ROCK MASS DISCONTINUITY CHARACTERISATION USING IMAGE ANALYSIS TECHNIQUE

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SCHOOL OF CIVIL ENGINEERING
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IMAGE ANALYSIS TECHNIQUE

by

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ABSTRAK

Mengukur ciri ruang (arah miring dan miring) kekar batu biasanya dilakukan dengan tangan dengan kompas/klinometer melalui tinjauan garis scan, yang memakan waktu yang lama dan melibatkan banyak kekurangan. Bagi pengamal cerun batu, fotogrametri digital telah berkembang menjadi teknik pencirian jarak jauh yang berguna, terutamanya dalam keadaan di mana pengukuran fizikal kekar sukar atau berisiko. Dalam kajian ini, model direka bentuk dan dicetak secara 3D untuk mewujudkan persekitaran kawalan yang mewakili kekar jisim batu yang selalunya terdapat di lapangan. Perolehan data diperoleh dengan menggunakan telefon pintar, Apple iPhone 12 Pro dan Unmanned Kenderaan Udara Tanpa Pemandu (UAV), DJI Phantom 4 Pro yang dipasang dengan kamera 20 megapiksel untuk mengumpulkan banyak gambar yang bertindih. Untuk analisis 3D, gambar-gambar ini diubah menjadi data awan titik padat menggunakan perisian Metashape dan kemudian dikira di CloudCompare untuk mendapatkan hasil orientasi dari segi arah miring dan miring dengan menggunakan plugin FACET. Sementara itu, satu gambar permukaan model dimasukkan dalam perisian Working Face untuk analisis 2D. Perbandingan antara kedua-dua analisis menunjukkan keupayaan dan batasan setiap perisian yang digunakan dalam penyelidikan ini dalam mengesan sifat kekar.

ABSTRACT

Measuring spatial attitude (dip and dip direction) of rock mass discontinuities is usually done by hand with a compass/clinometer via scanline survey, which takes time and involves some censoring. For rock slope practitioners, digital photogrammetry has evolved into a helpful remote characterisation technique, especially in circumstances where physical discontinuity measuring is difficult or risky. In this study, models are designed, and 3D printed as to create a control environment which represent the actual rock mass discontinuity commonly found at site. Data acquisition is obtained by using a smartphone, Apple iPhone 12 Pro and an Unmanned Aerial Vehicle (UAV), DJI Phantom 4 Pro mounted with 20 megapixels camera to collect multiple overlapping images. For 3D analysis, these images are transformed into dense point cloud data using Metashape software and later computed in CloudCompare to obtain the orientation results in terms of dip and dip direction by utilising its FACET plugin. Meanwhile, one single image of the surface of the model is computed in the Working Face software to compute for the 2D analysis. Comparison between the two analyses show the capabilities and limitations of each of the softwares used in this research in detecting the nature of discontinuities.

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LIST OF SYMBOLS

M1	Model 1
M10	Model 10
M11	Model 11
M2	Model 2
M3	Model 3
M4	Model 4
M5	Model 5
M6	Model 6
M7	Model 7
M8	Model 8
M9	Model 9
S	Joint spacing
α	Dip angle
β	Joint strike

LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
CAD	Computer-Aided Design
CRP	Close Range Photogrammetry
CSG	Constructive Solid Geometry
DEM	Digital Elevation Models
DSE	Discontinuity Set Extractor
DSLR	Digital Single-Lens Reflex
DSM	Digital Surface Models
GCP	Ground Control Points
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IDW	Inverse Distance Weighting
ISO	International Standards Organization
ISRM	International Society for Rock Mechanics
JRC	Joint Roughness Coefficient
Kd-tree	K-dimensional Tree
LiDAR	Light Detection and Ranging
MP	Megapixels
MVS	Multiview Stereo
PLA	Polylactic acid
RC	Remote Controlled
RGB	Red, Green, Blue
ROA	Remotely Operated Aircraft

RPV	Remotely Piloted Vehicle
RTK	Real-Time Kinematic
SDG	Sustainable Development Goal
SfM	Surface from Motion
SIFT	Scale-Invariant Feature Transform
STL	STereoLithography
TBC	Tunnel Behaviour Chart
TIN	Triangulated Irregular Network
TLS	Terrestrial Laser Scanning
UAV	Unmanned Aerial Vehicle
UCS	Unconfirmed Compressive Strength
UVS	Unmanned Vehicle Systems

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Discontinuities significantly influence the engineering response of natural rock masses, especially those within a few hundred metres of the surface (ISRM 1978). The morphology of discontinuities can be analysed using manual and subjective methods that involve measuring physical contact with the surface and highly advanced remote and automatic optical methods. Among the fundamental parameters for characterising a rock mass is the persistence of discontinuity, defined as the ratio between the total area of discontinuity and a reference area; it is very difficult to acquire direct measurements of the area of discontinuity, and another discontinuity function is used to derive the area of discontinuity and this is the trace of discontinuity. While orientation has typically been determined using a compass by popular techniques before this, latest remote sensing techniques such as Surface from Motion (SfM) and Terrestrial Laser Scanner (TLS) 3D-laser scanning allow discontinuities to derive both the strike and dip direction (Riquelme et al., 2017). Semi-automatic extraction of structural rock mass data from the high-resolution method of LIDAR point clouds is based on surface segmentation, and traces are obtained as the boundaries of the planes established (Gigli, G., and Casagli, N., 2011).

