tomás, 2015).
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the fundamental task involved as well as method employed in the whole project work. This project was started by investigating the geological mapping at Hume Cement Quarry Sdn Bhd and Cement Industries of Malaysia Berhard (CIMA). Method being used in this research was photogrammetry analysis using Agisoft Photoscan to generate 3D models and point clouds, Mathworks® (MATLAB) for the discontinuity analysis and the use of Unmanned Aerial Vehicle (UAV), DJI drone for the acquisition of high precision of images.

3.2 Planning and Investigation

Desk study is the first step of site investigation to study, collecting and interpret any existing data for initial view on that particular area. Thus, an informative geological area of Gopeng and Bukit Ketri need to be assured accordingly. This reduced time and provides some rough idea on the area to be investigated as well as gives more chances to predict and set up the survey succesfully.

3.2.1 Principal Aerial Survey Mapping

The OSS essentially means that the smart drone can sense obstacles and prevent itself from crashing into buildings. There are two cameras in front and another at the bottom with integrated optical sensors. This helps it to calculate the distance from any obstacle and take appropriate actions such as reducing its speed or coming to a halt.
When tested, the artificial intelligence machine refused to crash into a human, stopping about 2 meters away. It can connect to GPS and GLONASS, allowing for more accurate positioning and performance.

The camera on the Phantom 4 allows videos to be shot in 30 frames per second, while the high resolution allows for up to 120 frames per second. The lens of this model is even better than previous ones.

### 3.2.1.1 Aircraft Survey

DJI provided a various user friendly applications in mobile devices to provides near real-time image transmission and camera settings adjustment, as well as editing and sharing of aerial imagery. The application, DJI GO 4 even simplifies the task as the flight survey can be planned accordingly. DJI GO 4, provides an interface where ones can:

1. Check flight status and records.
2. Main controller settings.
5. Image transmission settings.
6. Full control of Aircraft and Controller.

Pre-flight checklist are important before an aerial survey be done. Flight route can be drawn on the application with provided updated maps. The aircraft and controller
need to be calibrated before take off. It is much more easier than old days, as the DJI GO 4 has a virtual condition of the aircraft and the controller. Calibration of the aircraft and the controller are means to calibrate every single components in it included (sensor, camera and gimbal sensitivity). Checklist such as overlapping, max flight altitude, obstacle avoidance, vision positioning, noise, flight time, camera and picture settings, unit measurements, auto takeoff and landing, auto and manually flight control need to check before the drone take in action.

Travel routes or fly path on area of interest should be plan accordingly to avoid obstacles and ensure the map of waypoints creates on the UAV mission software are similar in the existing conditions. Drones with waypoint technology typically utilize Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) where they are two different networks of satellites orbiting the earth still collecting a precise three-dimensional positioning coordinates. In addition, overlapping is one of the most important flight parameter where the amount by which one photograph includes the area covered by another photograph in percentage.

Upon pre-flight checklist has confirmed, the aerial survey can be started according to the set up details. Eventhough the drone are seem to fly vertically to the ground, the intelligence of the drones allows the camera turn 360 for the horizontal picture to be taken. Eventually, manual flight mode will consume more battery life. Last but not least, is the appointment of ground control points (GCPs) where its used as reference later.

Below are the step to create a path for the targeted area:

1) Open Google Earth.
2) Go to a place on the map.

3) Above the map, click Add Path. To add a shape, click Add Polygon. To make a path or polygon into a 3D object, click Altitude.

4) A ‘New Path’ or ‘New Polygon’ dialog will pop up. You may need to move it out of the way before moving on to the next step.

5) To draw the line or shape you want, click a start point on the map and drag it.

6) Click an endpoint. Then, enter the flight description and properties.

7) Click OK.

Ground Control Points (GCPs) are points of known coordinates marked on the ground that is spaced strategically throughout the area of interest. They are not required for processing a project as they increase the absolute accuracy of the project significantly as well as verifying the results. A number of GCP was placed homogenously in the area of interest to minimize the scale error and orientation. It should be visible during aerial survey by using high-contrast colors and make it large enough to be seen from flight altitude. Avoid placing a GCP at the edges of the area, in fact in center to improve the quality of the construction.

3.3 Data Processing and Analyzing

Data acquisition during the aerial survey conveys 3D information into 2D photograph with assigned coordinate in each picture taken. The picture taken is then transferred to the high specification laptop for further analysing. Recognise and select
the appropriate picture to be inserted in the Agisoft photoscan software. Workflow of the generation 3D modelled are quite easy with the provided user-friendly interface. Below are the workflow diagram processing of photogrammetry by using Agisoft PhotoScan.

3.3.1 Converting 2D to the 3D image by Agi PhotoScan Software

1) Uploading the Image

After capturing all the pictures that contain geological data, the raw pictures are processed and converting into 3D modelling pictures for further analysis of slope stability by using Agisoft PhotoScan Software. Procedure to construct a textured 3D model, DEM and orthomosaic photos begin with uploading the image into the PhotoScan.

