SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

ROCK SLOPE STABILITY ANALYSIS USING PHOTOGRAMMETRIC METHOD AT HUME CEMENT QUARRY, GOPENG, PERAK.

By

AISYAH SHAHIRAH BINTI JUHARI

Supervisor: Dr. Hareyani Bt. Zabidi

Dissertation submitted as partial fulfillment

of the requirement for the degrees of Bachelor of Engineering with Honours

(Mineral Resources Engineering)

Universiti Sains Malaysia

JUNE 2018

DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "Rock Slope Stability Analysis by Photogrammetric Method at Hume Cement Quarry". 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.

Name of Student : Aisyah Shahirah binti Juhari Signature:

Date : 25/06/2018

Witness by

Supervisor : Dr Hareyani Binti Zabidi Signature:

Date :25/06/2018

ACKNOWLEDGMENTS

Alhamdulillah to the Almighty Allah S. W. T whom with His willing giving me opportunity to complete this Final Year Project entitled “Rock Slope Stability Analysis by Using Photogrammetry Method at Hume Cement Quarry” within the time. The final year project was prepared for this course requirement of the undergraduate programme.

I would like to express my special appreciation and thanks to my supervisor, Dr. Hareyani binti Zabidi who give me support and help in advising and guiding me during completion of my final year project with her wide skills, knowledge, and speciality on this scope of the study. I also would like to thank you for encouraging my research and for allowing me to grow as a research scientist.

Other than that, I would like to thank master and PhD students, that helps us on guiding our project on quarry site and share their geological experience on manual mapping at the worksite. Besides, I also want to thank all my friends, family and parent that never stop supporting me from earlier until the end of this project. Your prayer for me was what sustained me thus far. Finally, for those who contribute and share some ideas for my project whether I realise or not, I really appreciate and may Allah bless on that kindness by simplifying your daily work with His grace. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ANALISA KESTABILAN CERUN BATUAN MENGGUNAKAN METOD FOTOGRAMMETRI DI KUARI HUME CEMENT

ABSTRAK

Penyelidikan ini menumpu kepada Analisa kestabilan cerun di kuari Hume Cement dengan menggunakan kaedah fotogrammetri dan data yang dianalisi di dalam program *Dips 7.0* menggunakan perisian *Rocscience*. Kuari merupakan kawasan yang sering berlaku ketidakstabilan cerun batuan sebagai masalah yang utama di sebabkan oleh aktiviti-aktiviti yang dilakukan di tapak kerja seperti penggalian dan letupan yang mana menghasilkan retakan, sesar, dan kekar. Dalam kajian ini, beberapa analisis telah dilakukan untuk mengetahui kestabilan cerun batuan, sama ada berlaku kegagalan atau tidak. Terdapat dua kaedah yang digunakan, iaitu analisis empirikal yang mana lebih konvensional seperti pemetaan garis imbasan juga analisis kinematic dengan menggunakan teknologi moden seperti dron bagi pemetaan fotogrametri. Beberapa perisian digunakan untuk kajian ini, iaitu *AgiSoft PhotoScan*, *Cloud Compare*, program *Discontinuities Set Extractor* di dalam perisian *MathLab* dan *Dips* 7.0 di dalam perisian *Rocscience*. Hasil daripada analisis empirikal didapati bahawa kelas batuan bagi *Window A* ialah jenis “batuan lemah”, di mana cerun tersebut memerlukan sokongan untuk mengekalkan kestabilan. Sementara itu, hasil analisis kinematik menunjukkan bahawa kebarangkalian kegagalan cerun batuan berlaku adalah tinggi bagi kegagalan jenis baji dan terbalikan namun tiada kegagalan satah berlaku. Satah utama ketakselanjaran adalah Set Ketakselanjaran 1 (DS1). Plot roset bagi kedua-dua kaedah analisis menunjukkan arah dominan yang sama tetapi kuantiti set ketakselanjaran adalah berbeza. Arah paling dominan yang diperoleh ialah N330°-N340° iaitu berarah pada NNW-SSE yang menunjukkan arah utama ketakselanjaran manakala orientasi ketakselanjaran yang paling sedikit berlaku di E-W pada arah N080°-N090°.