To be able to strategise and execute any project, civil engineering uses digital elevation models (DEMs) and orthophotos as the basic content. In an economical and realistic way, image analysis by photogrammetry has made it possible to obtain this type of information. Since laser scanning can be very costly and involves complex survey planning, digital photogrammetry allows for lower-cost and more user-friendly survey planning to obtain high-resolution data (Menegoni et al., 2019). The effect of the number of Ground Control Points (GCPs) and their distribution within the study area is particularly important for product accuracy (Martínez-Carricondo et al., 2018). This method makes it possible to detect traces created by the intersection of various visible planes, i.e. edges that are Digital Surface Models (DSMs) asperities or depressions (G. Umili et al., 2012). In addition, unmanned aircrafts offer low risk and high efficiency in its mission to capture photos which later would be stitched together using SfM to generate a high-resolution DEM (Trembanis et al., 2021). The point cloud derived from SfM is created from images and always comprises of red, green and blue (RGB) band attributes (Guo et al., 2019).

Since rock mass is generally heterogenous and anisotropic in nature, it would usually exhibit weaknesses such as faults, joints, contacts, planes and discontinuities. These structures excaberate the potential instability while experiencing the worsening of sliding and rotational movements on the assumption of discontinuum media altering the whole analysis conditions (Mohebbi et al., 2017). By quantifying any rock slope remotely using photogrammetry, cracks can be detected besides utilizing the conventional method of blasting and coring in order to test the strength of rock by identifying its UCS number. This study deploys the use of DSLR for close-range photogrammetry for both the rock mass sample and 3D-printed models under a controlled environment. Not only can the 3D-printed material produce mechanical properties similar to natural brittle rock, but it also has advantages such as material homogeneity, high flexibility of geometry, simple implementation of pre-flaw and prototyping speed (Sharafisafa et al., 2018). The validity of the real-time data obtain from the rock mass sample shall be compared to that of the 3D model.

1.2 Problem Statement

Current methods of obtaining discontinuity information may subject personnel to potentially hazardous and dangerous circumstances because of the need for physical access to the exposed rock outcrops. Furthermore, the integrity of the sample may be compromised if the structure is damaged or disrupted which is a precursor for inaccuracy of the final results. The collection of data manually may be subjective based on the visual perception of different individuals and the observations may differ from the recorded information whereby critical information may be amiss. Detecting a discontinuity requires assessment of the toe and crest of a rock slope which may be beyond the standard height of reach without the aid of advanced photogrammetry to cover a larger area. The overall process is mainly on a predicting and anticipating basis as sketching and the use of a compass at that particular moment can be time-consuming, unlike the image analysis technique that enables the analysis to be done outside of the field area (usually in laboratories) at a later time with ample provision of captured images.

1.3 Objectives

The purpose of this study is to assess the suitability of image processing of rock discontinuities by verifying parameters obtained from actual rock samples to that of the control samples. The objectives of the modelling study are as follows:

1. To produce rock mass discontinuities replica using 3D printing technology.

Physical replication of a typical discontinuity using 3D printing will enable quantitative and qualitative assessments of rock fracture patterns and depression that is designed on the control specimen.

2. To generate 3D point clouds of the rock mass discontinuity replica using close-range photogrammetry.

Multiple overlapping images of the specimen captured using close-range photogrammetry will be processed to obtain 3D point clouds. The point clouds will map out the physical model of the specimen in the form of coordinates with X, Y and Z values.

3. To evaluate the replicated rock mass discontinuities orientation and pattern using image analysis technique.

Checking and comparison between softwares as well as verification with the original specimen will be performed to gauge the limitations of the image analysis technique. Detection of both quantitative and qualitative parameters will be compared between CloudCompare and Working Face softwares.

1.4 Scope of Work

1. 3D printed models shall be within the dimension of 210mm x 210mm x 205mm by using Anycubic i3 Mega 3D printer.

2. Coordinates of more than 2 points assisted by coded targets shall be computed thus determining the orientation of planes. Precise mapping can be done for large planes but the accuracy is lower for smaller area of planes.

3. The Apple iPhone 12 Pro camera shall be set to Aperture mode with a fixed focal length and the Vibration turned off. The UAV camera shall be set to a fixed exposure throughout all photos for each specimen.

4. Computations in the Agisoft Metashape software to produce point clouds.

5. Analysis of point clouds in the CloudCompare and Working Face softwares.

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 paper highlights the research's main findings and provides an overview of the study's contents. The conceptual background for what the researcher would study, including scientific problems, hypotheses, and basic research structure, is outlined in this chapter.

Chapter 2: This chapter lays out a well-supported case for analyzing research topics and formulating a research methodology. The topic, the basic research problem, the question(s), and the design elements are all covered in this chapter, as well as the theoretical framework for the thesis.

Chapter 3: This chapter discusses the dissertation's research methodology. In this chapter, the study technique, research methodology, data collection methods, dataset planning, research procedure, data analysis format, ethical considerations, and project research constraints are discussed in greater detail.

Chapter 4: The aim of this chapter is to summarise the information gathered, analyse it, and present the results. This section of Chapter 4 briefly restates the problem statement, approach, research question(s), hypothesis(s), or phenomenon, before stating what will be covered in this chapter. The study findings should be summarized in Chapter 4 as briefly as possible, with a synopsis of the findings saved for Chapter 5.

Chapter 5: This chapter provides a clear review of the analysis' context. Assumptions, connotations, and suggestions will be made in this chapter.

1.6 Expected Outcome

The generated 3D model from multiple picture shots from varying perspectives will help determine the presence of joint set or random set within the rock mass. The orientation in terms of dip and dip direction data shall be extracted from the analysis and thus rock surface with a high tendency of daylighting can be identified. The discontinuities of the rock mass shall be configured from the 3D-printed model by designing each distinguished layer with precision. Meanwhile, the discontinuities from both the rock mass and 3D-printed model shall be deduced and characterized from the 3D model generated via photogrammetry.

1.7 Importance and Benefits

For the detection of discontinuities in areas where field mapping or laser scanner surveys cannot be used, the use of digital photogrammetry is beneficial because the slope is vulnerable, inaccessible, or formed by a complex geometry not visible from the ground, plus the data retrieved is of the highest accuracy. At locations of high accident risk such as steep and vulnerable slopes, digital photogrammetry will allow remote control of data collection without having to assess the rock condition while being subjected to potential danger the slope poses. In compliance with the 8th Sustainable Development Goal (SDG), all workers, especially those in precarious employment, should have their labour rights protected and their working conditions made safe and secure.