Loading of photo can be done in two easy ways by selecting Add Photos command from the Workflow menu as shown in Figure 3.1 or click Add Photos toolbar button on the workspace pane of Agisoft PhotoScan. In the Add Photos dialog box browse for the folder containing the images and select files need to be processed. Then click Open button to let the selected photos appear on the workspace pane. If some of unnecessary images included, it can be simply removed by right click on the selected photo and click Remove Items command toolbars on the workspace pane.
2) Aligning Photo

Select Align Photos command from the workflow menu as shown in Figure 3.2. In the Align Photos dialog box select the desired alignment options. Click OK button when done so the progress dialog box will appear displaying the current processing status. To cancel processing click Cancel button if any missing photo discovered by clicking on the camera button to display the position of each photo. After an alignment having been completed, a computed camera positions and a sparse point cloud will be displayed on the workspace pane.
3) **Build Mesh**

   After the photo has been align, proceed to select the Build Mesh command from the workflow menu as shown in Figure 3.3. In the Build Mesh dialog box one can select the desired reconstruction parameters then click OK button when done. If the guided marker does available, reconstruct geometry for GCP will be faster and easier. One image may contains more than 1 GCP, so we need to zoom in to identify each GCP located according to sketch. Each marker should have the Coordinates (x, y & z) that taken from the high accuracy survey equipment GPS Garmin®.
4) Set Bounding Box

Check the reconstruction volume bounding box. It can be freely to adjust the bounding box use the Resize Region, Move Region and Rotate Region toolbar buttons as shown in Figure 3.4. To resize the bounding box, drag corners of the box to the desired positions and to move it, hold the box with the left mouse button. It is recommended to set the bounding box to avoid waste computing time on unnecessary parts. Typically set the “Region” to encompass the part of the point cloud that contains the object or area you want to make the model in. This will saves on processing time, and reduces the amount of manual editing work you might have to do later.
5) Build Dense Point Cloud

Select Build Dense Cloud command from the Workflow menu as shown in Figure 3.5. Set the following recommended values for the parameters in the Build Dense Cloud dialog:

**Quality:** Medium will provide higher quality but takes quite a long period of time and demands more computational resources; lower quality can be used for fast processing.

**Depth filtering:** Aggressive, if the geometry of the scene to be reconstructed is complex with enormous small details or untextured surfaces, like roofs, it is recommended to set Mild depth filtering mode, for important features not to be sorted out.
Figure 3.5 Step to build dense point cloud

6) Build Mesh – Dense Cloud Model

After dense point cloud has been complete reconstructed, it is possible to generate polygonal mesh model based on the dense cloud data. Select the Build Mesh command from the workflow menu and then click OK button to start mesh reconstruction as shown in Figure 3.6. It will result in a better smooth surface with alignment of point clouds. If the overlap of the original images taken was not sufficient, it may be required to use Close Holes command from the Tools menu at geometry editing stage to produced a model with less hole. Select the size of the largest hole to be closed in percentage of the total model size. In the Decimate Mesh dialog specify the number of target faces that should remain in the final model.
Figure 3.6 Step to build mesh for dense cloud model

7) Build Texture

Select Build Texture command from the workflow menu as shown in Figure 3.7. Set the following recommended values for the parameters in the Build Texture dialog and click OK button to start texture generation. Orthophoto is the recommended mapping mode and mosaic blending mode.

Figure 3.7 Step to build texture
8) Build Tiled

Select Build Tiled Model command from the workflow menu as shown in Figure 3.8. Set the following recommended values for the parameters in the Build Tiled Model dialog. Click OK button to start texture generation.

![Build Tiled Model dialog](image)

Figure 3.8 Step to build tiled model

9) Generate DEM

Select Build DEM command from the workflow menu as shown in Figure 3.9. Coordinate system should be specified in accordance with the system used for model referencing. At the export stage it will be possible to project the results to a different geographical coordinate system. After DEM generation process is finished, it is possible to open the reconstructed model in Ortho view by double-clicking on the DEM label in the chunk's contents on the workspace pane.
10) Generate Orthomosaic

Orthomosaic can be generated geographically under DEM surface parameter. Select the Build Orthomosaic command from the workflow menu as shown in Figure 3.10. Generated orthomosaic can be reviewed back in Ortho mode similar to the digital elevation model. It can also be opened in this view mode by double-clicking on the orthomosaic label at the workspace pane.
11) Export Orthophoto

Head to Export Orthomosaic on the command file and select Export JPEG/TIFF/PNG to finish up the project as shown in Figure 3.11. This step is very important as we need to check the coordinate system that relates to your GPS measurements. Choose your EPSG code by modifying in the settings of your GPS measurement devices. In most cases, we recommend using WGS84/UTM zone 47N (EPSG: 32647). Then, click Export and specify target file name to save it.
Figure 3.11 Step to export orthoimage

12) Export DEM

Click File in the command workspace pane, on Export DEM, select Export TIFF/BIL/XYZ and reconfirm the coordinate system being used then click Export and specify target name and location. Digital Elevation Model will result in very useful information during the height analysis.
13) Generate Google Earth

Lastly, select Export Orthomosaic and head to Export Google KMZ from command file menu as shown in Figure 3.13. Export and save the specify target location and name for further references. After it had be done in a smooth step conducted from above, there should be a good and better result with less error and high accuracy model mapping projection.
3.3.2 Discontinuity Analysis

Upon performing a photogrammetry, it is recommended to test the quality of the model in term of the accuracy. It will help and emphasise more onto detail analysis which related to the coordinates of the model. It is known that, photogrammetry were about to read the point cloud produce from photogrammetry method, so we need to be precise in order to produce better data and result.

Thus, it become compulsory to have view the 3D model in the software named CloudCompare. This software allow us to visualize a model in any scalar direction with multiple scale available. CloudCompare is a viewpoint for every project analysis that were calculated during MATLAB® process. It helps to compare and differentiate the small changes taken.

Matlab is a combines desktop environment that tune for iterative analysis, design processes with a programming language that can expresses matrix and array mathematic directly. It can handle big data for deep learning data analytics, computer
vision, signal processing, robotics, control system and so do mining. Discontinuity Set Extractor (DSE) is an open-source software programmed by AdrianRiquelme used to extract discontinuity sets of rockmass. The input data is from 3D point cloud in term of coordinates (x, y, z) done during the photogrammetry process previously.