ROCK SLOPE STABILITY ANALYSIS USING PHOTOGRAMMETRIC METHOD AT HUME CEMENT QUARRY

ABSTRACT

This project focused on rock slope stability analysis at Hume Cement Quarry by using photogrammetry method and analysis data by Dip 7.0 program in rocscience. Quarry is a common place which is instability of the rock slope happen as the big issues due to the activities on site work such as excavation and blasting where it creating fractures, faults, and joints. In this project, several kinds of analysis are taken to investigate the stability of the rock slope whether it might be fail or not. There are two methods used which is empirical analysis, where it is more conventional i.e scanline mapping and kinematic analysis by using modern technology i.e drone for photogrammetry mapping. The software used in this project is *AgiSoft PhotoScan, Cloud Compare, Discontinuities Set Extractor program in MathLab software, and Dips 7.0 in Rocscience software.* As result from empirical analysis, the rock at window A is classified as “poor rock”. Meanwhile kinematic analysis result shows the probability of the rock slope to be a failure is high for wedge and toppling failure but does not occur for planar failure. The major plane of discontinuities is Discontinuity Sets 1 (DS1). Rosette plot of both methods shows the same direction but different in quantity of the discontinuities set. The most dominant direction is N330˚ - N340˚ which trends on NNW-SSE where it describes the major direction of discontinuities while the least dominant discontinuities orientation happens to occur at E-W with the direction of N080˚-N090˚.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Open pit mine is common mining method that been used in quarrying industry which involving the huge quantities of overburden removal, backfilling and dumping in excavation areas and also providing the design of benching system. The activities of blasting and excavating at slope surface will introduce to the slope stability problem where it creates the discontinuity whether by natural occurrence or those activities impacts.

Therefore, the variation in the rock mass conditions, material characterisation of rock slope, the face angle and also orientation of the rock also play a significant effect on the stability of the rock slope. Slope stability problems attract major concerns from researchers, and consequently, several techniques and methods for slope stability evaluation have been proposed. That method can be basically grouped into four categories, i.e. kinematic analysis, limit equilibrium, numerical modelling, and empirical methods (Basahel and Mitri, 2017)

Kinematic analysis is a commonly function as a prediction of potential structural for the failure mechanism such as planar, wedge, and toppling by using stereonet projection technique. By this technique, the orientation of discontinuities can be projected by pole where it contains the information about the dip, dip direction or strike of the joint on two-dimensional (2D) stereonet. Limit equilibrium method is an estimation of a factor of safety where the magnitude of driving forces is compared with resisting forces that act along the sliding planes. The slope structural stability can also be examined.

Numerical modelling is used in more complex slope geometries and failure mechanism. It usually is useful when both above methods cannot representing the behaviours of the slope. Therefore, it provides the effect of stress distribution in the slope and displacements on its behaviour. (Wyllie and Mah, 2017)The empirical methods are also known as rock mass classification systems where it represents an important tool that is often used for preliminary assessment of engineering behaviours of the rock mass (Duran and Douglas, 2000).

By rating the value of some parameter, it can help engineering judgement of underground projects for design purpose and also evaluate the rock slope to make it applicable to surface excavations in rock. The empirical method is basically about rock mass characterisation and discontinuity conditions and it can be summarised into five categories, i.e. unconfined compressive strength (UCS) of intact rock, the spacing between discontinuities, rock quality designation (RQD), groundwater condition, and discontinuity condition. These five factors also refer to as the well-known rock mass rating (RMR) by Bieniawski and give a value that ranges between 0 and 100 (Bieniawski, 1973).

Throughout the years, technology has widely increased from a small application to the biggest invention in all industry sector depending on their functionality and specification. Some of them are used in mining industry, where their application absolutely improves the data obtained and reasonable to be used in a critical problem from the working site. Especially in analysing the rock slope stability study, the technology such as remote sensing, aerial photography, stimulation software and etc. are very helpful for the geologist and researcher to be used in their work where the data obtained is more easy to analyse, accurate, faster, and safer than the conventional method.

Since the early 2000s, the applicability of high-resolution imaging tools for rock mass classification study have currently used in research project and publication i.e. remote imaging technique (LiDAR or photogrammetry). The data captured by aerial photography tools such as drone from the working site will be used in order to convert the information in two-dimensioanal (2D) pictures into three-dimenssional (3D) modelling by using specific software. In general terms, stereo photogrammetry works by comparing two overlapping images (overlap from 60-100%) and using the parallax to calculating the stereomodel by triangulation of light rays 3D points in the overlapping area. One of the conditions that consider in planimetric accuracy is the topographic depth accuracy varies as fuction of base distance ratio, where the distance is between camera to the subject. (Lato *et al.*, 2013)

This thesis is focused on the stability of the rock slope analysis by using photogrammetry method for Window A, at Hume Cement Quarry Sdn Bhd , Lot 300254, Jalan Gopeng Kota Bharu, Kota Bharu Gopeng, 31610 Gopeng, Perak Darul Ridzuan, for rock mass characterisation (empirical method) on site and kinematic analysis using Rocscience software called Dip 7.0 .

1.2 Problem Statement

The previous study has mentioned about how they have to use photogrammetry method in their study on interpreting the data of characterizing the rock faces. The data collection included the three-dimensional location of features, orientation dip, and dip direction, trace the length and plane area (also used to calculate joint persistence), the large-scale joint surface roughness, termination indexes (to ascertain feature chronology) and also fracture set spacing.

