ROCK MASS CHARACTERISATION OF TUNNEL FACE USING IMAGE ANALYSIS TECHNIQUE

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SCHOOL OF CIVIL ENGINEERING
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By

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ABSTRAK

Pemerhatian geologi adalah penting untuk mencirikan jisim batuan sebelum mengklasifikasikannya ke dalam gred klasifikasi jisim batuan yang sesuai. Cara tradisional mengukur orientasi menggunakan kompas geologi menunjukkan kesukaran untuk mendapatkan hasilnya kerana pekerja terdedah kepada risiko jatuh batu. Selain itu, kerumitan muka terowong boleh menghasilkan hasil pemetaan muka yang berbeza antara ahli geologi. Dalam kajian ini, fotogrametri jarak dekat digunakan untuk mencipta 3D point cloud. 3D point cloud dieksport ke CloudCompare untuk mendapatkan facet dengan orientasi yang sama. Hasil daripada orientasi menggunakan compass plugin disahkan dengan orientasi yang diperoleh menggunakan kompas geologi. Bilangan foto, bilangan GCP (Titik Kawalan Tanah), tetapan kualiti, kecerahan dan suhu warna sumber cahaya adalah kriteria penting dalam mewujudkan ketumpatan awan titik yang lebih tinggi, kurang masa analisis dan menunjukkan orientasi yang betul bagi ketidaksinambungan pada muka terowong. Parameter optimum dan minimum kemudiannya diambil kira dalam projek kehidupan sebenar kerana ia boleh menjejaskan masa dan kos semasa penggalian terowong.

ABSTRACT

Geological observation is important to characterize the rock mass before classified it into the suitable rock mass classification grade. Traditional way of measuring orientation using geological compass show difficulty in obtaining the result as the worker is exposed to the risk of rock fall. Moreover, the complexity of the tunnel face can produce different results of the face mapping between the geologists. In this study, close range photogrammetry is used to create 3D point cloud. The 3D point cloud is exported to the CloudCompare to obtain facet with the same orientation. The result of the orientation using compass plugin is verify with the orientation obtained using geological compass. Number of photos, number of GCPs (Ground Control Points), setting of the quality, brightness and colour temperature of the light source is the important criteria in creating higher density of the point cloud, less time of analysis and show the correct orientation of the discontinuity on the tunnel face. The optimum and minimum parameter is then taken into consideration in real-life project as it can affect the time and cost of the during tunnelling excavation.

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LIST OF SYMBOLS

J1	Joint Set 1
J2	Joint Set 2
J3	Joint Set 3
J4	Joint Set 4
J5	Joint Set 5

LIST OF ABBREVIATION

2D	Two-Dimensional
3D	Three-Dimensional
AM	Agisoft Metashape
CC	CloudCompare
GCP	Ground Control Points
GNSS	Global Navigation Satellite System
Kd-tree	K-dimensional Tree
NATM	The New Austrian Tunnelling Method
RTK	Real-Time Kinematic
SfM	Surface from Motion
RMSE	Root Mean Square Error

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Tunnelling by drilling and blasting is the most common method used. The New Austrian Tunnelling Method (NATM) use this method for underground tunnelling that is suitable for hard rock conditions, soft rock conditions and mixed ground conditions (Phadke and Titirmare, 2017). In extremely tough or changing geological circumstances, sequential tunnelling provides the face cross section-section according to the geological condition along with the tunnelling progress (Jodi and Resch, 2011). After blasting, the temporary support is installed using wire mesh, tunnel arches or bolts depending on the type of rock to prevent rockfall or collapse. Then, the surveying stage takes place by mapping the tunnel face. The geological sketch of the tunnel face is usually used to obtain the geological condition during the tunnel construction period. After that, the secondary support is determined using rock mass classification.

Several elements influence the stability of an underground tunnel, including rock mass characteristics, in situ stresses, geological conditions, blasting-induced dynamic loading, and support systems (Das and Singh, 2021). The strength of jointed rock masses is influenced by the degree of interlocking between individual rock blocks separated by discontinuities such as bedding planes and joints (Satici, 2006). The discontinuity can highly affect the mechanical behaviour of rock masses. Rock with visible discontinuities will influence the blasting outcome. Accidental falling of rock blocks created by the intersection of the tunnel surface and discontinuities in the rock mass is one of the most critical challenges in tunnel excavation (Keykha *et al.*, 2011). The assessment of discontinuity of the rock mass is important during excavation to predict the changes in the rock environment. The data on discontinuity can be acquired using visual and manual technologies such as geological mapping and compass-clinometer to characterize rock masses or using image analysis techniques.

1.2 Problem Statement

The traditional method of mapping required physical access to all measurement areas. Elevated risk, cost and time consuming, subjective data, and inconsistency result are the factor contributing to the problem when using the traditional method. The larger area of the rock mass is limited for the geologist to cover and potentially dangerous to reach high area. The accessibility of the measurement location is limited and not safe (Buyer & Schubert, 2017; Haneberg, 2008b; Schubert, 2006a). The location of the orientation chosen is likely to be less important by choosing one easier to reach rather than choosing the significant one (Schubert, 2006) and beyond the reach of the geologists on foot (Haneberg, 2008). The geologist needs an alternative such a mechanical lift to measure the orientation that will significantly slows the rate and increases the cost of data collection (Haneberg, 2008).

The inconsistency result from the original rock structure may have changed due to excavation or erosion, making it difficult to reconsider or recreate mapping results (Schubert, 2006). Mapping in the tunnel is under the time restriction. It is time-consuming for a bigger area. Although the area can be covered, geological map disadvantages in terms of human bias as it produces subjective data from human eye visual to characterize rock masses. Figure 1.1 shows the tunnel face with highly heterogenous, disrupted and fractured rock mass. The complex geological condition of the tunnel face making difficult to completely record the geological condition using the traditional geological sketch (Qiu *et al.*, 2021). Traditional measurement techniques are prone to human bias and provide only a basic understanding of a discontinuity network.

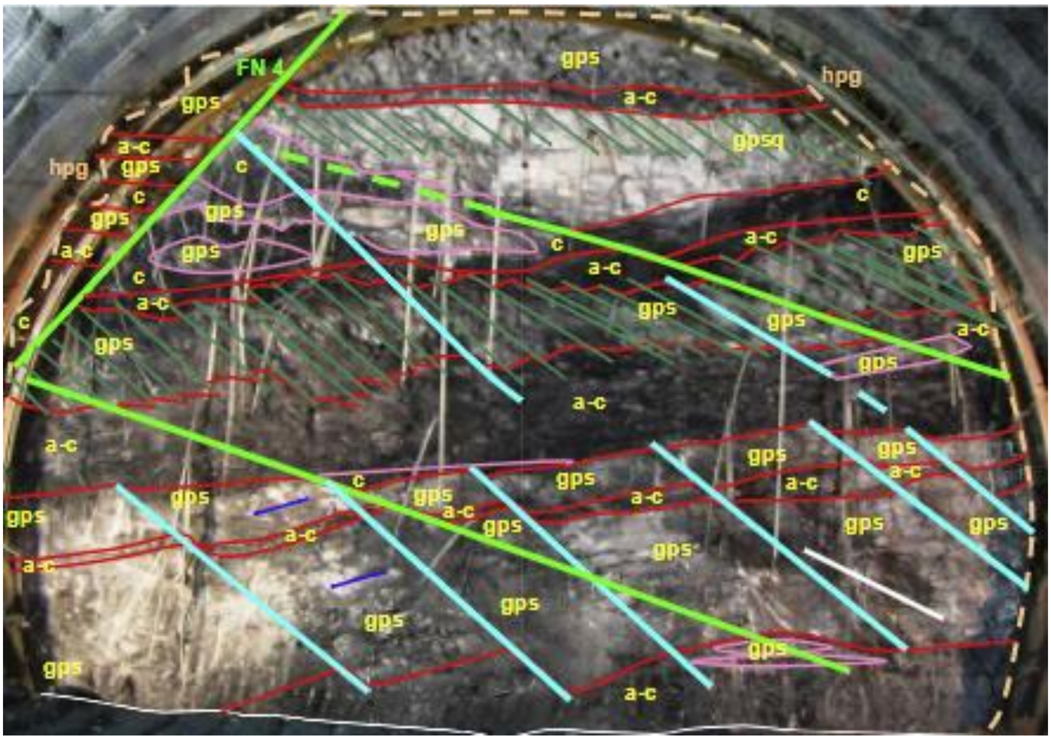


Figure 1.1:Geological mapping of tunnel face (Barla, 2016).