Analysis of the discontinuity is calculated based on identifying point members of an unorganised 3D point cloud that are arranged in 3D space into planes. A unit step taken as shown below:

1) Uploading the Data

The directory path of Discontinuity Set Extractor (DSE) was drag and drop the program into Matlab environment and run the program. After DSE program has load succesfully, head to File command to insert data in (.txt) file format or can be click on Load 3D point cloud icon below the command as shown in Figure 3.14. Locally, this software currently can load text format where generally all photogrammetry software can be extract to. Once it already done loading the file, the software directly identifies the coordinates a,b and c and n, inc and error found in the file.
2) Local Curvature Calculation

During this process, the input raw data points (P), where Pi is a point member of P while their neighbouring points denoted as Qi and the size of the neighbour points is nn points. It is a method for calculating the normal vector for each 3D points. Nearest neighbouring searching can be carry out by two difference approaches from fixed distance or fixed number neighbour points available. Usually fixed number approach was established due to some error in the heterogeneity of the density of points (J. Lato, Diederichs and Hutchinson, 2010).

In the set up planes as shown in Figure 3.15, knn neighbours are calculated by using knn search function and the or a distance between two points (Riquelme et al., 2014). Next step is to check whether the neighbour points are coplanar or not prior to \( \alpha \) orientation calculations. The coplanarity test is done by the Principal Component Analysis (PCA) (Rebher and Christensen, 2012). The parameter tolerance (nmax) is defined as the maximum allowable deviations in a subset points where the subset plane can be reasonable...
considered a plane. Hence, if the nmax value is below than 20%, it will proceed to the calculation orientation of the coplanar set of points.

Calculation of the orientation is based on three components of the unit normal vector to the plane where A, B, C and D which gives the perpendicular distance from the origin to the plane. The calculation will based on the following equations:

\[ Ax+By+Cz+D=0, \text{where} [A,B,C,D] \]

![Figure 3.15 Step to principal planes calculation](image)

3) Statistical Analysis of the Plane Poles

In the statistical analysis, it is performed by means of the stereographic projection of the planes poles as shown in Figure 3.16. In order to define the main discontinuity set, calculate the normal vector for each plane and convert to the stereographic projection, the density of the poles for each region and the local maxima (Lisle and Ramsay, 2000). According to (Botev, Grotowski and P. Kroese, 2010), the method of implementation uses the Matlab (KDE) Kernel Density Estimation, kde2d by a Gaussian kernel which allows the automatic calculation of the width and density computation. At this point, it can be identifies the peaks for each poles which reasonably represent the orientations of the 3D point cloud and their neighbours.
Next, is the assignment of principal orientation to every single point in the point cloud and its neighbours as shown in Figure 3.17. If the point is not represented by any principal orientation, thus there are no assignment. Usually, the density analysis function shows many local maximum but it is only a few are principal poles. It is due to the fact that the existence of errors reading and curved surfaces. The density function obtained in no filters shows many local maxima available and by accepting a minimum $\gamma_1 = 20$ a cleaner plot of the principal planes can be obtained specifically by indicated the relevance discontinuity sets that are obvious by using the edit poles button. Each point of the point cloud has been segmented into the closest principal families where the discontinuity set only represent the minimum angle $\gamma$ between the associated normal vector and the assigned principal plane normal vector.
4) Cluster Analysis

It is necessary to find the discontinuity subset data whose points are grouped in according to the planar clusters, where the obtain clusters are members of the discontinuity set \( I \) which are defined in the space through its planes. Figure 3.18 show how to run cluster analysis. Clustering of 3D datasets are employed from (Sander et al., 1998), Density-Based Scan Algorithm with Noise (DBSCAN) for class identification in spatial databases which has been proven in (Tonini and Abellan, 2013). This algorithm requires several input parameter such as maximum distance between two points to be consider as neighbours and a minimum number of neighbour point q to consider q as a major point. In this real cases cluster analysis, it is usually to find a high number of small cluster and thus it is more interesting for big clusters by stating a selection threshold parameter points as per cluster available.

Generation of the plane of the discontinuities can be calculated by the following algebraic equations:

\[
A_{ij}x + B_{ij}y + C_{ij}z + D_{ij} = 0
\]

It is also possible to calculate the parameter \( A_{ij}, B_{ij}, \) and \( C_{ij} \) using the normal vector of the discontinuity set principal pole, so that all the cluster will
have exactly the same orientation. While, $D_{ij}$ can be calculated by least square method where $n$ is the cluster size of $R_{ij}$. Once the $R_{ij}$ plane equation has been calculated, the error $e_{rij}$ is associated to the cluster $R_{ij}$ and it is convenient to check the quality of the data fitting and the value of standard deviation $\sigma(rij)$ must be low.

![Figure 3.18 Step for cluster analysis](image)

Once all the steps for the determination of the discontinuity sets data given, it is recommended to save all data with report into (.txt) format and to analyse it in cloudcompare. If helps one for further analysis to view the complete data between poles density and poles discontinuity sets. Discontinuity set of each of the window can be further discussed by using DIPS software from Rockscience where the analysis of each windows can be presented in rosette diagram.
CHAPTER 4
RESULT AND DISCUSSION

4.1 Introduction

This chapter is consisting of two major parts, which the contents are directly correlated to the objectives of this research. The first part discusses on the photogrammetry mapping through its discontinuities set for every window. The second part describe the comparison result between using the software and by manual mapping.