Therefore, in this research, the photogrammetry method will be used to analyse the rock slope stability according to its function of capturing the those geological structure, converting those information into 3D by such software and the interpret those data to identify the possible failure of the slope and the figure out some of solution or support system as result of preventing the failure from occurring.

1.3 Study Area

Perak state is located between the latitudes of 3°30' and 5°21' North, and the longitudes 100°00' and 101°45' East. In Director of National Mapping Malaysia 1989, borders Kedah state and the Thailand Yala Province to the north; Penang state was to the northwest; Kelantan and Pahang state to the east; Selangor state to the south, and the Straits of Malacca to the west. It has an area of 21 006 km^2. Perak state is selected based on its unique geological context which is located on The Main Granite Range of Peninsular Malaysia. (Ramli *et al.*, 2015)

Hume Cement Quarry Sdn Bhd which is located in Gopeng, Perak with latitude 4º23’ North and longitude 101º5’ East. The distance of Hume quarry was 1.94 km away from Hume Cement Plant and main office as (Figure 1.1) and topography map as (Figure 1.2). The Hume Quarry is also located in Kampar and Kinta District which have limestone deposit at some of the places and also granite deposit. This company has been operating almost 5 years since 2012 with integrated cement plant that utilizes ground-breaking technology. History of this quarry has stated that this place was the ex-pond of the tin mining operation.

Figure 1.1: Location site and the distance between the main office to the quarry site by satellite map

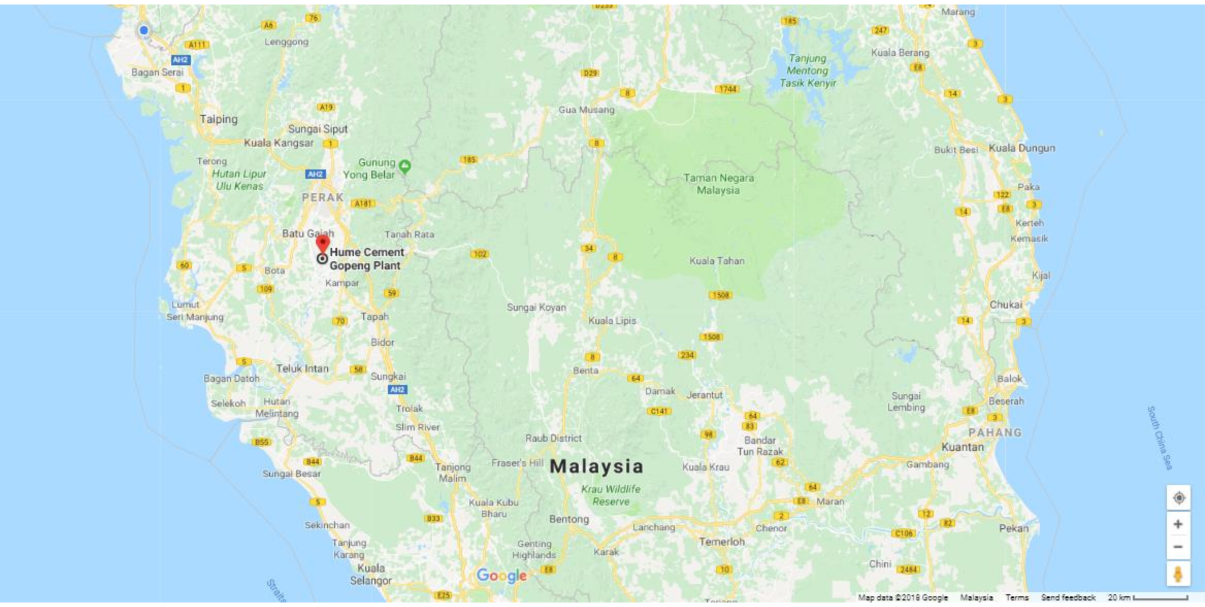

Figure 1.2: Location site by topography map at the state of Perak

From observation, the location of the pinnacle of this quarry is located at the ground level where when the water comes out from the bottom has been pumping out after the limestone was excavated. The specific location is chosen to analyze the rock slope stability by using photogrammetry method for limiting the study area for this research (Figure 1.3).