1.3 Objective of The Study

1. To create 3D models of the tunnel face using close range photogrammetry technique.
2. To determine the discontinuity orientation using image analysis technique.
3. To evaluate the optimum and minimum variable of the discontinuity orientation detection using image analysis technique.

1.4 Scope of Work

The scope of work of image analysis is using two tunnel face replicas with different discontinuity from each other.

1. Two replicas of the tunnel face are created using polystyrene located for an indoor and outdoor model.
2. 10 ground control point is well distributed to determine the orientation of the tunnel face.

3. A mirrorless camera with a fixed lens is used to take the image. The camera is stabilized using a tripod to get better image.
4. The image is then computed in the Agisoft Metashape to get the 3D points cloud.
5. Facet extraction into family's colour in Cloud Compare.

1.5 Dissertation Outline

For a better understanding of this analysis, the dissertation paper has been divided into several chapters. Thus, below are the chapters included.

Chapter 1: This chapter summarizes the key findings of the study and provides an overview of its contents. This chapter lays out the conceptual framework for the researcher's research, which includes scientific challenges, hypotheses, and basic research structure.

Chapter 2: This chapter concludes by arguing for evaluating research issues and developing research methodologies. This chapter covers the topic, the underlying research problem, the question(s), and the design aspects, as well as the theoretical framework for the thesis.

Chapter 3: The dissertation's research approach is discussed in this chapter. The study method, research methodology, data collection methods, dataset design, research procedure, data analysis format, ethical issues, and project research limits are all explored in further depth in this chapter.

Chapter 4: The goal of this chapter is to summaries, analyses, and present the information gathered. Before outlining what will be covered in this chapter, this section of Chapter 4 summarizes the issue statement, approach, research question(s), hypothesis(s), or phenomena. The findings of the investigation should be described as concisely as possible in Chapter 4, with a summation saved for Chapter 5.

Chapter 5: This chapter provides a comprehensive overview of the context of the analysis. This chapter will make assumptions, connotations, and recommendations.

1.6 Expected Outcome

In this research, the 3D model with points cloud is generated by taking multiple pictures from multiple angles. The orientation of the tunnel face can be determined using ground control points using Real-Kinematics-Time Positioning (RTK) to mark the exact point on the earth. The discontinuity of the tunnel face can be determined using a different number of the GCP, number of pictures, lighting conditions and the quality of the setting to produce the best condition to determine more distinct features of the discontinuity. The minimum and minimum variable of the parameter is then determined.

1.7 Importance and Benefit

The 3D model can give the overview of the characteristic of the rock condition along the tunnel alignment. With the help of image analysis technique geologist and engineer will be able to visualize the location of the problematic area of the project with the real-life coordinate.

Traditionally, geologist record their observation that include sketch and measurement of the site on the paper. This also includes making field interpretations of the position of features such as geologic contacts and faults. Photogrammetric 3D models were created continuously as the excavation proceeded, resulting in high-resolution 3D data serving as a permanent digital record for future use, even after the tunnel walls are covered behind structural supports, shotcrete, and cabling.

The development of image analysis technique helps the documentation can be well visual, easier to understand and can be organized in computer and the personal digital assistant. Thus, using image analysis technique will help in standardize and well organized the format of the documentation

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Chapter provide overall view on underground tunnelling, geological mapping, discontinuity, rock mass classification, photogrammetry, and rock stability in tunnel. The literature review will assist in locating the research gap, issues, and trustworthy methodological approach that will be used as references in this study. In addition, the literature evaluation will aid in identifying the fundamentals learned during this research.

2.2 Underground Tunnelling

Underground excavation involves in removing the soil or rock from its original condition. Depending on the underground condition different method of underground tunnelling excavation can be used. Each of the tunnelling method provide benefit depending on the condition.

2.2.1 New Austrian Tunnelling Method (NATM)

Figure 2.1 show the NATM process of tunnelling excavation NATM method is performed by drilling the blast hole and load it with the explosive. After the blasting, ventilation in the tunnel is to remove the blast fume. The blasted rock is then removed. Any of the loosened pieces of rock is removed by scaling the crown and the wall. Temporary support should be provided after the excavation such as shotcrete or rock bolt. Then any deformation is monitored. After that, the initial ground support is installed.

NATM give advantages in give clear understanding of the geological condition during the excavation. It can be constructed with almost any profile depending on the geology (Jodi and Resch, 2011). NATM method allow the deformation to happen before the additional support is install which reduce the cost of the construction.

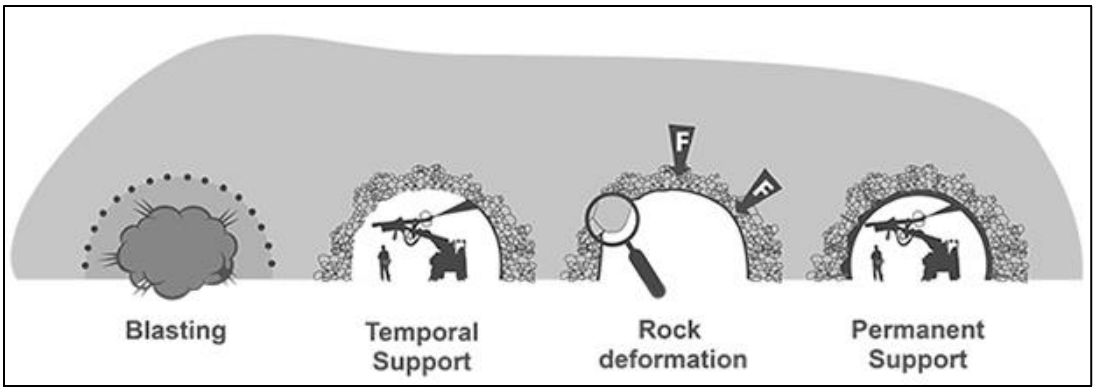


Figure 2.1: NATM method (source https://bestsupportunderground.com)

2.2.2 Tunnel Boring Machine (TBM)

Figure 2.2 show the single-shield TBM. The disc cutter located in front of the TBM, spinning and digging away the soil and the rock. Disc cutters need to be replaced over the time when it became dull. Roof shields protect the TBM body and the worker inside. Then, concrete panel is installed behind the shield. The excavated earth material by the cutter is transfer to the back of the TBM using conveyor belt. TBM can be used in continuously tunnelling in hard rock. A TBM's design and construction must be precisely suited to a certain rock mass behaviour.