4.2 Photogrammetry Mapping

In this exercise, a total of 29 photos and 27,639 points from Hume Quarry while 20 photos and 15,949 points from CIMA Quarry available to construct a 3D model of the quarry face. According to the following methodology as prescribed in Chapter 3, an ortho-photo of a quarry face can be completely presented. The quarry face is splitted into two different distances which is 10 meter and 15 meter for both quarries. Each window represented the dominant discontinuities joint set found.

This project focus on the major formation of discontinuities available on the site that is clearly visible with bare eyes. Simultaneously, encourage the deep study on the recognition of the discontinuity in details. CloudCompare gives an extra hand on translating the calculation analysis into more informative and understandable to deliver information.
4.3 Hume Quarry

Modelled photos taken by drone shows discontinuities joint set that include fault, bedding plane and joint. Figure 4.1 shows the coordinate of Hume Quarry (4°23’09.55’’ N 101°06’21.62’’ E) while Figure 4.2 shows the raw picture of Hume Quarry (Window A). The outcrop shows massive limestone, light grey in color with third (3) grade weathering (Bieniawski, 1999) is shown in Appendix B.

Figure 4.1 Location for study area at Hume (Google Earth, 2019)
Window A at 10 meter results in six (6) discontinuity joint sets while Window A at 15 meter only have five (5) discontinuity joint sets with different clusters were observed. The plane represent the actual condition for each window with different colour labelling according to the number of cluster available.

By using Agisoft PhotoScan software, the 3D model for Window A was constructed from 29 photos taken into one window at different distances of 10 meter and 15 meter. Photogrammetry mapping is an analysis based on the point cloud that providing a vector that can produce the orientation of the discontinuities joint set.

**Window A at 10 meter**

The 3D model for Window A at 10 meter were constructed from 19 photos taken into one window as shown in Figure 4.3. The extracted original number of points of the point cloud for Window A at 10 meter is around 910,223 points, where 797,791 of the points was classified on point cloud while 112,432 are unassigned points. Table 4.1
shows a summary of result, where six (6) sets of discontinuities joint set were extracted from the database. Overview report for the overall data collection is shown in Appendix A.

Table 4.1 Discontinuities set of Window A at 10 meter

<table>
<thead>
<tr>
<th>Discontinuities Joint Set</th>
<th>Dip Direction</th>
<th>Dip</th>
<th>Density</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>79.94</td>
<td>44.68</td>
<td>9.0877</td>
<td>37.34</td>
</tr>
<tr>
<td>J2</td>
<td>346.63</td>
<td>54.40</td>
<td>5.2012</td>
<td>22.42</td>
</tr>
<tr>
<td>J3</td>
<td>234.88</td>
<td>76.28</td>
<td>1.7389</td>
<td>9.67</td>
</tr>
<tr>
<td>J4</td>
<td>18.43</td>
<td>25.48</td>
<td>1.3505</td>
<td>17.06</td>
</tr>
<tr>
<td>J5</td>
<td>130.40</td>
<td>80.31</td>
<td>0.0721</td>
<td>2.18</td>
</tr>
<tr>
<td>J6</td>
<td>169.81</td>
<td>86.61</td>
<td>0.0557</td>
<td>3.00</td>
</tr>
</tbody>
</table>

% the number of assigned points to a DS over the total number of points

The discontinuities joint were arranged from the highest density to the lowest density. This correspond to the major and minor plane of discontinuities set. The highest value of density is 9.0877 for J1 followed by 5.2012 for J2, 1.7389 for J3, 1.3505 for J4,
0.0721 for $J_5$ and the lowest value of density is 0.0557 for $J_6$. Figure 4.4 (a-f) show the result of the point cloud segmentation where labelled as cluster for each discontinuities joint set. Figure 4.4 (g) shows all the discontinuities joint set that available for this window. This discontinuities joint set described as the major discontinuities set for this Window A.
Figure 4.4 (a-g) Segmented 3D point cloud. J₁ (a), J₂ (b), J₃ (c), J₄ (d), J₅ (e), J₆ (f) and all set available (g)

In Figure 4.5, the 3D stereonet shows the density of pole plot for Window A at 10 meter where discontinuities J₁ is the highest value of density pole plot compare to other discontinuities joint sets.

Figure 4.5 Pole density plot of six joints set of discontinuities extracted from DSE program
**Window A at 15 meter**

For Window A at 15 meter, there were five (5) discontinuity joint sets with different clusters were observed. Table 4.2 shows a summary of result, where five (5) sets of discontinuities joint set were extracted from the database. Overview report for the overall data collection is shown in Appendix A.

The 3D model for Window A at 15 meter were constructed from 10 photos taken into one window as Figure 4.6. The extracted original number of points for Window A at 15 meter is around 403,855 points, where 347,424 of the points was classified on point cloud while 56,431 are unassigned points.

![Figure 4.6 The real model of CloudCompare for Window A at 15 meter](image)

<table>
<thead>
<tr>
<th>Discontinuities Joint Set</th>
<th>Dip Direction</th>
<th>Dip</th>
<th>Density</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>J1</strong></td>
<td>65.85</td>
<td>74.24</td>
<td>5.4489</td>
<td>42.01</td>
</tr>
<tr>
<td><strong>J2</strong></td>
<td>1.66</td>
<td>79.64</td>
<td>3.5321</td>
<td>28.40</td>
</tr>
<tr>
<td><strong>J3</strong></td>
<td>244.98</td>
<td>42.96</td>
<td>3.0498</td>
<td>8.54</td>
</tr>
<tr>
<td><strong>J4</strong></td>
<td>222.38</td>
<td>73.07</td>
<td>0.3184</td>
<td>9.06</td>
</tr>
<tr>
<td><strong>J5</strong></td>
<td>115.89</td>
<td>85.62</td>
<td>0.0611</td>
<td>1.79</td>
</tr>
</tbody>
</table>
The highest value of density for this window is 5.4489 for $J_1$ followed by 3.5321 for $J_2$, 3.0498 for $J_3$, 0.3184 for $J_4$ and the lowest value of density is 0.0611 for $J_5$. Figure 4.7 (a-e) show the result of the point cloud segmentation where labelled as cluster for each discontinuities joint set. Figure 4.7 (f) shows all the discontinuities joint set that available for this window.
Figure 4.7 (a-f) Segmented 3D point cloud. $J_1$ (a), $J_2$ (b), $J_3$ (c), $J_4$ (d), $J_5$ (e) and all set available (f)