Figure 1.3: Specific study area

1.4 Objective of the Research

There are several objectives of this research which are:

a) To identify the rock mass characterization of rock slope at Hume Quarry

b) To investigate the potential stability of rock slope and class rock type by empirical analysis

c) To analyze the stability of the rock data with kinematic analysis

1.5 Research Method

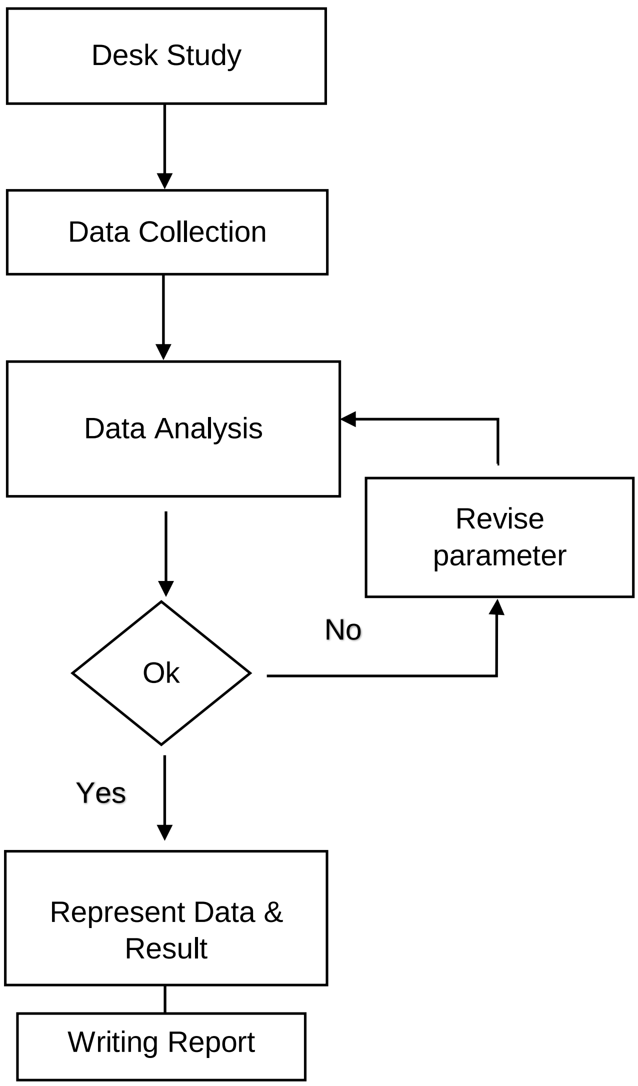

Figure 1.4: Flowchart of the research methodology

1.6 Outline of the Thesis

This thesis is presented in of five chapter which starts with an introduction, then followed by the literature review, methodology, results and discussion, and conclusion. The first chapter introduces the overview of the introduction of the research, the objective, a method of this research.

For the second chapter, the literature review has justified the theory & mechanism of slope failure. The literature of Rocscience in Dips 7.0 application, software involve and a short note about discontinuities.

In Chapter 3, a method of 3D modeling image in Agi PhotoScan software, DSE program in MatLab software, Cloud Compare & Rocscience Software (Dips 7.0) is presenting. The kinematic Analysis method of failure was explained in this chapter and Empirical method such as RMR study of the location. All the process and the procedure was based on objective requirement listed in chapter 1.

In Chapter 4, the evaluation and discussion of that analysis were explained based on data output and result come from the modeling presented.

In the last chapter, all the working research whether theory or modeling result have been concluded and some recommendation for future research have been presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Failure of the rock slope is the most critical situation that cannot be identified easily by naked eyes. It will happen when the pit is deepened the extent of this distressed zone increases and the consequence of failure become more severe and also by large amount of discontinuities such as fault, dyke, weak zone and etc, that have on the rock mass was further reduce resisting force as soon as driving force exceeds the resisting force, then the failure takes place.

Therefore, people that involve on mining and quarrying industry in all over the world have already take an actions on preventing those failure by analyse the probability factor that will influence and affect the failure of the rock slope stability based on measures for the steep rock slopes rely on knowledge of the rock face geometry, the rock mass condition, and orientations of joint sets as well as specific geological features such as faults.

Traditionally, a geologist has used field measurement called scanline survey and cell mapping such as using a geological compass in order to obtain joint orientation data to analyze the rock slope stability and getting characterization information. However, that technique will present several kinds of problems to the geologist for example:

(i) the safety access does not provide the geologist to be near to the rock face for carrying out the geological mapping,

(ii) it also difficult to measure the orientation and the line of the fault that occurs on the face,

(iii) and possibilities of the rock might fall down when the mapping study is being conducted in the weak zone area (Tannant, 2015)

Nowadays, people come out with various type of the technology which more precise and practicable to be used on site to measure and map features of interest from a safe distance. Such as drone, photogrammetry and also laser scanner (LiDar). Therefore, the digital camera is the lower cost rather than using the laser scanner and also easy to be handled on fieldwork as it is safe rather than traditional technique. The techniques using photogrammetric image process are particularly useful for geotechnical characterization of the rock slope.

2.2 Rock Mechanic &Engineering Study

The study of rock mechanics depends on the principles plays in the engineering field where it is used in analyzing the rock and rock mass for engineering purposes. The plane of discontinuities of the rock mass and the weak structural features of the rock including fractures, faults, bedding plane, foliation plane, joint, and also clay seam is the geological parameter that can influence the stability of the slope.