The process is time-saving whereby data can be immediately collected on-site in the form of images as opposed to the traditional method of relying on geologists' sketches of the discontinuities. Furthermore, the conventional method gives varying output from each individual because of their own subjective perspective and perception. Thus, digital photogrammetry is a reliable solution to standardise input data at a quicker pace. Analysis of the data is more accurate and can be performed any place away from the site as to not disrupt further works.

Photogrammetry is the inexpensive option when compared with other methods such as LiDAR whereby the cost difference is by one figure cheaper for photogrammetry. The equipment required for the procedure is easily available and the setup is not as tedious whereby in can be performed almost anywhere.

PLA (poly lactic acid) is a novel type of biodegradable polymer that may be manufactured from renewable plant-based starch (such as corn). It does not pollute the environment during manufacture and can be degraded. It is currently the most extensively used 3D printing material. Contributing to the 12th Sustainable Development Goal (SDG) which is Responsible Consumption and Production, using PLA filament will promote a greener approach to the replication of rock mass in the form of 3D printing. Since photogrammetry is not a test for strength, this is a cheaper alternative to moulding the rock mass imitation using concrete or other construction materials.

All in all, photogrammetry method and image analysis are instrumental in providing a better approach for safety and efficiency in evaluating rock mass discontinuities. In addition, 3D printing the replicated model will ensure accuracy of a controlled model with an environmental-friendly filament material.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Chapter

This chapter shall underline the key parameters commonly or rarely covered in previous researches that have been performed prior to this study. A descriptive comparison of the definitions, parameters, methodology, results & discussions, conclusion and limitations will be tabulated as a summary. The topics and parameters include orientation, spacing, persistence, roughness, filling, seepage, and number of sets.

2.2 Rock Discontinuities

When it comes to solid mechanical behaviour, it is normal to assume that they are homogeneous, continuous, and isotropic. However, since rocks contain discontinuities, they vary from most engineering materials. As a result, there must be a strong distinction made between rock material and rock mass (ISRM, 1979).

Table 2.1: Difference between rock material and rock mass (ISRM, 1979)

Rock Material	Rock Mass
A continuum or polycrystalline solid between discontinuities composed of mineral aggregates or grains.	An assemblage of rock blocks separated by different types of geological discontinuities.

Any distinction in a rock mass with zero or poor tensile strength is referred to as "discontinuity." Most types of joints, weak bedding planes, weak schistocity planes, weakness zones, and faults are all collectively referred to as discontinuities (Palmstr, 2006). It is widely accepted that as the pressure of a rock mass increases and pre-existing discontinuities remain, the peak strength of the rock mass declines (Gao & Kang, 2016).

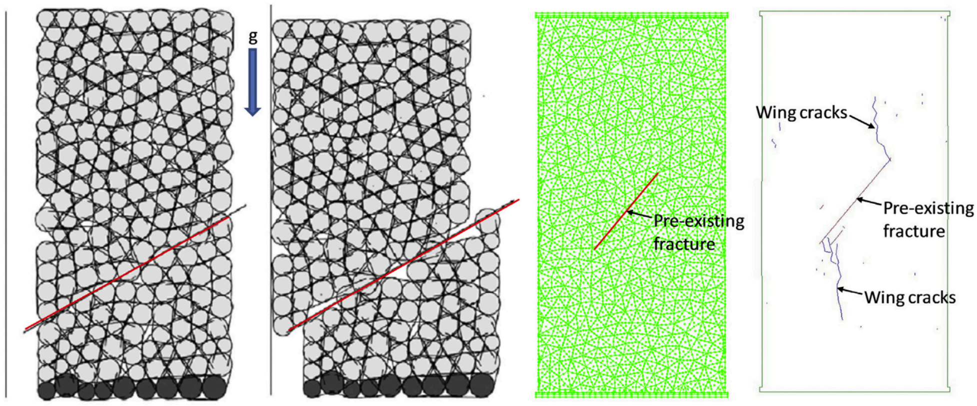


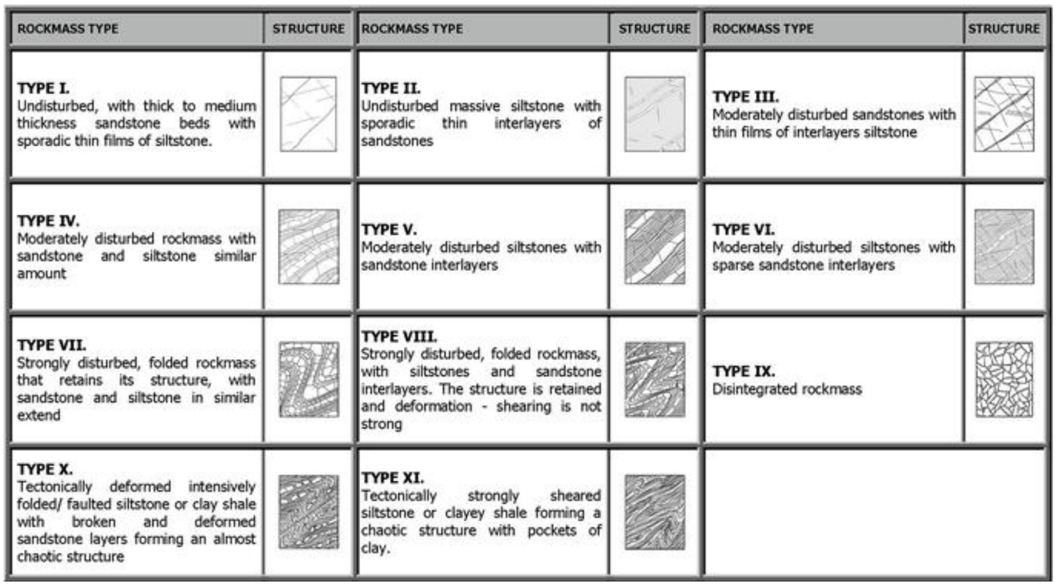
Figure 2.1: Examples of pre-existing discontinuity representation in DEM (Gao & Kang, 2016)