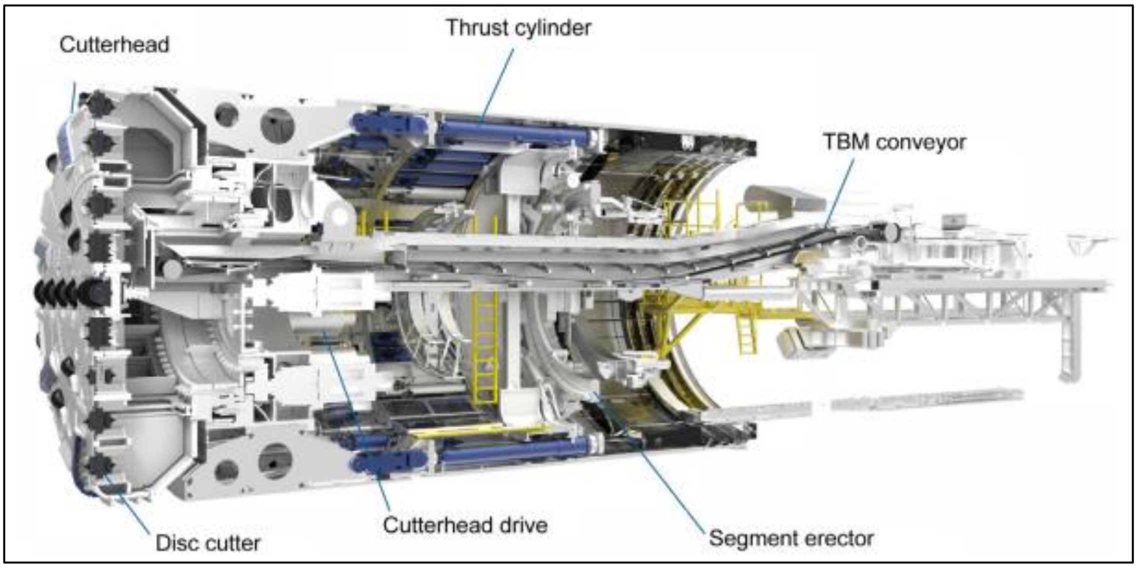


Figure 2.2: Typical diagram of single-shield TBM (Yun, 2019).

2.3 Discontinuity of Rock Mass

Based on Figure 2.3, the fundamental parameters of rock mass discontinuities, including orientation, spacing, persistence, roughness, aperture, wall strength, filling, seepage, number of joint sets, and block size (ISRM, 1978).

1. Orientation: Dip direction and dip of the line steepest declination in the plane of discontinuity
2. Spacing: Perpendicular distance between adjacent discontinuities
3. Persistence: Discontinuity trace length as overserved in an exposure
4. Roughness: Inherent surface roughness and waviness relative to the mean plane of the discontinuity
5. Wall Strength: Equivalent compression strength of the adjacent rock walls of a discontinuity.
6. Aperture: Perpendicular distance between adjacent rock walls of a discontinuity, can be filled air or water
7. Filling: Material that separates the adjacent walls of a discontinuity
8. Seepage: Water flow and free moisture visible in individual discontinuities or in the rock mass as a hole.
9. Number of Set: The number of joint sets comprising the intersection joint system.
10. Block Size: The rock block dimension resulting from the mutual orientation of intersecting joint sets and resulting from the spacing of the individual sets. Individual discontinuities may further influence the block size and shape.

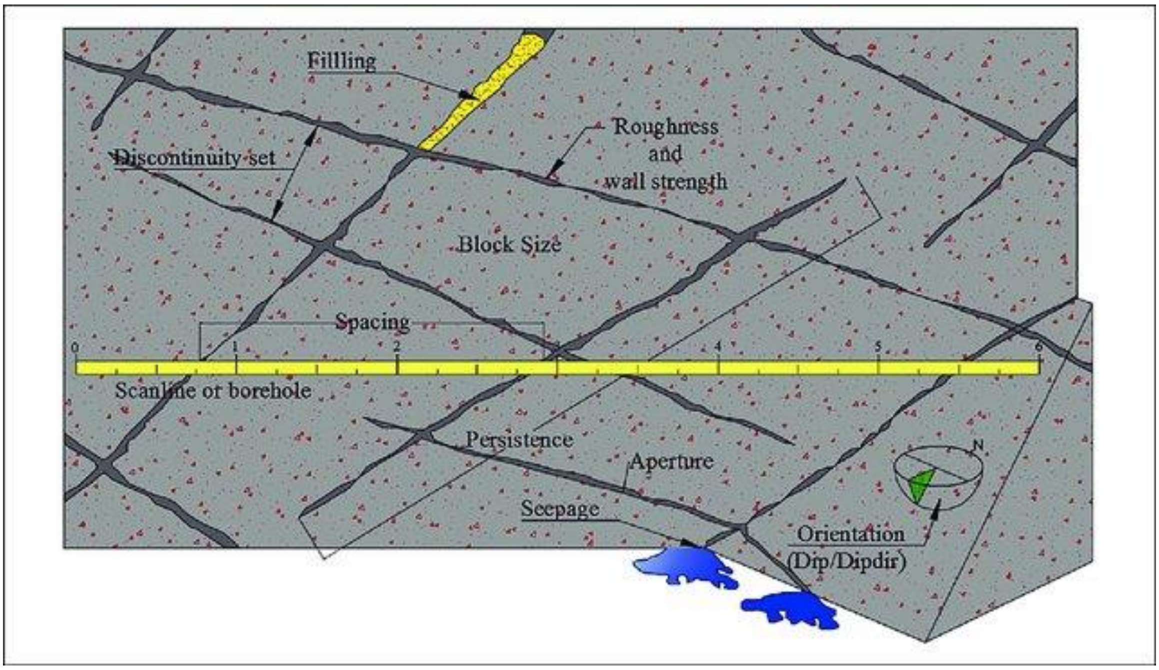


Figure 2.3: Schematic of the primary geometrical properties of discontinuities in rock (modified after Hudson & Harrison, 2000).

2.4 Geological Mapping

Geological mapping is processed to extract the information to represent the rock condition. In rock mapping, the parameter measure is type and weathering grade of rock, orientation (dip amount /dip direction or strike), spacing, persistence, roughness, wall strength, aperture, type of filling, seepage, number of joint sets, block size and shape and type of discontinuity (Wanna Phyo et al., 2014). The geological mapping is being used in determining the orientation of the major joint sets and identified the potential mode of structural failures. In deep excavation, the exposed rock of the shaft and tunnel are mapped after every stage of blasting.

There are several types of underground geologic mapping methods which include full periphery mapping, plan and section, face maps, photogrammetric mapping and exploration mapping method selection and construction mapping. Figure 2.4 show the 2D tunnel face mapping. Face mapping is the common use mapping used.

TUNNEL FACE GEOLOGICAL MAPPING

Date: 20-8-2014	Time:
Site: North Portal	Chainage: 15+415 - 15+680
Rock Type: Schist	Rock Support Class:
Round Length: 265m	Phot No.