In Figure 4.8, the 3D stereonet shows the density of pole plot for window A at 15 meter where discontinuities $J_1$ is the highest value of density pole plot compare to other discontinuities joint sets.
4.4 CIMA Quarry

Figure 4.9 shows the coordinate for CIMA Quarry (6°29’50.98” N 100°15’49.55” E) while Figure 4.10 shows the raw picture of CIMA Quarry (Window B). The outcrop for this window shows massive limestone, reddish white with third (3) grade weathering. The reddish colour come from iron that presented from the weathering (Bieniawski, 1999) is shown in Appendix B.
Figure 4.9 Location for study area at CIMA Quarry (Google Earth, 2019)

Figure 4.10 Study area for Window B

Window B at 10 meter results in five (5) discontinuity joint sets while Window B at 15 meter only have four (4) discontinuity joint sets with different clusters were
observed. The plane represent the actual condition for each window with different colour labelling according to the number of cluster available.

By using Agisoft PhotoScan software, the 3D model for Window B was constructed from 20 photos taken into one window at different distances of 10 meter and 15 meter

**Window B at 10 meter**

The 3D model for Window B at 10 meter has been constructed from 7 photos taken into one window as Figure 4.11. The extracted original number of points from Window B at 10 meter is around 854,322 points, where 336,078 of the points was classified on point cloud while 518,244 are unassigned points. Table 4.3 shows a summary of result, where five (5) sets of discontinuities joint set have been extracted from the database. Overview report for the overall data collection is shown in Appendix A.

![Figure 4.11 The real model of CloudCompare for Window B at 10 meter](image-url)
Table 4.3 Discontinuities set of Window B at 10 meter

<table>
<thead>
<tr>
<th>Discontinuities Joint Set</th>
<th>Dip Direction</th>
<th>Dip</th>
<th>Density</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>290.29</td>
<td>72.71</td>
<td>0.3072</td>
<td>12.34</td>
</tr>
<tr>
<td>J2</td>
<td>262.43</td>
<td>24.39</td>
<td>0.1635</td>
<td>0.93</td>
</tr>
<tr>
<td>J3</td>
<td>332.53</td>
<td>88.87</td>
<td>0.0338</td>
<td>4.86</td>
</tr>
<tr>
<td>J4</td>
<td>199.54</td>
<td>76.10</td>
<td>0.0238</td>
<td>2.04</td>
</tr>
<tr>
<td>J5</td>
<td>79.47</td>
<td>97.39</td>
<td>0.0017</td>
<td>26.12</td>
</tr>
</tbody>
</table>

The highest value of density for this window is 0.3072 for J1 followed by 0.1635 for J2, 0.0338 for J3, 0.0238 for J4 and the lowest value of density is 0.0017 for J5. Figure 4.12 (a-e) show the result of the point cloud segmentation where labelled as cluster for each discontinuities joint set. Figure 4.12 (f) shows all the discontinuities joint set that available for this window.

(a)
In Figure 4.13, the 3D stereonet shows the density of pole plot for window B at 10 meter where random cluster is the highest value of density pole plot but we rejected because the data was not accurate. Thus, J₁ is the highest value of density pole plot compare to other discontinuities joint sets.
**Window B at 15 meter**

Window B at 15 meter results in four (4) discontinuity joint with different clusters were observed. The 3D model for Window B at 15 meter were constructed from 13 photos taken into one window as Figure 4.14. Table 4.4 shows a summary of result, where four (4) sets of discontinuities joint set have been extracted from the database. Overview report for the overall data collection can be seen in Appendix A.

The extracted original number of points for Window B at 15 meter is around 678,048 points, where 303,386 of the points was classified on point cloud while 374,662 are unassigned points.
Figure 4.14 The real model of CloudCompare for Window B at 15 meter

Table 4.4 Discontinuities set of Window B at 15 meter

<table>
<thead>
<tr>
<th>Discontinuities Joint Set</th>
<th>Dip Direction</th>
<th>Dip</th>
<th>Density</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>J₁</td>
<td>293.39</td>
<td>65.93</td>
<td>0.3541</td>
<td>10.07</td>
</tr>
<tr>
<td>J₂</td>
<td>212.53</td>
<td>85.83</td>
<td>0.1779</td>
<td>7.00</td>
</tr>
<tr>
<td>J₃</td>
<td>224.47</td>
<td>19.29</td>
<td>0.1138</td>
<td>0.76</td>
</tr>
<tr>
<td>J₄</td>
<td>82.37</td>
<td>101.55</td>
<td>0.0007</td>
<td>30.87</td>
</tr>
</tbody>
</table>

The highest value of density for this window is 0.3541 for J₁ followed by 0.1779 for J₂, 0.1138 for J₃ and the lowest value of density is 0.0007 for J₄. Figure 4.15 (a-d) show the result of the point cloud segmentation where labelled as cluster for each discontinuities joint set. Figure 4.15 (e) shows all the discontinuities joint set that available for this window.
In Figure 4.16, the 3D stereonet shows the density of pole plot for window B at 15 meter where random cluster is the highest value of density pole plot but we rejected because the data not accurate. Thus, discontinuities J₁ is the highest value of density pole plot compare to other discontinuities joint sets.
In comparison, the data from distance of 10 meter is more accurate compare to distance of 15 meter. The 3D image for 10 meter is sharper than 3D image for 15 meter because of its resolution. When the distance is close to the plane, the image will be more clear and sharp. After that, the number of points of original point cloud at 10 meter is higher than 15 meter distance for both window.