Some of the common properties of the rock such as specific gravity, density, unit weight, porosity, and etc. are used in analyzing the strength of the rock mass because the stability of the rock mass depends on the strength of the foundation rock and behavior under pressure and stress.

Instability of the slope of the open pit is quite different with the application for civil work, where the excavation of the open pit is too high and more extensive. Basically, the slope for open pit mine is mined as steep as possible to avoid excavating waste rock because their trends continue toward deeper pits and steeper slopes in the search for economical extraction of rock and mineral product.

Therefore, mining proposed the pit slope that can tolerate much greater slope movement due to the slide are active moving up to 1 or 2 m per day than civil work where it can sustain the stability just a few month or years. Limiting equilibrium analysis led to a curved slope profile for a pit wall up to 1000m high, with the overall slope of 45º in competent rock, but 30º to 35º in weathered rock and at the foot of the highest slopes where the highest stress prevailed. Efficient managing drainage system and design of the quarry or mine will contribute to increasing the safety of the pit wall from sliding or rockfall (A. Franklin and Dusseault, 1992).

Rock mass is not clearly solid as human expected. In fact, it actually full of the fractured and rare situation will say the spacing between the discontinuities are appreciably greater than the dimension of the rock engineering project. Therefore the stability and the number of discontinuities and engineering dimension can relate in the form of(Hudson *et al.*, 1997b):

$$\text{Stability} \propto \frac{1}{\text{Number of Discontinuities}} \propto \frac{1}{\text{Engineering Discontinuities}}$$

The main features of the rock mass geometry can be illustrated in Figure 2.1 below and the parameters being illustrated is (Hudson *et al.*, 1997b) :

i. *Spacing and frequency*: spacing is the distance between adjacent discontinuity intersections with the measuring scanline. Frequency (i.e. the number per unit distance) is the reciprocal of spacing (i.e. the mean of these intersection distances).

ii. *Orientation, dip direction and dip angle*: the discontinuity is assumed to be planar and so the dip direction (the compass bearing of the steepest line in the plane) and the dip angle (the angle that this steepest line makes to the horizontal plane) uniquely define the orientation of the discontinuity.

iii. *Persistence, size, and shape*: the extent of the discontinuity in its own plane, incorporating factors such as the shape of the bounded plane and the associated characteristic dimensions (e.g. the discontinuities could be assumed to be circular discs for the purpose of analysis and sampling).

iv. *Roughness*: although discontinuities are assumed to be planar for the purposes of orientation and persistence analysis, the surface of the discontinuity itself may be rough. Discontinuity roughness may be defined either by reference to standard charts or mathematically.

v. *Aperture*: the perpendicular distance between the adjacent rock surfaces of the discontinuity. This will be a constant value for parallel and planar adjacent surfaces, a linearly varying value for non-parallel but planar adjacent surfaces, and completely variable for rough adjacent surfaces.

vi. *Discontinuity sets*: discontinuities do not occur at completely random orientations: they occur for good mechanical reasons with some degree of 'clustering' around preferred orientations associated with the formation mechanisms. Hence, it is sometimes convenient to consider the concept of a discontinuity set (which consists of parallel or sub-parallel discontinuities), and the number of such sets that characterize a particular rock mass geometry.

vii. *Block size*: depending on the previously described characteristics, rock blocks can be present. In terms of excavation and support, it is helpful to have an estimate both of the mean block size and the block size distribution, which is an in situ analogs of the particle size distribution used in soil mechanics.