Weathering:	Fresh	Slightly	Moderately	Highly ✓	Completely	Residual Soil
Rock Strength:	Very Strong	Strong	Med. Strong	Weak ✓	V. Weal ✓	Ext. Weak
Rock Quality	V. Good	Good	Fair	Poo ✓	V. Poo ✓	Ext. Poor
Water Condition:	Dry	Damp	We ✓	Dripping	Seepage	Flowing

Discontinuity Characteristics

Set No.	Three joint set + Random
Type	Schist
Strike	Perpendicular o Tunnel Axis
Dip	Drive against the Dip between 45 - 90 degree
Persistance (m)	3-10 m
Apenture (mm)	0.1-1mm
Spacing (mm)	> 60 mm
Filling	Soft filling <5mm
Weathering	Highly Weather

Rock Support

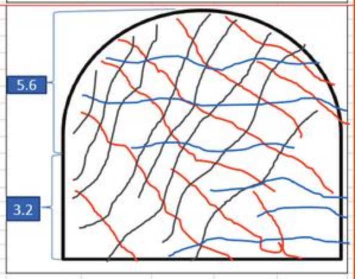
	Recommended	As built
Lattice Girder		(25x25 cm) (1-1.5m) spacing
Rock Bolt 20mm	Length 4m-5m @ (1.5m)	Length (3-4m) @ (1-1.5m) Ø 32mm
Wire Mesh	-	(75*75cm) spacing 7.5cm
Force Polling	-	
Shotcrete	20-15 cm	30-40 cm

Type		Roughness		Aperture (mm)	
Fault	F	Stepped Rough	Sr	Very Tight	<0.01
Joint	J ✓	Stepped Smooth	Ss	Tight	0.01-0.2 ✓
Slickensided	Sl	Stepped Slickensided	Ssl	Partly Open	0.25-0.5 ✓
Fractured	F ✓	Undulating Rough	U ✓	Open	0.5-2.5 ✓
Schistosity	Sc	Undulating Smooth	Us	Widely open	2.5-10
Bedding Plan	B	Undulating Slickensided	Usl	V. Wid. Open	10-jan
Foliation	Fl	Planar Rough	Pr	Extr. Wid. Oper	10-100
Shear	Sh	Planar Smooth	Ps	Cavernous	>1
Fold	Fo	Planar Slickensided	Psl		

Spacing (m)		Persistance (m)		Block size Joint/ m²	
Extr. Low	<0.02	very Low	<1	very Large	<1
Very Low	0.02-0.0 ✓	Low	1-3	Large	1-3
Close	0.06-0.2 ✓	Medium	3-1(✓	Medium	3-10
Moderate	0.2-0.6	High	10-20	Small	10-30
Wide	0.6-2	Very High	>20	Very Small	>30
Very Wide	2-6			Crushed	>60
Extr. Wide	>6				

Geology

The exit section at North Portal of Nahakki tunnel is characterized by the presence of schist and metacrbonate. This strata is highly weathered and mainly very weak metamorphic rock. The rock across the proposed tunnel alignment are characterised by the presence of well developed three to three plus radom joint sets. Discontinuity length (Persistence) is medium and varies between 3 to 10m. The aperture size varies between tight to partly open i.e 0.1 to 1 mm Average spacing of joints in the schist are extremely low to very low and ranges between 0.02 to 0.06mThe major controlling joint set is the one parallel to the schistosity which is generally dipping 40⁰ Water condition is wet



RQD/JN:	Jr/Ja:	Jw/SRF:	Q Va;ue:	Rock Class:
10/24=0.416	1.5/4=0.375	0.66/1=0.66	0.103	E

Figure 2.4: Geological face mapping sheet

2.5 Rock Mass Classification

In classifying rock mass, it required judgment from the experience geologist to classify the rock mass into the suitable parameter. There are few methods in classifying rock mass such as Rock Mass Rating (RMR), Q-System Classification, Geological Strength Index (GSI), Rock Mass Index (RMi) Classification. The characteristic of the fault zone between localized and non-localized fault zone differentiates. Then, the fault is classified fractured zone, discontinuity density and rock type (Reinhold, Cordes and Bergmeister, 2019).

RMR and Q system is commonly use and both methods have similarities parameter such as UCS of the rock material, RQD, spacing of discontinuities, condition of discontinuities, groundwater condition and orientation of the discontinuity. This parameter is used in grading the rock mass in Table 2.1. The different between RMR and Q-System is RMR use compressive strength directly while Q-System only consider strength as it relates in situ stress in competent rock. Q-system has been used as a preliminary empirical design support systems for tunnel and cavern in Sundar Khadka & Kumar Maskey (2017).

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

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)						
Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS					
Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

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

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

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**			
Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.
** Modified after Wickham et al (1972).

Table 2.1: Rock Mass Rating System (After Bieniawski, 1989)

2.6 Rock Failure Causes in Tunnel

Stability and serviceability must satisfy in designing and constructing tunnel and underground excavation. is typically required to add some support to the internal boundary via linings after a tunnel has been excavated to maintain stability. Failure in the tunnel involving wedge falling from the roof or sliding out of the sidewalls of the opening. The displacement because of the tunnelling must not affect the surrounding building and the structure. Figure 2.5 show support overstressing, face collapse and water inflow are the most common tunnel failure happen in both in the operation and construction (Spyridis and Proske, 2021).

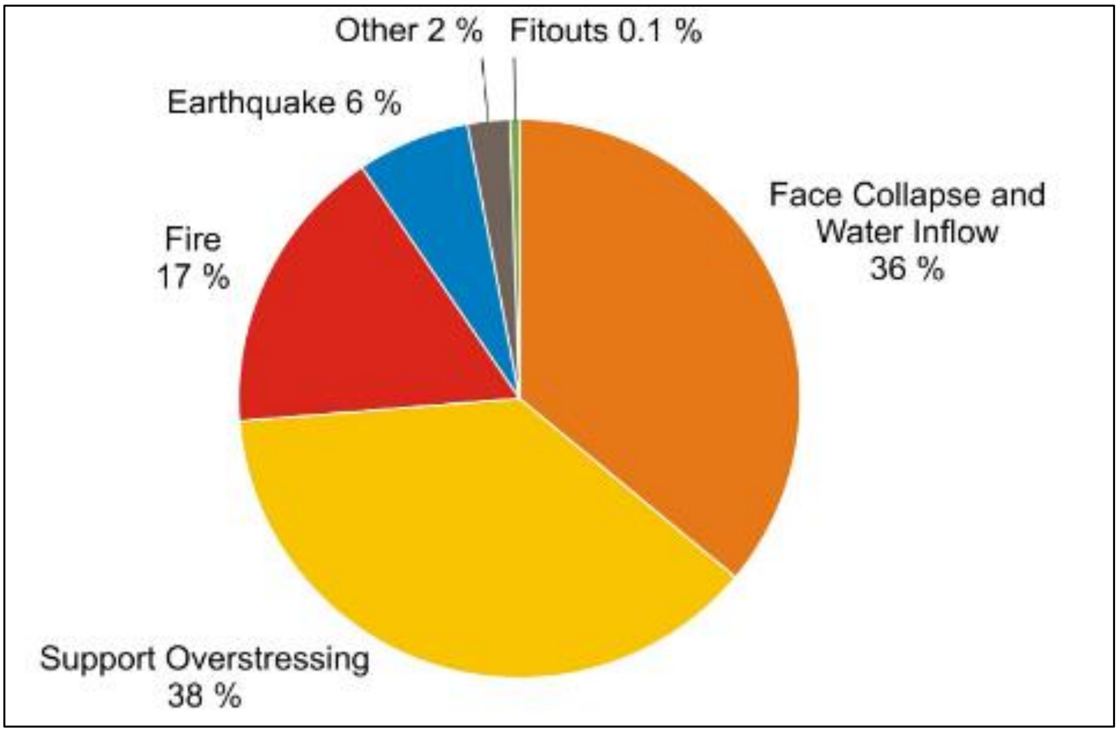


Figure 2.5:Distribution of tunnel failure types (Spyridis and Proske, 2021).

Drilling and blasting have the significant side potential to have an impact excavation damage outside the planned tunnel area. A tunnel's contour becomes irregular because of over-break, and more material must be transported, which increases the expense. The stability of the tunnel over the long term and the necessity for sufficient ground support are both impacted by the existence of a damage zone (van Eldert, 2018).