Next, the total discontinuities joint set for 10 meter is more than the distance at 15 meter. For Window A, 6 set of discontinuities joint set at 10 meter while only 5 set of discontinuities joint set at 15 meter. Window B at 10 meter also have one more discontinuities joint set compare to 15 meter distance.

**4.5 Manual Mapping**

Figure 4.17 and Figure 4.18 show the rosette plot of Window A describing the major direction of discontinuities by photogrammetry mapping while Figure 4.19 shows the rosette plot of Window A by a manual scanline mapping.

The difference between both rosette plot diagrams is the quantity of discontinuities set extracted from Window A. In comparison on that differences, the photogrammetry mapping produce a huge number of cluster detected that show the orientation of discontinuities in comparison to a manual scanline mapping technique. Nonetheless, both method of mapping should show the same major direction of discontinuities or joints.

The most dominant direction for photogrammetry mapping at 10 meter is 70-90 E-W and 140-180 SE-NW to SSE-NNW while for photogrammetry mapping at 15 meter is 150-160 SSE-NNW and less dominant trend on 80-100 E-W. For scanline mapping, the most dominant trend on 150-160 SSE-NNW followed by less dominant 90-130 which trends on E-W to ESE-WNW. The least dominant is on 50-60 ENE-
WSW. This study can be accepted because all of their trend range between 150-170 SSE-NNW.

Figure 4.17 Rosette Plot by photogrammetry mapping (10 meter)

Figure 4.18 Rosette Plot by photogrammetry mapping (15 meter)

Figure 4.19 Rosette Plot by scanline mapping (manual)
Figure 4.20 and Figure 4.21 show the rosette plot of Window B by photogrammetry mapping while Figure 4.22 shows the rosette plot of Window B by a manual scanline mapping.

The most dominant direction for photogrammetry mapping at 10 meter is N-S with direction of 350-20 and SSE-NNW with direction of 150-160 while for photogrammetry mapping at 15 meter is SSE-NNW to N-S with directions of 140-180. For scanline mapping, the most dominant trend on E-W with direction of 80-90, followed by SE-NW with direction of 130-140. The least dominant trend for this scanline mapping is NE-SW with direction of 30-40 and SSE-NNW with direction of 160-170.

It is believed that the difference of dominant joint and orientations shown in both method is due to that the software used difficult to detect the joint because lot of disturbance. There are some slope face that covered by soil. Both result from UAVDP and manual mapping show inagreement with each other. Hence, the data got from DSE is too much compare to manual mapping. Only two windows use for this research. To get more accurate data, number of window taken should be more than this for future research. In simple word, this photogrammetry mapping method are valid to the manual mapping.
Figure 4.20 Rosette Plot by photogrammetry mapping (10 meter)

Figure 4.21 Rosette Plot by photogrammetry mapping (15 meter)

Figure 4.22 Rosette Plot by scanline mapping (manual)
CHAPTER 5
CONCLUSION AND FUTURE RECOMMENDATIONS

5.1 Conclusion

This project was carried out to study the structural geology properties of limestone and to determine the most effective distance variations in UAV-Photogrammetric mapping at Hume Quarry, Gopeng, Perak and CIMA Quarry, Bukit Keteri, Perlis. The specific quarry face has been choosing and investigation involve getting the geological information and characterization. Analysis of that geological information provides the result of discontinuities in the rock mass.

There are one quarry face selected for both quarries which known as window. The distance used for this study is 10 and 15 meter for every face. The result from photogrammetry method for both window show the original point clouds at 10 meter is more than the distance from 15 meter even more photos inserted in Agisoft Photoscan for 15 meter compare to 10 meter. This is because the resolution images for the distance of 10 meter is higher than the resolution images for 15 meter.

The result from Discontinuity Set Extractor (DSE) program in MATLAB also proved that 10 meter distance is more effective than 15 meter distance. DSE detected more joint set in both windows at 10 meter compare to the windows at 15 meter. Window A at 10 meter results in six (6) discontinuity joint sets while Window A at 15 meter only have five (5) discontinuity joint sets. For Window B, the result shown almost same with Window A. Window B at 10 meter results in five (5) discontinuity joint sets while Window B at 15 meter only have four (4) discontinuity joint sets.

In conclusion, data extracted from DSE at 10 meter distance is more accurate than 15 meter distance. If the distance of drone and quarry face is far, the resolution of
images will become lower which can affect the selection of discontinuity joint sets. More random joint sets will be selected because the software used difficult to detect the joint sets because lot of disturbance.

5.2 Recommendations for Future Research

Some of the recommendations for future research is more number of window need to be taken and some preliminary approaches which can make easily and quickly set up and require any limitation that obligate this study. This is important in terms of effort, time and cost.
REFERENCES


APPENDIX A: Report analysis from DSE program

File: C:\Users\User\Desktop\FYP\new\hume 10\hume 10

Used parameters:
- Calculation of the normal vectors of each point and its corresponding poles:
  - knn: 30 (k nearest neighbours).
  - eta: 0.2 (tolerance for the coplanarity test).
- Calculation of the density of the poles:
  - rbins: 64 (number of bins for the kernel density estimation).
  - angleppal: 30 (minimum angle between normal vectors of discontinuity sets).
- Assignment of a discontinuity set to each point:
  - cone: 30 (minimum angle between the normal vector of a discontinuity set and the normal vector of the point).
- Cluster analysis
  - All clusters members of a discontinuity set have the same normal vector.
  - ksigmas: 1.5 (parameter used for test if two clusters should be merged).