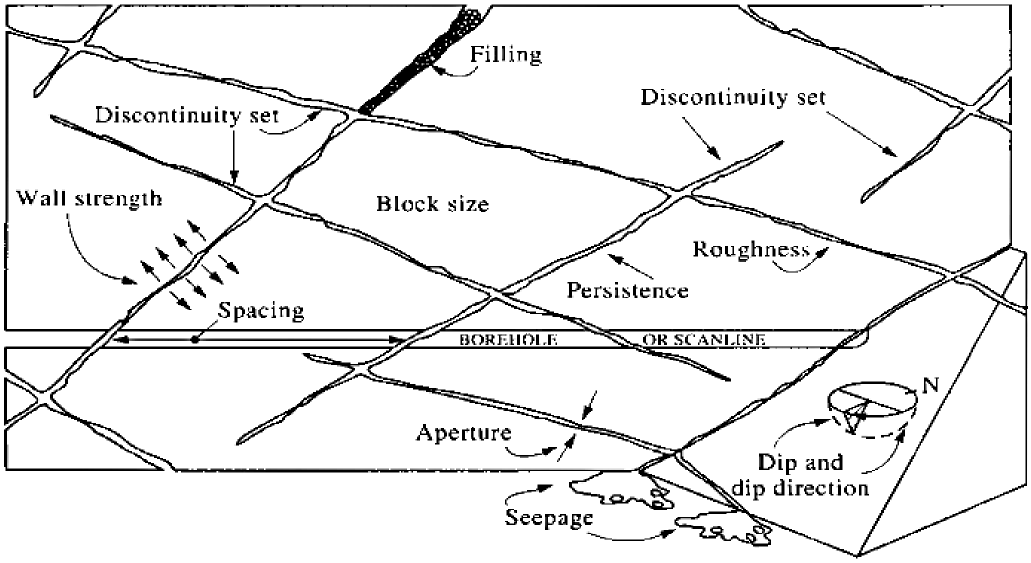

Figure 2.1: Schematic of the primary geometrical properties of discontinuities in rock *(Hudson et al., 1997b).*

2.3 Rock mass Properties and Classification

Rock mass property is governed by the properties of intact rock materials and of the discontinuities in the rock. In fact, in-situ stress and the groundwater will influence the condition and behavior of the rock mass. Then, rock mass classification study is used for quantifying the quality of the rock mass. There are properties of rock mass that are controlled by parameters of the rock joins, rock material and boundary condition as shown in Table 2.1:

Table 2.1: Parameter that can influence the rock mass property (Gangopadhyay, 2013)

Joint Parameters	Material Parameters	Boundary Condition
Number of joints set	Compressive strength	Groundwater pressure & flow
Orientation	Modulus of elasticity	In situ stress
Spacing		
Aperture		
Surface roughness		
Weathering & alteration		

2.3.1. Rate Mass Rating (RMR) System

The rate mass rating (RMR) system is developed by South African Council for Scientific and Industrial Research (CSIR) which is a rock mass quality classification that closes associated with excavation for the quarrying and mining industry (Bieniawski, 1973). There are 5 basic parameters of RMR system:

i. *The intact rock material strength*: Point load index is acceptable for a rock of moderate to high strength while uniaxial compressive strength is preferred.

ii. *Rock quality design (RQD)*: to quantify rock mass quality

iii. *Joint / Discontinuities spacing*: use all the rock's discontinuities average spacing

iv. *Joint /Discontinuities surface condition*: includes joint surface weathering and alteration, roughness, persistence, joint aperture and presence of infilling.

v. *The condition of groundwater*: it is to account for groundwater inflow in excavation stability.

Table 2.2: Rock Mass Classification RMR system *(Bieniawski, 1999)*

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

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

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

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

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

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

D. MEANING OF ROCK CLASSES

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

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

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

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

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

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

Table 2.2 shows the RMR system for rock mass classification. For Part A, there is 5 parameter that shows the characteristic of the rock mass. The individual rate for each parameter is gained by the property of the parameter. The weight of the parameter is considered in the rating. Then result from the rating will be summed for showing the Part A rating result.

For part B, since the orientation of the joints relative to the work can have an influence on the behaviour of the rock, Bieniawski recommended adjusting the sum of RMR according to the effect on the orientation of discontinuity. The rock classes according to the rating and the description of the rock mass are given in Part C.

In Part D the meaning of the total rating is described in accordance with the tunnel or underground excavation stand up time. Part E of the table shows the ratings for discontinuity characteristics. The orientation of the discontinuities become more important from tunnel and mines, through the foundation, to slopes, Part F, and Part B. Equation below is the summation of all the rating value including the adjustment of discontinuities orientation (Coutinho and Mayne, 2012)

$$\textbf{RMR} = \sum \textbf{(classification parameter) + discontinuity orientation adjustment}$$

2.3.2. Rock Quality Design (RQD)

RQD is Rock quality design which represents the degree of rock mass's fracture and introduced in the 1960s by Deere. The rock mass quality classification is expressed in Table 2.3. It does not account for the strength of the rock or mechanical and other geometrical properties of joints and reflecting the rock mass quality. It defined as the percentage of intact core pieces where it is longer than 100mm (4 inches) in the total length of the core. Therefore it can be obtained by 2 methods:

i. *Direct Method:* The core size recommended by International Society for Rock Mechanic (ISRM) is at least NX (size 54.7mm) drilled with double-tube core barrel using diamond bit. Engineering quality of rock mass and RQD value that proposed by Deere in 1968 as in Table 2.3 and Figure 2.2 below:

Table 2.3: Rock Mass quality classification according to RQD *(Deere and Deere, 1988)*

RQD	**Rock Mass Quality**
< 25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