The following is a list of the most common types of discontinuities, along with a brief description of their engineering properties:

Table 2.2: Description of common types of discontinuities

Type	**Description**	**Source**
Faults	- discontinuities with identifiable shear displacement - pervasive characteristics that span a wide area or relatively limited to a local extent - often occur in echelon or in groups	(Palmstr, 2006)
	- a fracture or a fracture zone where there has been distinguishable displacement - walls are polished due to shear displacement - shattered and weathered sides of faults result in fillings	(ISRM, 1979)
Bedding planes	- classify sedimentary rocks into strata or beds - may contain different grain sizes of parting material with cohesion between beds	(Palmstr, 2006)

Joints	- a geologically induced break in the continuity of a body of rock along which no apparent displacement occurred - set: a group of parallel joints; joint system: intersection of joint sets - form parallel to bedding planes, foliation and cleavage	(ISRM, 1979), (Palmstr, 2006)
Cleavage	- fracture cleavage: parallel discontinuities that are recurrent, cemented, or welded and are independent of any parallel alignment of minerals. - closely-spaced discontinuities are created by shearing, extension, or compression, and are separated by thin slivers of intact rock. - flow cleavage: inter-leaving or foliation structure is formed by the recrystallization and parallel alignment of platy minerals such as mica - formed by metamorphism in fine-grained rocks at high temperatures and/or pressures - develop significant anisotropy in the deformability and strength of rocks	(Palmstr, 2006)



ROCKMASS TYPE	STRUCTURE	ROCKMASS TYPE	STRUCTURE	ROCKMASS TYPE	STRUCTURE
TYPE I. Undisturbed, with thick to medium thickness sandstone beds with sporadic thin films of siltstone.		**TYPE II.** Undisturbed massive siltstone with sporadic thin interlayers of sandstones		**TYPE III.** Moderately disturbed sandstones with thin films of interlayers siltstone	
TYPE IV. Moderately disturbed rockmass with sandstone and siltstone similar amount		**TYPE V.** Moderately disturbed siltstones with sandstone interlayers		**TYPE VI.** Moderately disturbed siltstones with sparse sandstone interlayers	
TYPE VII. Strongly disturbed, folded rockmass that retains its structure, with sandstone and siltstone in similar extend		**TYPE VIII.** Strongly disturbed, folded rockmass, with siltstones and sandstone interlayers. The structure is retained and deformation - shearing is not strong		**TYPE IX.** Disintegrated rockmass	
TYPE X. Tectonically deformed intensively folded/ faulted siltstone or clay shale with broken and deformed sandstone layers forming an almost chaotic structure		**TYPE XI.** Tectonically strongly sheared siltstone or clayey shale forming a chaotic structure with pockets of clay.			

Figure 2.2: Rock mass types in tectonically disturbed heterogeneous formations (Vassilis Marinos, 2019)

In the Tunnel Behaviour Chart (TBC), the rock mass structure is an important parameter to evaluate its prompt reaction in underground opening. The tectonic disruption, the blockiness of the mass, the probable size of blocks, the shape of rock elements (massive, blocky, foliated or sheared) or the tendency of the rock blocks to rotate can all be deduced from the structure of the rock mass.

The potential of unstable circumstances or excessive deformations emerging is largely controlled by the orientation of discontinuities relative to an engineering structure. When other deformation conditions exist, such as low shear strength and a sufficient number of discontinuities for slip to occur, orientation becomes even more important. The morphology of the individual blocks, beds, or mosaics that make up the rock mass is determined by the mutual orientation of discontinuities.