Results
- Number of points of the original point cloud: 918223
- Number of points of the classified point cloud: 797791
- Number of unassigned points: 112432
- Number of discontinuity sets: 6
- Extracted discontinuity sets:

<table>
<thead>
<tr>
<th>Dip dir</th>
<th>Dip</th>
<th>Density</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>79.04</td>
<td>44.68</td>
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<td>37.34</td>
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<td>346.63</td>
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<tr>
<td>234.88</td>
<td>76.28</td>
<td>1.7309</td>
<td>9.67</td>
</tr>
<tr>
<td>18.43</td>
<td>25.48</td>
<td>1.3565</td>
<td>17.96</td>
</tr>
<tr>
<td>130.40</td>
<td>80.31</td>
<td>0.0721</td>
<td>2.18</td>
</tr>
<tr>
<td>169.81</td>
<td>86.61</td>
<td>0.0557</td>
<td>3.00</td>
</tr>
</tbody>
</table>

Where % is the number of assigned points to a DS over the total number of points

File: C:\Users\User\Desktop\FYP\new\hume 15\hume 15

Used parameters:
- Calculation of the normal vectors of each point and its corresponding poles:
  - knn: 30 (k nearest neighbours).
  - eta: 0.2 (tolerance for the coplanarity test).
- Calculation of the density of the poles:
  - rbins: 64 (number of bins for the kernel density estimation).
  - angleppal: 30 (minimum angle between normal vectors of discontinuity sets).
- Assignment of a discontinuity set to each point:
  - cone: 30 (minimum angle between the normal vector of a discontinuity set and the normal vector of the point).
- Cluster analysis
  - All clusters members of a discontinuity set have the same normal vector.
  - ksigmas: 1.5 (parameter used for test if two clusters should be merged).

Results
- Number of points of the original point cloud: 400355
- Number of points of the classified point cloud: 347424
- Number of unassigned points: 56431
- Number of discontinuity sets: 5
- Extracted discontinuity sets:

<table>
<thead>
<tr>
<th>Dip dir</th>
<th>Dip</th>
<th>Density</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.85</td>
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<td>5.4489</td>
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<tr>
<td>1.66</td>
<td>79.04</td>
<td>3.5312</td>
<td>20.40</td>
</tr>
<tr>
<td>244.90</td>
<td>42.96</td>
<td>3.8408</td>
<td>8.54</td>
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<tr>
<td>222.38</td>
<td>73.87</td>
<td>0.3184</td>
<td>9.06</td>
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<tr>
<td>115.89</td>
<td>85.62</td>
<td>0.8611</td>
<td>1.79</td>
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</table>

Where % is the number of assigned points to a DS over the total number of points
File: C:Users\User\Desktop\YPV\new\clima 10\cima 10

Used parameters:
- Calculation of the normal vectors of each point and its corresponding poles:
  - kmn: 30 (k nearest neighbours).
  - eta: 0.2 (tolerance for the coplanarity test).
- Calculation of the density of the poles:
  - rhins: 64 (number of bins for the kernel density estimation).
- angleopps: 30 (minimum angle between normal vectors of discontinuity sets).
- Assignment of a discontinuity set to each point:
  - cone: 30 (minimum angle between the normal vector of a discontinuity set and the normal vector of the point).
- Cluster analysis:
  - ksigmas: 1.5 (parameter used for test if two clusters should be merged).

Results:
- Number of points of the original point cloud: 854322
- Number of points of the classified point cloud: 336078
- Number of unassigned points: 518244
- Number of discontinuity sets: 5
- Extracted discontinuity sets:

<table>
<thead>
<tr>
<th>Dip dir</th>
<th>Dip</th>
<th>Density</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>290.29</td>
<td>72.71</td>
<td>0.0072</td>
<td>12.34</td>
</tr>
<tr>
<td>262.43</td>
<td>24.39</td>
<td>0.1635</td>
<td>8.93</td>
</tr>
<tr>
<td>332.53</td>
<td>88.87</td>
<td>0.0338</td>
<td>4.86</td>
</tr>
<tr>
<td>199.54</td>
<td>76.10</td>
<td>0.0284</td>
<td>2.04</td>
</tr>
<tr>
<td>79.47</td>
<td>97.39</td>
<td>0.0017</td>
<td>26.12</td>
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</table>

Where % is the number of assigned points to a DS over the total number of points.

File: C:Users\User\Desktop\YPV\new\clima 15\cima 15m

Used parameters:
- Calculation of the normal vectors of each point and its corresponding poles:
  - kmn: 30 (k nearest neighbours).
  - eta: 0.2 (tolerance for the coplanarity test).
- Calculation of the density of the poles:
  - rhins: 64 (number of bins for the kernel density estimation).
- angleopps: 30 (minimum angle between normal vectors of discontinuity sets).
- Assignment of a discontinuity set to each point:
  - cone: 30 (minimum angle between the normal vector of a discontinuity set and the normal vector of the point).
- Cluster analysis:
  - All clusters members of a discontinuity set have the same normal vector.
  - ksigmas: 1.5 (parameter used for test if two clusters should be merged).