On the incident side of the tunnel, the pre-crack spreads under blasting loads before a new crack starts (Li *et al.*, 2022). The cross-sectional shape of an underground tunnel has an impact on the process of fracture propagation and tunnel failure (Hao *et al.*, 2019).

2.7 Important Orientation of the Discontinuity in Structural Involving Rock Mass

Rock mass is known to be highly anisotropic. In designing support system in the tunnel, the behaviour of in the rock mass rely primally on the discontinuity distribution on the rock mass. The orientation of the tunnel with respect to the rock structure will affect the tunnel behaviour and has significant impact in term of total cost and cycle time of the tunnel.

Displacements may take place in front of the face, where they are challenging to control (J. Logar and J. Klopčič, 2018). Based on Figure 2.6, higher displacement of the tunnel excavated with dip compared to the tunnel excavated against dip (Vitali et al., 2021). (J. Klopčič & J. Logar, 2014; Vitali et al., 2021). According to Vitali et al., (2021), the study also shows that, higher displacement of the unsupported tunnel at the perimeter of the opening compared to supported tunnel.

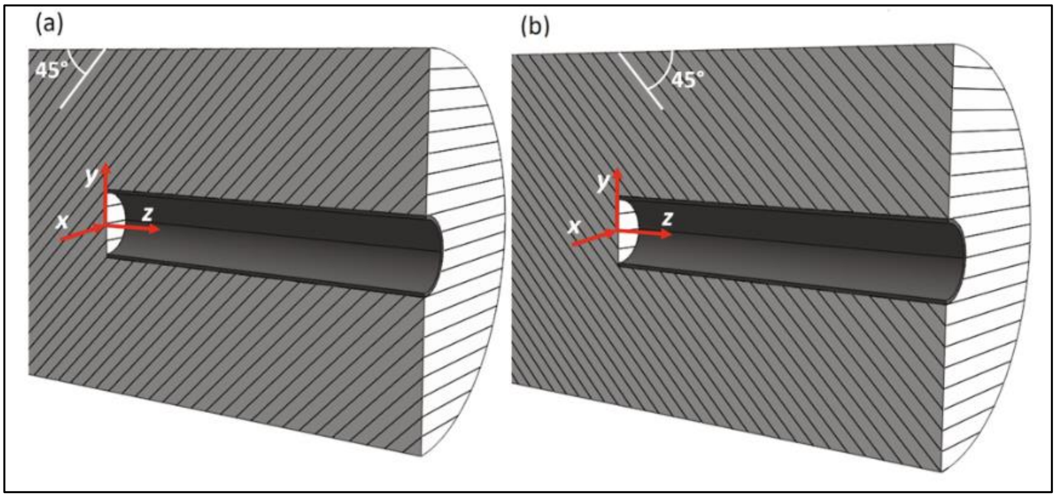


Figure 2.6: The tunnel excavation (a) with dip and (b) against dip (Vitali et al., 2021).

Study from Kais et al., (2009) Figure 2.7 show the condition 1, 5, 6 and 7 is preferable as the joint orientation with dip angle for a joint strike parallel to the tunnel axis is 90 degrees while dip angle dip angle for a joint strike perpendicular to the tunnel axis is 0 degree.

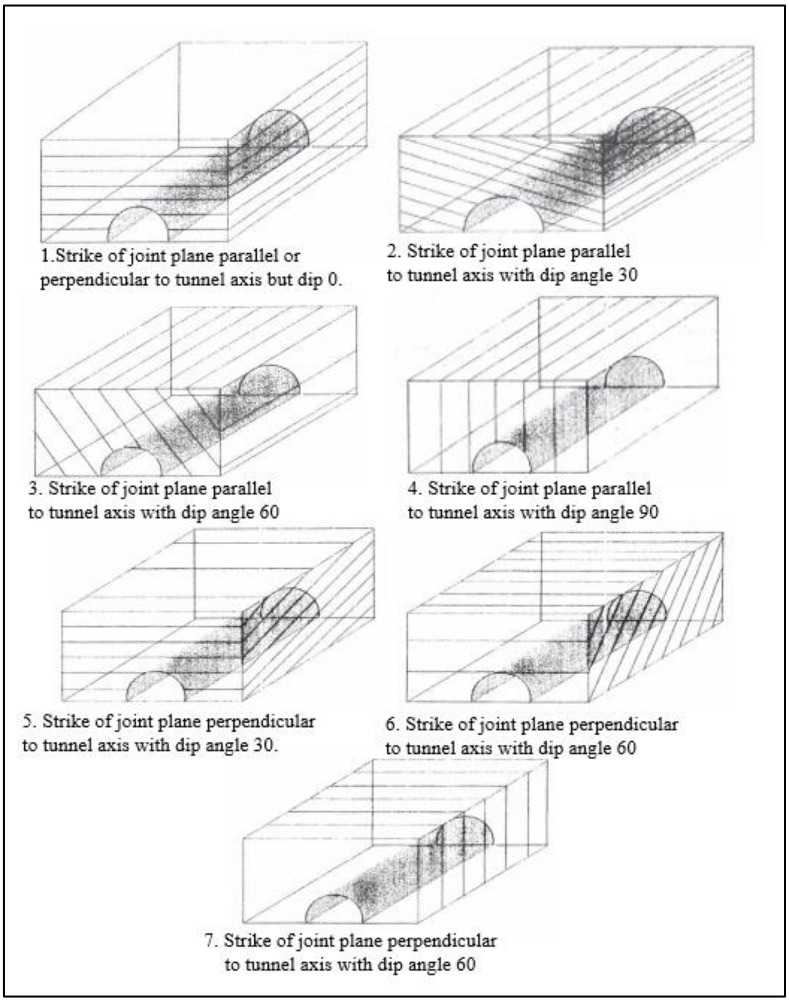


Figure 2.7: The effects of joint orientation with respect to the direction of tunnel axis (Kais et al., 2009)

From Figure 2.8, the relationship between bedding plane that is parallel to tunnel axis with dip angle (Figure 2.9; condition 2,3,4) show the largest damage region happen with dip angle 45º followed by 30º and 60º (Cai *et al.*, 2019). This support study Kais et al., (2009) as condition 2,3,4 is not preferable joint orientation when excavating.

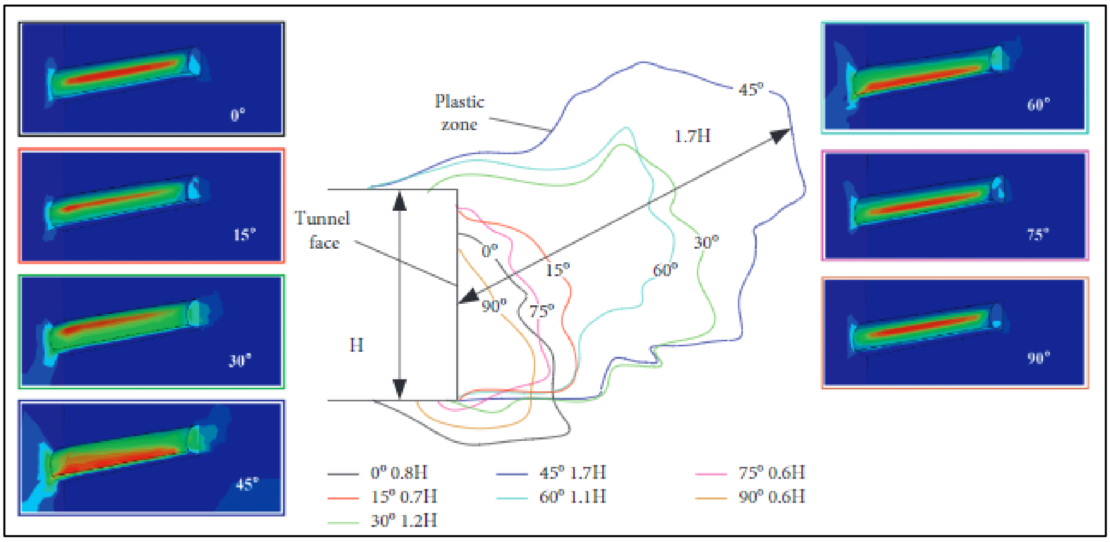


Figure 2.8: Tunnel plastic zone and plastic zone sketch ahead the tunnel under different dip angles (Cai et al., 2019)

The dip angle 30 ° and 45 ° influence the fracture formed in the rock mass compared to dip angle 0 °. When the uniform stress load is applied on the tunnel, the stress redistributes and formed fracture. Thus, the lower the reduction of the rock strength causes the stress transfer to the deepest part of the of the surrounding rock and more fracture appear (Jivkov *et al.*, 2022). The condition of the joint play important part as random of joint set can formed linear cracks connecting the close weak joint (Jeon *et al.*, 2005).