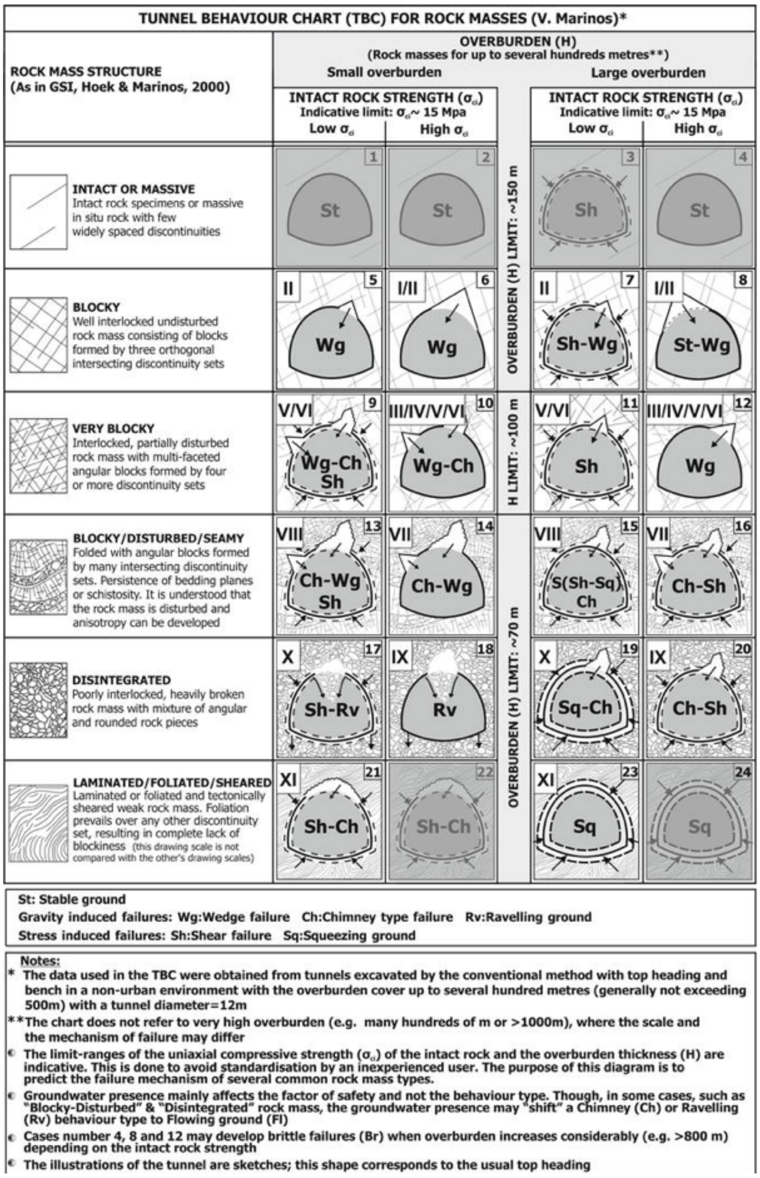


Figure 2.3: Tunnel behaviour chart showing projections of the principal failure mechanisms for the rock mass types (Vassilis Marinos, 2019)

2.2.1 Parameters to Describe Discontinuities and Rock Masses

1. Orientation: The attitude of a discontinuity in space. It is described by the dip direction (azimuth) and dip of the line of steepest declination in the plane of the discontinuity.

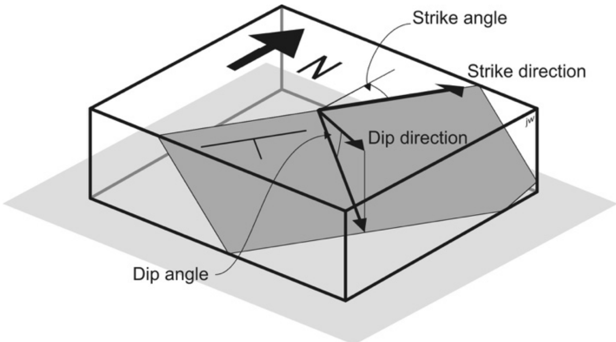


Figure 2.4: Strike, dip, and dip-direction of a plane (Waldron & Snyder, 2020).

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

3. Persistence: The discontinuity trace length as observed in an exposure. It 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.

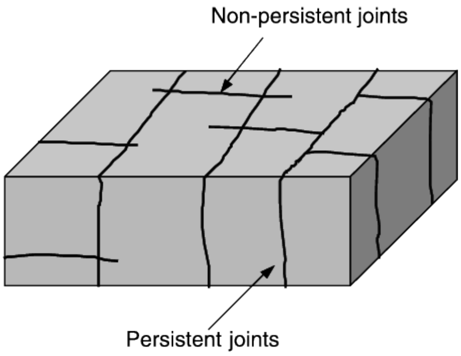


Figure 2.5: Persistent and non-persistent joints (K. Zhang, 2020)

4. Roughness: The inherent surface roughness and waviness relative to the mean plane of a discontinuity. Both roughness and waviness contribute to the shear strength. Large scale waviness may also alter the dip locally.

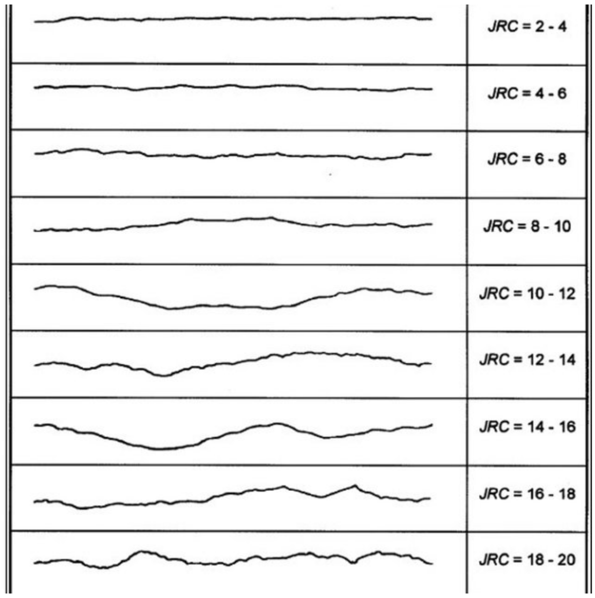


Figure 2.6: Joint Roughness Coefficient (JRC) profiles (Serasa et al., 2017)

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

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

7. Filling: The material that separates the adjacent rock walls of a discontinuity and that is usually weaker than the parent rock. Typical filling materials are sand, silt, clay, breccia, gouge, mylonite. It also includes thin mineral coatings and healed discontinuities such as quartz and calcite veins.

8. Seepage: The water flow and free moisture visible in individual discontinuities or in the rock mass as a whole.

9. Number of Sets: The number of discontinuity sets comprising the intersecting discontinuity system. The rock mass may be further divided by individual discontinuities.

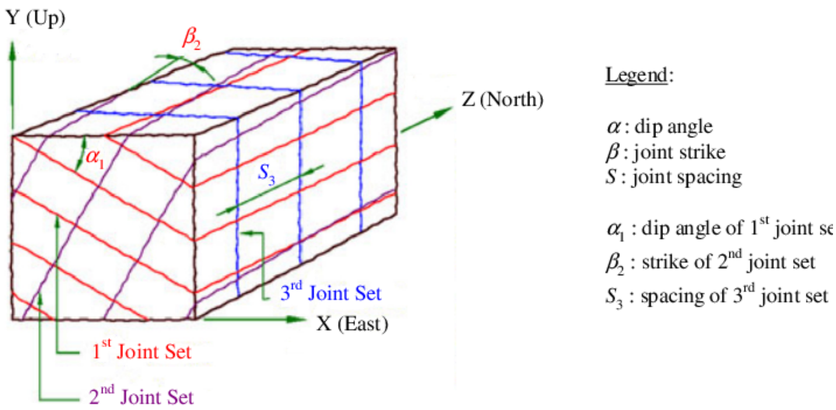


Figure 2.7: Joint sets within block (Simanjuntak et al., 2016)

10. Block Size: The rock block dimensions resulting from the mutual orientation of intersecting discontinuity sets, and resulting from the spacing of the individual sets. Individual discontinuities may further influence the block size and shape.