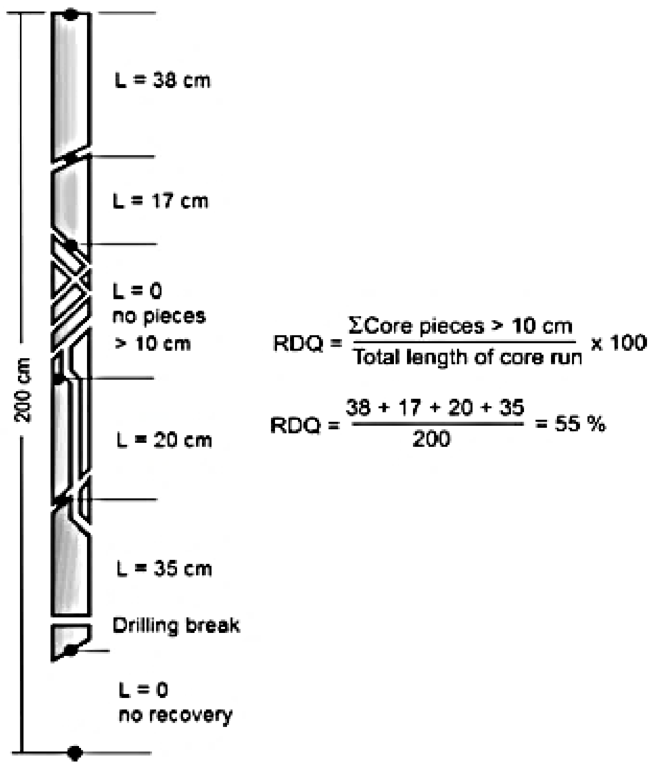

Figure 2.2: Procedure for measurement and calculation of direct method of RQD *(Deere and Deere, 1988).*

ii. *Indirect Method:* volumetric joint count method.

- *Volumetric Joint Count Method:* The number of joint or discontinuities per unit volume can be counted to find RQD number. According to Palmstrom, the simple relationship can be used to convert Jv into RQD for clay free rock masses (Palmstrom, 2005).

RQD = 115-3.3Jv

(RQD = 0 for Jv >35, and RQD =100 for Jv < 4.5)

Where Jv is the number of joint per cubic meter of the rock mass.

According to Hudson and Priest (1979), they have presented the following, mathematical relation equation between RQD and fracture frequency (Palmstrom, 2005):

RQD = 100 $e^{-0.1\lambda}$ **(1+ 0.1** λ**)**

Where λ = the total joint frequency

2.3.3. Rock Strength

A number of discontinuities show the strength of the rock mass when the stress is applied. Basically, the stress applied to the sample is resolved into the normal and shear stress on the plane of weakness and the Mohr – Coulomb failure criterion applied to consider the possibility of a slip. The orientation of the discontinuities will affect the strength of the sample. Figure 2.3 shows the Mohr's circle which represent the failure loci for both intact rock and the discontinuity. Three Mohr's circle also shows the lowest, middle and highest strength which represent A, B, and C.

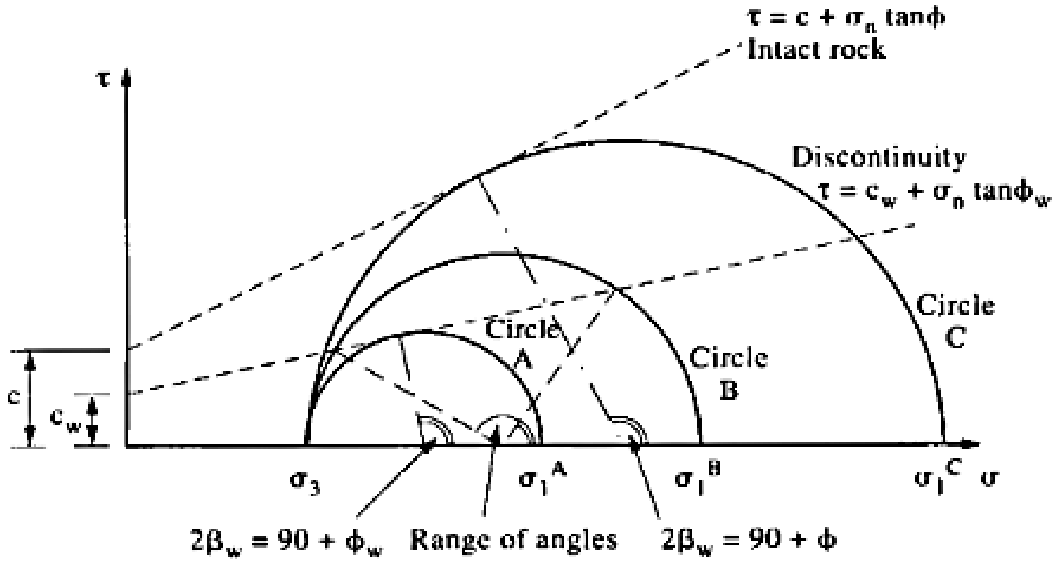

Figure 2.3: Mohr's circle representation of the possible modes of failure for rock containing a single plane of weakness *(Hudson et al., 1997a).*

Circle A shows a case when the failure of the locus for the discontinuity is just reached.