Support pressure and deformation can be accurately estimated from the numerical analysis (Sun et al., 2019; Sundar Khadka & Kumar Maskey, 2017). Finite element method showed the design of the tunnel with combination of bolts, reinforced concrete, given support and evaluated tunnel support design given (Riaz *et al.*, 2016).

2.8 Image Analysis

Image analysis is a technique to extract information from an image. It has been used to been used to assess or quantify the external characteristics such as colour, size, shape and surface texture, and internal structures such as architecture. Using this technique, it is possible to enhance an image's visual while also extracting necessary details or characteristics.

2.8.1 2D image analysis

2D image analysis can extracted information from greyscale digital images of the rock mass exposure. Based on the Figure 2.9 the discontinuity trace can be seen using pixel brightness that differentiate the line of discontinuity (Reid and Harrison, 2000). This method show detection of 4 joint set using one picture in Figure 2.10 (M. Mohebbi *et al.*, 2016).

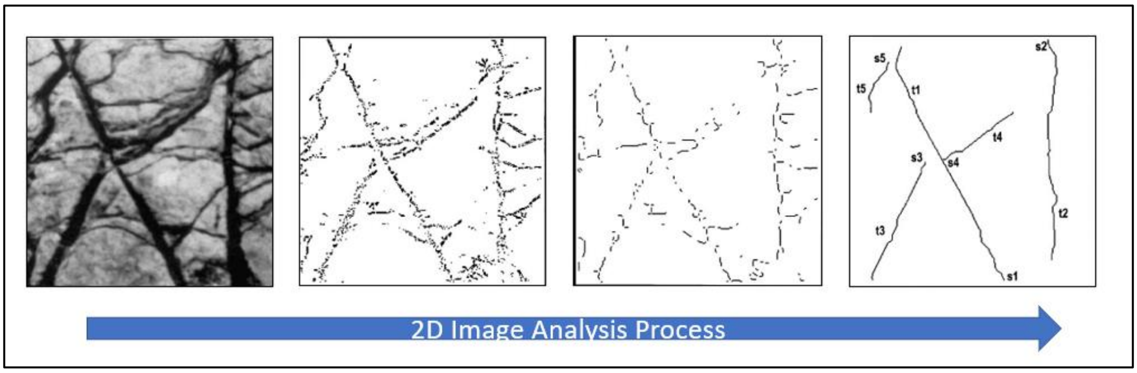


Figure 2.9 : 2D Image analysis process tracing (Reid and Harrison, 2000)

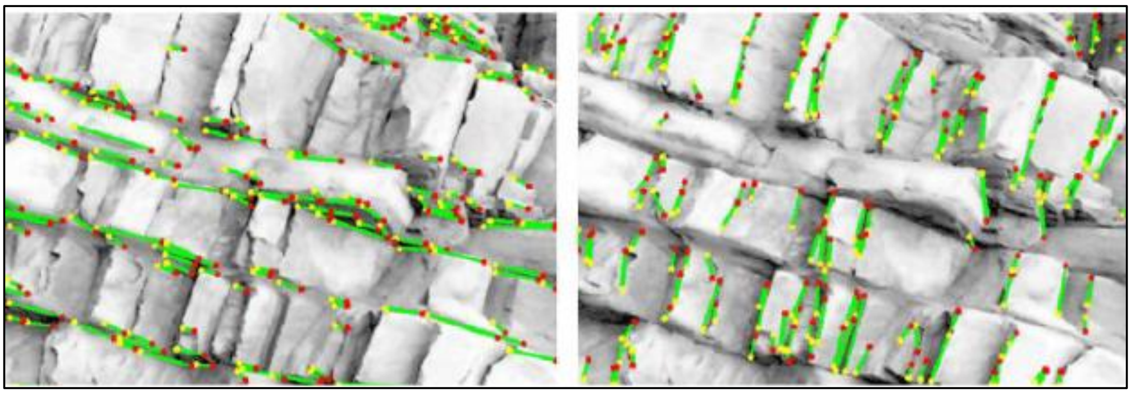


Figure 2.10: 4 Joint sets (M. Mohebbi et al., 2016).

2.8.2 3D image analysis

Photogrammetry can generate 3D model from 2D images. It uses overlapping images to build three-dimensional surfaces. From Figure 2.11, the 3-D surfaces are generated with thousands of x, y and z coordinates using SfM from the pictures with multiple viewpoints. Photogrammetry can be classified into two which are aerial by taking pictures in the air and terrestrial (close range) by taking pictures on the ground.