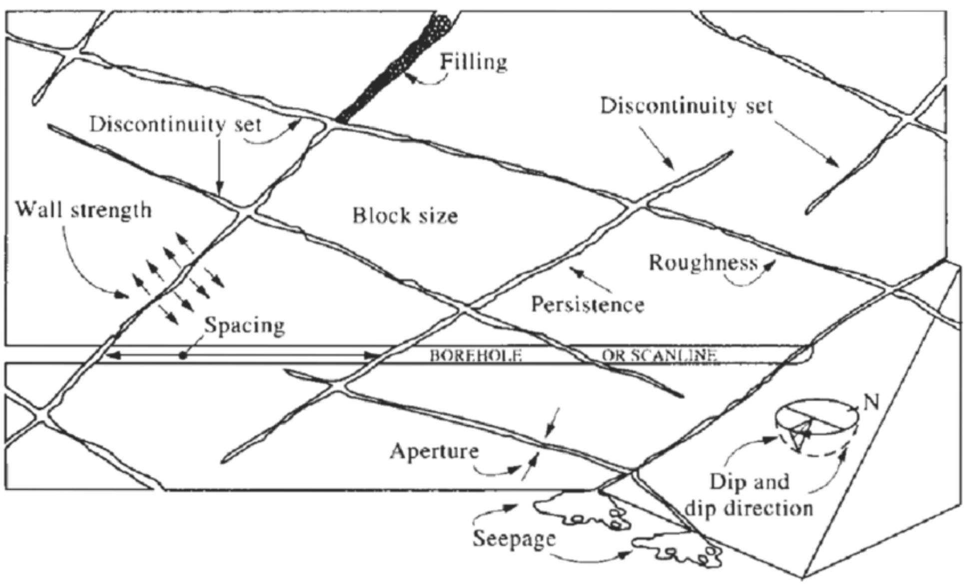


Figure 2.8: Discontinuity characteristics in rock mass (Singh et al., 2019)

2.2.2 Effects of Discontinuities to Civil Engineering and Rock Engineering Infrastructures

The stability of the rock mass surrounding underground excavations is a task that must be investigated both during and after the construction of underground structures. It is associated to the workplace's safety, as well as the project's long-term viability and profitability. The stability assessment of underground openings is a grueling job due to the intricacies that exist in the geology, in situ stress field, engineering constructions, and so on. The precise description of the rock mass is one necessity for dealing with such an issue. The rock, as a natural geological material, comprises pre-existing imperfections in the form of small-scale discontinuities such as fissures, fractures and joints, or large-scale discontinuities namely faults, dikes and shear zones. The rock mass becomes discontinuous, anisotropic, and non-linear as a result of these discontinuities, which weakens the material's deformability and strength. The orientations of the discontinuities are crucial to the behavior of the rock mass; they generally cause anisotropy and alter the stress distributions in the rock mass (Simanjuntak et al., 2016).

Continuum mechanics suffers from substantial deficiencies due to the discontinuity of rock materials such as joints, fissures, bedding, and diverse mineral compositions (Yang et al., 2017). Anisotropic rocks, such as schistosity in schists, which exhibit anisotropic strength and deformability, may be used as a site to construct pressure tunnels. Due to the orientation of discontinuities in the rock mass, determining anisotropic deformation as a result of tunnel excavation has become difficult. Designing pressure tunnel linings will inevitably be influenced by the rock mass's response to excavation as well as the behavior of joint planes within the rock mass (Simanjuntak et al., 2016).

Accidental falling of rock blocks created by the intersection of the tunnel surface and discontinuities in the rock mass is one of the most excruciating difficulties in tunnel excavation. Wedges falling from the roof or sliding out of the sidewalls of the openings are the most typical types of failure. The limitation from the surrounding rock is eliminated when the opening is excavated to provide a free face. Sliding is common in fractures, which can lead to block movement (Keykha et al., 2021).

Figure 2.9: Sliding of a step-over fracture in wall of tunnel (Keykha et al., 2021)

Case studies on the collapse of tunnel surrounding rock show that the position of the discontinuity in relation to the mining tunnel, as well as the discontinuity's mechanical qualities, always govern the failure pattern of the surrounding rock and the supporting system. In terms of the lateral pressure coefficient in the rock stratum, there are different influence laws at the crown and sidewall on the displacement of the mining tunnel surrounding rock mass. The vertical displacement of the crown reduces as the lateral pressure coefficient increases, whereas the horizontal displacement of the sidewall increases. The tensile stress on the sidewall is significantly higher than that in the case without fault. (Z. Zhang et al., 2019).