Results:
- Number of points of the original point cloud: 678048
- Number of points of the classified point cloud: 303386
- Number of unassigned points: 374652
- Number of discontinuity sets: 4
- Extracted discontinuity sets:

<table>
<thead>
<tr>
<th>Dip dir</th>
<th>Dip</th>
<th>Density</th>
<th>%</th>
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<tr>
<td>295.39</td>
<td>85.93</td>
<td>0.3541</td>
<td>10.97</td>
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<tr>
<td>212.62</td>
<td>85.83</td>
<td>0.1779</td>
<td>7.00</td>
</tr>
<tr>
<td>224.47</td>
<td>19.29</td>
<td>0.1138</td>
<td>0.76</td>
</tr>
<tr>
<td>82.37</td>
<td>101.55</td>
<td>0.0007</td>
<td>30.87</td>
</tr>
</tbody>
</table>

Where % is the number of assigned points to a DS over the total number of points.
APPENDIX B: Rock Mass Classification RMR System (Bieniawski, 1999)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength of intact rock material</td>
<td>&gt;0 MPa, 6-10 MPa, 2-4 MPa, &lt;1 MPa</td>
</tr>
<tr>
<td>Uniaxial compressive strength</td>
<td>&gt;20 MPa, 10-25 MPa, 5-10 MPa, &lt;5 MPa</td>
</tr>
<tr>
<td>Condition of discontinuities</td>
<td>Very rough, Rough, Fairly rough, Smooth</td>
</tr>
<tr>
<td>Degree of jointing</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td>Degree of weathering</td>
<td>Unweathered, Slightly weathered, Moderately weathered, Highly weathered</td>
</tr>
</tbody>
</table>
|岩层岩体分类RMR系统（Bieniawski, 1999）

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength of intact rock material</td>
<td>&gt;0 MPa, 6-10 MPa, 2-4 MPa, &lt;1 MPa</td>
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<tr>
<td>Uniaxial compressive strength</td>
<td>&gt;20 MPa, 10-25 MPa, 5-10 MPa, &lt;5 MPa</td>
</tr>
<tr>
<td>Condition of discontinuities</td>
<td>Very rough, Rough, Fairly rough, Smooth</td>
</tr>
<tr>
<td>Degree of jointing</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td>Degree of weathering</td>
<td>Unweathered, Slightly weathered, Moderately weathered, Highly weathered</td>
</tr>
</tbody>
</table>

B. RATING ADJUSTMENTS FOR DISCONTINUITY MAPPING

<table>
<thead>
<tr>
<th>Discontinuity rating</th>
<th>Very favourable</th>
<th>Favourable</th>
<th>Fair</th>
<th>Unfavourable</th>
<th>Very unfavourable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tectonic, Extension</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Faulting</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Shear zones</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
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</table>

C. ROCK MASS CLASSIFIED FROM TOTAL RATINGS

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<thead>
<tr>
<th>Total rating</th>
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<th>20</th>
<th>25</th>
<th>30</th>
<th>40</th>
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<tr>
<td>Class</td>
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<td>Ⅳ</td>
<td>Ⅲ</td>
<td>Ⅱ</td>
<td>Ⅰ</td>
<td>0</td>
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</tbody>
</table>

D. MEANING OF ROCK CLASSES

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<tr>
<th>Class</th>
<th>Description</th>
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</thead>
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<tr>
<td>V</td>
<td>Very poor rock, Poor rock, Very weak rock, Weak rock</td>
</tr>
<tr>
<td>Ⅳ</td>
<td>Weak rock</td>
</tr>
<tr>
<td>Ⅲ</td>
<td>Fairly weak rock, Fairly weak rock, Fairly weak rock, Weak rock</td>
</tr>
<tr>
<td>Ⅱ</td>
<td>Weak rock</td>
</tr>
<tr>
<td>Ⅰ</td>
<td>Strong rock, Good rock</td>
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</tbody>
</table>

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY CONDITIONS

<table>
<thead>
<tr>
<th>Discontinuity</th>
<th>1-5 mm</th>
<th>5-20 mm</th>
<th>&gt;20 mm</th>
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</thead>
<tbody>
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<td>Groundwater</td>
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<td>Yes</td>
<td>No</td>
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<tr>
<td>Roughness</td>
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<td>Soft</td>
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<tr>
<td>Weathering</td>
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<td>Slightly weathered, Moderately weathered, Highly weathered</td>
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</tr>
</tbody>
</table>

F. EFFECT OF DISCONTINUITY ON ORIENTATION IN TUNNELLING*

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<th>Orientation in tunnel axis</th>
<th>Orientation in tunnel axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
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<td>+/-45°</td>
</tr>
<tr>
<td>Hard</td>
<td>+/-45°</td>
<td>+/-45°</td>
</tr>
<tr>
<td>Soft</td>
<td>+/-45°</td>
<td>+/-45°</td>
</tr>
<tr>
<td>Normal</td>
<td>+/-45°</td>
<td>+/-45°</td>
</tr>
<tr>
<td>Infilling type</td>
<td>Orientation in tunnel axis</td>
<td>Orientation in tunnel axis</td>
</tr>
<tr>
<td>None</td>
<td>+/-45°</td>
<td>+/-45°</td>
</tr>
<tr>
<td>Hard</td>
<td>+/-45°</td>
<td>+/-45°</td>
</tr>
<tr>
<td>Soft</td>
<td>+/-45°</td>
<td>+/-45°</td>
</tr>
<tr>
<td>Normal</td>
<td>+/-45°</td>
<td>+/-45°</td>
</tr>
</tbody>
</table>

* Some conditions are mutually exclusive. For example, if infilling is present, the roughness of the surface will be influenced by the infilling. In such cases, use A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z. Klimpem et al. (1993).