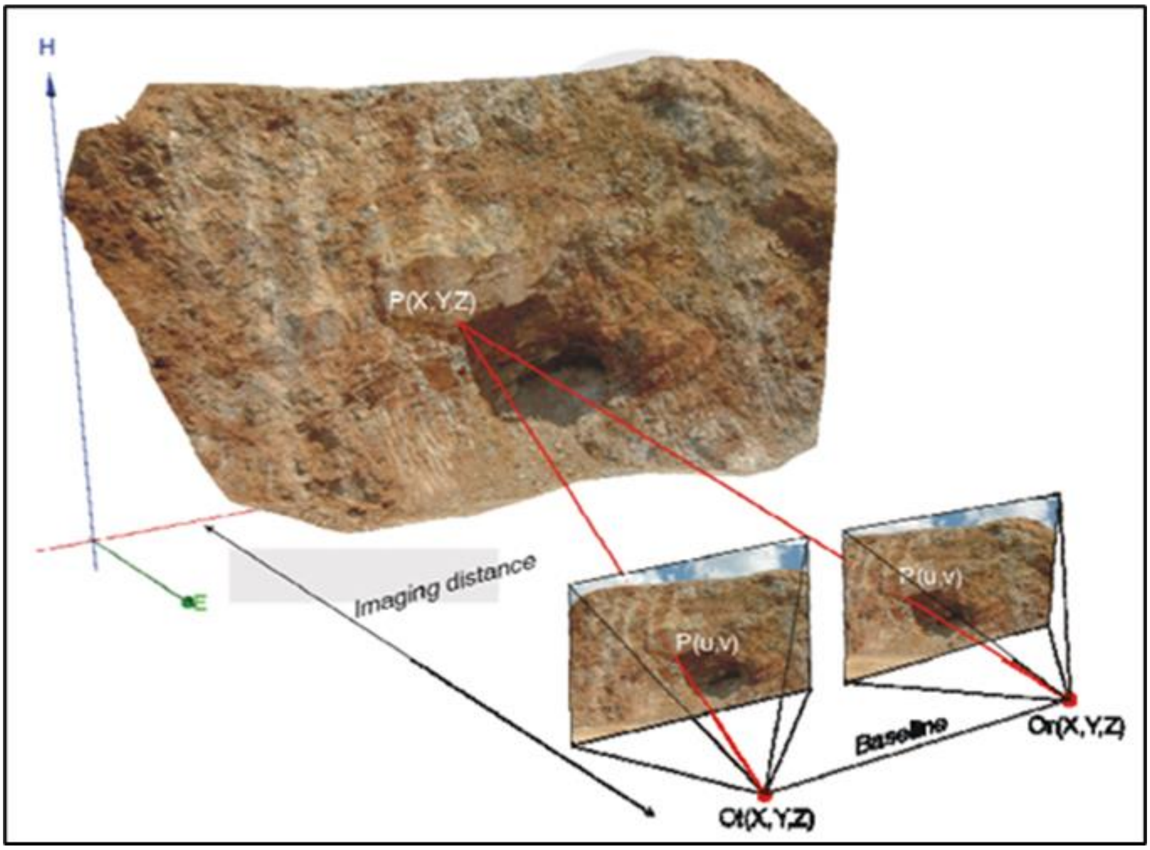


Figure 2.11: Photogrammetry technique

2.9 The application of photogrammetry

The use of 3D image analysis technique using photogrammetry increase of its available digital cameras, storage media, computer hardware and software at affordable cost. Photogrammetry provides 3D models in of the field work, monitoring and documentation.

- Geological 3D analysis such as geological mapping (Eder, Kontrus and König, 2019) and detecting discontinuities (Janiszewski *et al.*, 2020).
- Monitoring changes in channel profile (Faezal Norizan *et al.*, 2016).
- Monitoring landslide (Bt, Mohd Mokhtar and Matori, 2013).
- Cultural heritage documentation (Evagorou *et al.*, 2020).
- Processing coastal imagery (Over *et al.*, 2021).

2.10 Effectiveness using photogrammetry in measuring orientation.

Photogrammetry has been used in comparing scanline survey as it provides consistent data when measuring the dip and dip direction of rock masses (Nagendran, Ismail and Tung, 2019). The result from the 3D point cloud and then the discontinuity extracted from program DSE (Discontinuity Set Extractor) show the same number of discontinuities sets with similar orientations when compared to the traditional analysis (García-Luna *et al.*, 2019). The comparison of software and compass measurement shows the result is within 10° of both dip and strike (Dewez *et al.*, 2016; Kumar and Ismail, 2020). The difference between the information collected using a point cloud-based approach and the geological compass is less than 10% (Papathanassiou et al., 2020). Furthermore, in terms of identifying discontinuities, automatic mapping processes are faster than the human method (Menegoni et al., 2019),

2.11 Gap of Research

The effectiveness of 2D image analysis provides a step towards automated rock mass classification However, automated fracture trace map extraction and evaluation from rock tunnel face images provide three quantitative evaluation indexes of fracture length, dip angle, intensity, and density of the fracture. The whole processes of trace characterization are complex due to poor program integration for 2D image analysis technique (Chen *et al.*, 2021).

The use of 3D image analysis able to visualisation of the model. Simplified geological models are frequently used to classify and describe deep tunnels from a geotechnical standpoint (Reinhold, Cordes and Bergmeister, 2019). 3D image analysis propose method by Qiu et al., (2021) need further work in automatic identification of the joints, fissures, and water leakage.

The image's quality is important as the processing can be simpler and easier using a higher-quality image. Therefore, appropriate computational image processing techniques, such as noise removal, geometric correction, edge and contrast enhancement, illumination correction or homogenization, are needed to increase the original quality of the input images (João Manuel R. S. Tavares, 2010). Only a few studies have been conducted on this image research analysis because of the bias coming from image processing, data accuracy, and precision is still too high for fully automated analysis (Buyer and Schubert, 2016).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter propose methodology for achieving the objectives. The selection of all the approaches was influenced by the in-depth review of the literature, the recommendations, and the critical analysis from Chapter 2.

Figure 3.1 explained from creating physical model using polystyrene, setting ground control point, creating the 3D point cloud using close range photogrammetry technique. The dip / dip direction of the data set is compared between geological compass and compass plugin. The suitable minimum and optimum of the variable is determine.

This close-range photogrammetry method uses mirrorless camera to find good quality of photo. The surrounding lighting condition such as brightness and colour temperature effect the quality of photo. The 3D point cloud density depends on the quality setting chosen.

Data comparison is important to verify the result orientation in the software compared to manually using geological compass. Thus, this show, the important of GCP to establish the actual location of the model that respect to the true north.

Number of GCP, brightness, colour temperature, number of photos and quality setting act as a variable to evaluate the minimum and optimum. The important criteria in determining the variable are time of the analysis, quality of the 3D point clod and the orientation of the discontinuity.