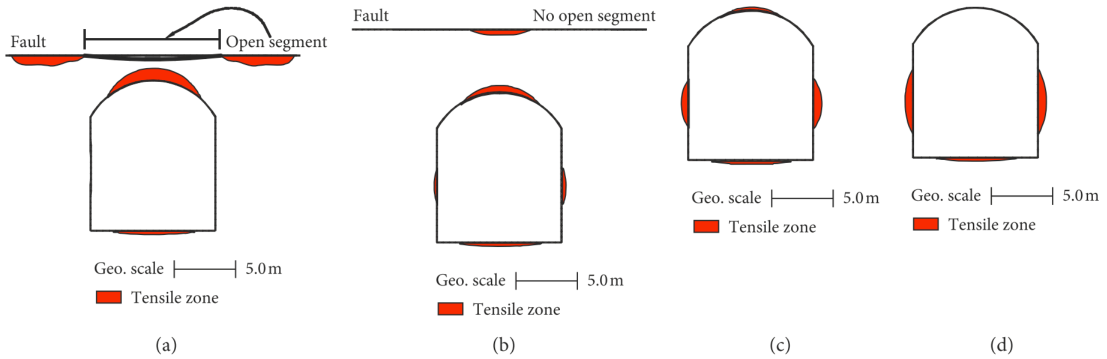


Figure 2.10: Tensile stress area of the surrounding rock mass for (a) 0.2 spans; (b) 0.5 spans; (c) 1.0 span; (d) no fault (Z. Zhang et al., 2019)

Where fault and fracture systems are the principal conduits for water flow, there could be a significant correlation between instability and water seepage. Discontinuities, faults and fracture systems, which are actively evolving structures, are one of the structural restraints on the development of drainage in contemporary orogens. The structural associations that contribute to a transverse drainage pattern are related to superimposed drainage. The risk of water loss and instability is increased when dams and reservoirs are built in karstified rocks with known high perviousness due to dissolution discontinuities and conduits. Water seepage and loss through dam foundations and abutments, particularly those built in karstic areas, results in significant expenses and delays dam completion targets (Barjasteh, 2019).

Surfaces of discontinuity can develop in a rock mass to varying degrees and regions, which can be influenced by tectonic failure. This can result in groundwater accumulation, groundwater acceleration, or deep weathering. Unsuitably oriented discontinuity systems might also have a substantial impact which may result in the rock mass falling out of open road cuttings or tunnels and could also lead to landslides. Wrong filling can also be a major issue where it may bring about water buildup or permeability via the geological environment (Vondráčková et al., 2016).

2.2.3 Importance of Understanding Discontinuity Information

The strength, deformability, and permeability of rock masses are all influenced by geological discontinuities. The initial step in understanding the general behavior of rock masses is to characterize discontinuity geometry (i.e. aperture, persistence, length, and spatial connectivity). Most joints, weak bedding planes, weakness zones, and faults are all examples of geological discontinuity, which is a broad term for any mechanical break (lacking considerable tensile strength) within rock masses. This concept, however, does not apply to incipient indications of any strength, despite the fact that such traces are frequently documented during outcrop discontinuity logging. This typical technique leads to an overestimation of permeability and an underestimation of rock mass strength. It has the potential to significantly increase the cost of rock support systems while also affecting the accuracy of water, oil, and gas extraction predictions (Shang et al., 2018).

2.3 Conventional Techniques for Discontinuity Data Collection

Statistical sampling methods like as scanlines and window approaches have been widely utilised to quantify the characteristics of discontinuities intersected at planar or nearly planar rock exposures. These techniques are a form of manual data acquisition methods.

2.3.1 Scanline Survey

In practice, surveys with 150 to 350 discontinuities are recommended, as are colour photographs of exposed rock faces and scale makers. Only the scanline's location, chainage at each intersection, plunge, and azimuth of joint traces are documented in a quick scanline survey. On the other hand, discontinuity types (e.g. joints, bedding, foliation, lamination, and cleavage), trace length, aperture and infilling condition, planarity, waviness, termination, and water condition are usually included in detailed scanline surveys (evidence of seepage).

However, this method is subject to a few drawbacks. Listed below are the disadvantages of scanline survey based on their biases (Shang et al., 2018).

i. Size bias - Small traces on exposures are ignored because scanlines preferentially locate discontinuities with a longer trace length.

ii. Orientation Bias - Discontinuities that strike roughly parallel to the scanline will be under-represented in the sample results and will be omitted. Since some crucial information is lacking, this will result in a major misinterpretation of discontinuity extent.

iii. Censorship Bias - When compared to major joints, rock exposures are limited and relatively small. Large discontinuities invariably extend beyond the visual exposure on one or both ends, therefore they are censored to some extent depending on discontinuity size.

2.3.2 Window Sampling

The preliminaries and measuring techniques are analogous to those used in scanline surveys, with the exception that all discontinuities are measured in a finite area rather than at the scanline's intersection. With each side intersecting between 30 and 100 discontinuities, the window should be broad enough to reduce sampling bias. Despite the fact that window sampling suffers from censoring, it is generally able to eradicate size and orientation biases. Window sampling can also be used to record discontinuity termination features; however this method does not provide information regarding discontinuity orientation or surface geometry (Shang et al., 2018).

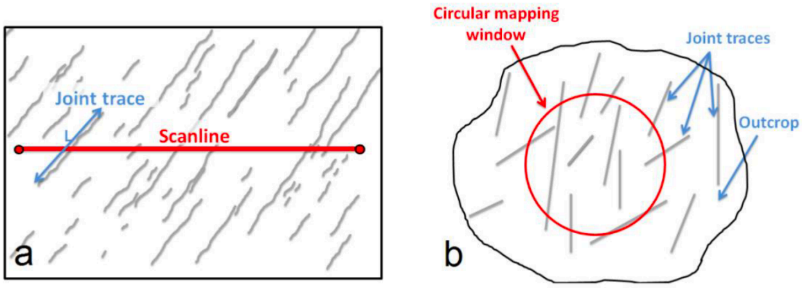


Figure 2.11: Measurement of structural discontinuity parameters: a) Scanline Method b) Window sampling (Mohebbi et al., 2017)

2.3.3 Limitations of Conventional Techniques of Discontinuity Data Collection

Manual data collection techniques have some drawbacks. The first is that they are time and labor intensive. Sampling should be done at a variety of places in order to reduce sampling bias. Another concern is the operator's safety when sampling. The second point to consider is that unbiased discontinuity characterisation necessitates professional interpretation (rock engineer or geologist). The third constraint is that manual approaches are unable to collect data from inaccessible rock exposures. As a result, academics have focused their efforts on developing alternate methods for obtaining discontinuity data from outcrop (Shang et al., 2018).

2.4 Image Analysis Technique for Discontinuity Data Collection

The construction of detailed simulations of jointed rock masses has been made possible because to recent advances in discrete element modeling and computer power. The numerical approach employed must meet two characteristics in order to model a realistic jointed rock mass: include a realistic geometric model of fracturing and capture rock block breakage through fracture growth (Gao & Kang, 2016).

Complex landscapes with high topographic relief and intricate geometry present challenges for complete and accurate mapping of both lateral (x, y) and vertical (z) detail without deformation (Nesbit & Hugenholtz, 2019). Latest remote sensing techniques such as Surface from Motion (SfM) and Terrestrial Laser Scanner (TLS) 3D-laser scanning allow discontinuities to derive both the strike and dip direction (Riquelme et al., 2017).

In the photogrammetric remote sensing section, based on multiple UAV imagery of the rock slope, the SfM-MVS technique reconstructs the 3D virtual slope with high resolution and accuracy in the form of both 3D point clouds and photo-realistic 3D mesh models (Y. Zhang et al., 2019). Semi-automated discontinuity mapping using the point cloud was performed using the DSE, qFacet FM, and qFacet KD-tree methods applied to the same 3D model (Menegoni et al., 2019).

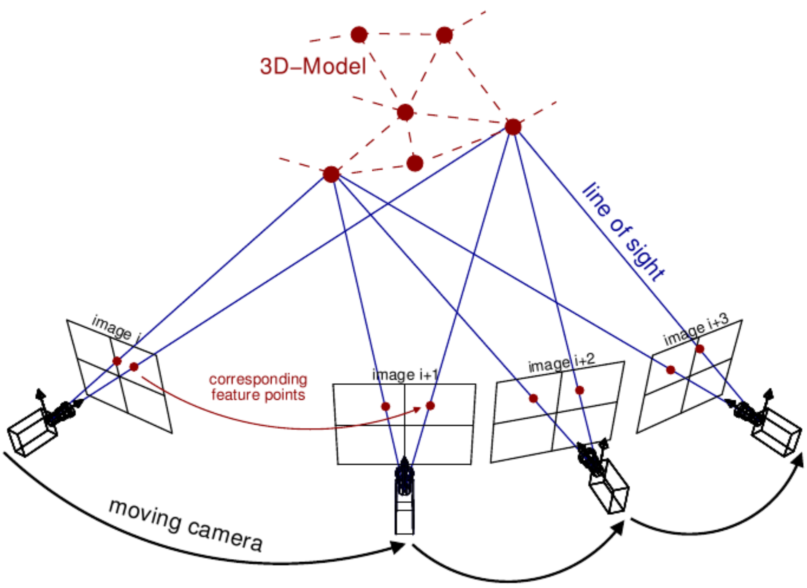


Figure 2.12: Surface from Motion (SfM) photogrammetric model (Riel, 2016)

Textural information not only provides more features for trace extraction but also introduces more interference, such as that due to the influence of shadows and other noise, and this interference needs to be eliminated (Guo et al., 2019). The criterion for crack initiation is characterised by rapid jump in the strain at a point of interest or displacement discontinuity along a line crossing the crack. 3D printed material can effectively mimic the mechanical behaviour of natural brittle pre-flawed rocks (Sharafisafa et al., 2018). The most important parameters of discontinuities including dip, dip direction, extension, infilling materials and percentage of infilling, roughness, and joint compressive strength are measured (Mohebbi et al., 2017).

Earth-based technologies such as LiDAR, TLS, robotic total station, or terrestrial photogrammetry cannot be easily applied to subvertical coastal cliffs overlooking the sea, while boat-based mobile laser scanning techniques are severely hampered by logistic restrictions and coastal morphology (Fazio et al., 2019). When the examined locations present logistic challenges linked to operator safety and inaccessible places, a semi-automatic extraction of discontinuities using UAV helps to reduce efforts in in-situ geological surveys. In order to properly identify discontinuities, 3D models must be used to represent the surface complexity at the relevant spatial scale (Riquelme et al., 2017).

In the computer science and artificial intelligence community, the name UAV is often used, but other terms such as Remotely Piloted Vehicle (RPV), Remotely Operated Aircraft (ROA), Remote Controlled (RC) Helicopter, Unmanned Vehicle Systems (UVS), and Model Helicopter are also commonly used. Unmanned aerial vehicles (UAVs) are unpiloted and reusable motorized aerial vehicles that are remotely controlled, semi-autonomous, or have a combination of these capabilities and can carry a variety of payloads, allowing them to perform specific tasks within the earth's atmosphere or beyond for a period of time that is related to their missions (Uysal et al., 2015).

2.4.1 Photogrammetry

The fundamental data foundation that governs the resolution, precision, and reliability of the susceptibility analysis is detailed 3D outcrop models. Close-range remote sensing technologies, such as Light Detection and Ranging (LiDAR) and photogrammetry, are revolutionizing the acquisition of 3D virtual outcrops of rock slopes with high resolution and high precision for susceptibility analysis, far surpassing traditional survey methods of fracture windows sketching and the assumption that simplifies the entire slope with a uniform dip and dip direction (Y. Zhang et al., 2019).

The various capabilities of LiDAR and photogrammetry for rock mass evaluation and characterization have been demonstrated in numerous publications in recent years. Terrestrial remote sensing techniques such as terrestrial laser scanning (TLS) and structure from motion (SfM) photogrammetry are increasingly being used to recognize and track rock slope hazards, as well as other geomorphic processes. Millimetre-scale deformation monitoring of columnar basalt; discontinuity mapping in drill and blast tunnels and caverns; discontinuity mapping and rockfall modelling along transportation corridors; and discontinuity mapping and kinematic assessment in mountainous terrain are examples of such applications. All of the examples and references presented utilize terrestrial remote sensing technologies to create three-