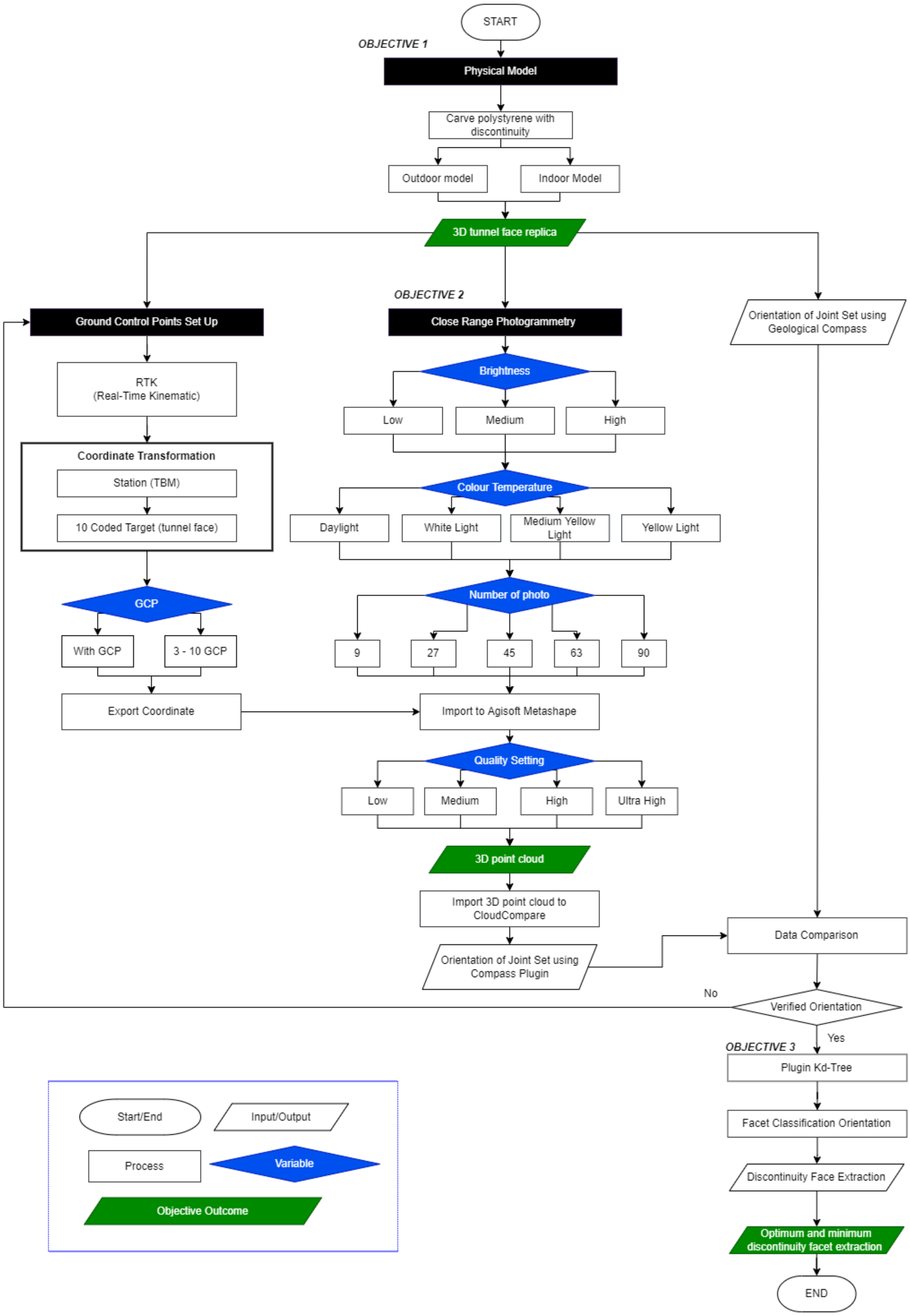


Figure 3.1: Flowchart of methodology

3.2 3D Tunnel Face Replica

The polystyrene is carved to replicate the discontinuity of the tunnel face that include joints, fault line and discontinuity as shown in the Figure 3.2. There are two polystyrene model which represent the condition of the tunnel face outdoor and indoor location. Table 3.1 show the justification of the tunnel face model.

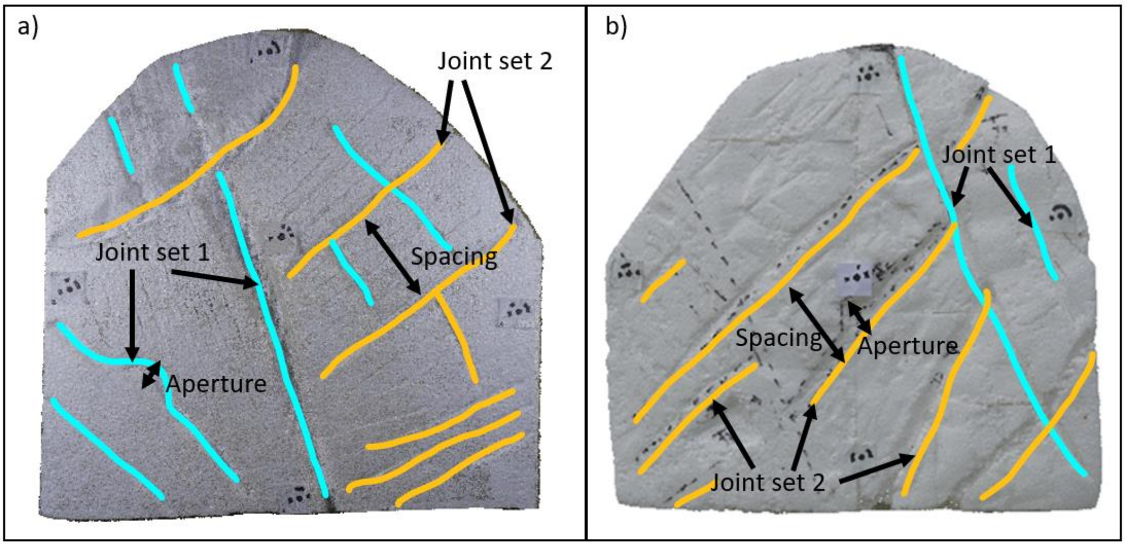


Figure 3.2: a) Indoor model b) Outdoor model

Table 3.1 Discontinuity parameter on the tunnel face

Parameter	Indoor	Outdoor	Justification
Joint Set	2	2	Joint set with different orientation
Aperture (cm)	1.5-5	1.5 -2.5	Different depression in the rock fractures
Spacing (cm)	2-10	6-12	Dimensions of rock block

3.3 Ground Control Point (GCP) Set Up

Identification of the position and orientation of cameras inside the coordinate system related to the coded target is the main goal of coded targets. From Figure 3.3, various shape of coded target is used for measurement in camera calibration, 3D reconstruction and pose estimation. Coded target in Agisoft Metashape provides automatic detection by match between photo to aid in camera alignment using Align Photo option. Coded target is used in this study for positioning the model and improve photo alignment procedure.

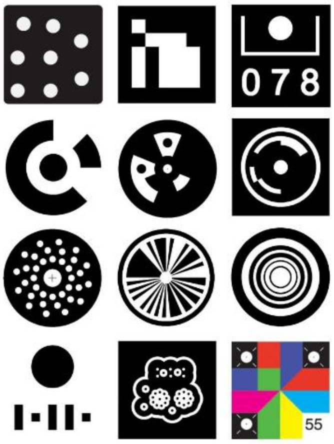


Figure 3.3: Various type of coded target (Tushev, Sukhovilov and Sartasov, 2017).

In this study, coded target with coordinate system functions the same as GCP. The use of ground control point gives actual scale of the model in actual location and positioning in the map. The coordinate system used is a projected coordinate system with Geocentric Datum Malaysia (GDM 2000) for Penang grid. The coordinate system in GDM is represent in northing, easting, and altitude.

From Figure 3.4 and Figure 3.5, there are 5 GCPs placed on the tunnel face and 4 GCP are placed on the wall. The coded target is placed before the photos and surveying take place with different number as shown in Table 3.2 and Table 3.3. The best accuracies are obtained when GCPs are placed around the study area's perimeter (Martínez-Carricondo *et al.*, 2018).

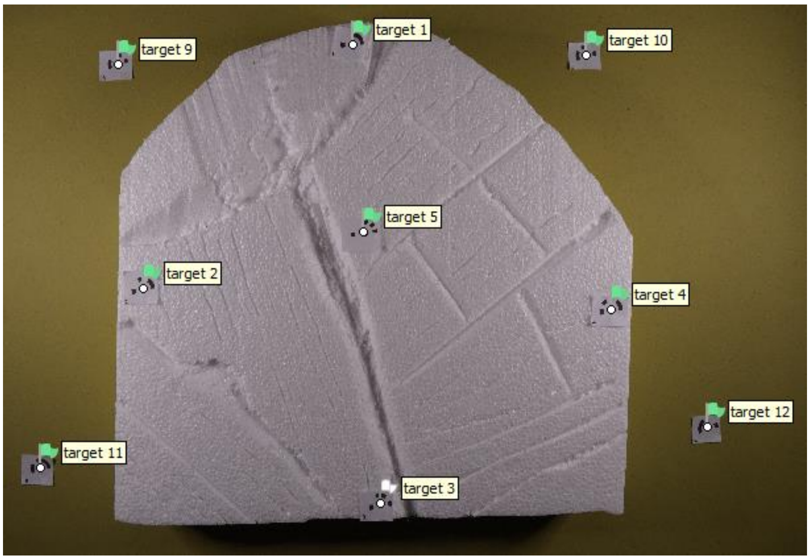
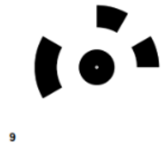
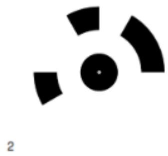
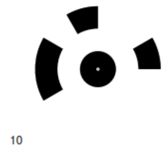
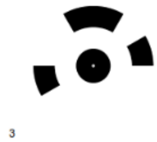
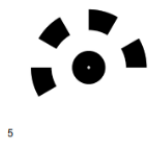


Figure 3.4: Location of the indoor GCP

Table 3.2: Indoor coded target

No.	Coded Target	No.	Coded Target
1		9	
2		10	
3		11	
4		12	
5		13