Circle B shows a case when failure can occur along the discontinuity for a range of angles.

Circle C shows a case where the circle touches the intact rock failure locus.

2.4 Orientation of Discontinuity

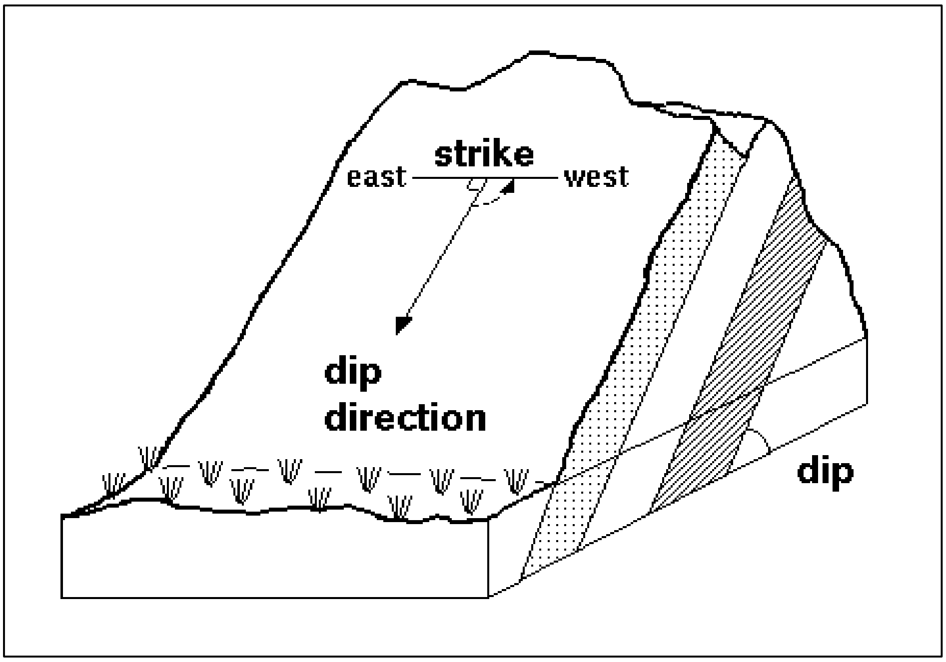

Figure 2.4: Orientation of Plane *(Price and Juan, 2013).*

Description of each term for the orientation of Figure 2.4:

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.

2.5 Slide Mechanism for Slope Stability

According to the geometry of the sliding mass, the slide can be classified such as a wedge, slab slides, block, deep seated or shallow rupture surfaces. According to the Varnes (1978) and Brunsden and Prior (1984), the slide can be classified based on the movement, distinguish in terms of type of motion, translational, planar, rotational, or toppling failure.

Based on the orientation of the bedding with respect to the geometry of the slope, categories of dip and overdip slopes, reverse-dip slopes, oblique and strike- slopes, and underslip slopes, the classification of the slope will be identified especially for stratified rock.

Planar Failure happens when a block of rock that contain discontinuities sliding along a single plane considering some of parameter and condition that influencing their stability as Figure 2.5.

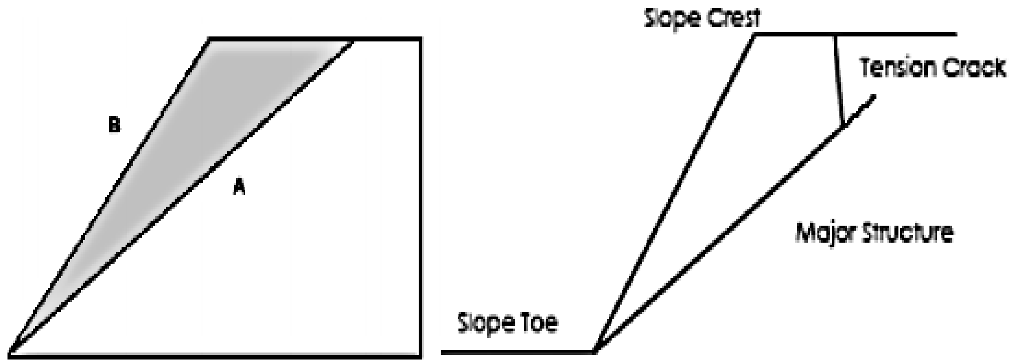

Figure 2.5: Typical View of Planar Failure (A: sliding plane B: slope face) *(Admassu, 2012)*

Wedge failure occurs when two planes of intersecting discontinuities dipping out of the cut slope at an oblique angle to the cut face, thus forming a wedge- shaped block as Figure 2.6. Wedge failure can occur in a rock mass with two or more sets of discontinuities whose lines of intersection are approximately perpendicular to the strike of the slope and dip towards the plane of the slope.

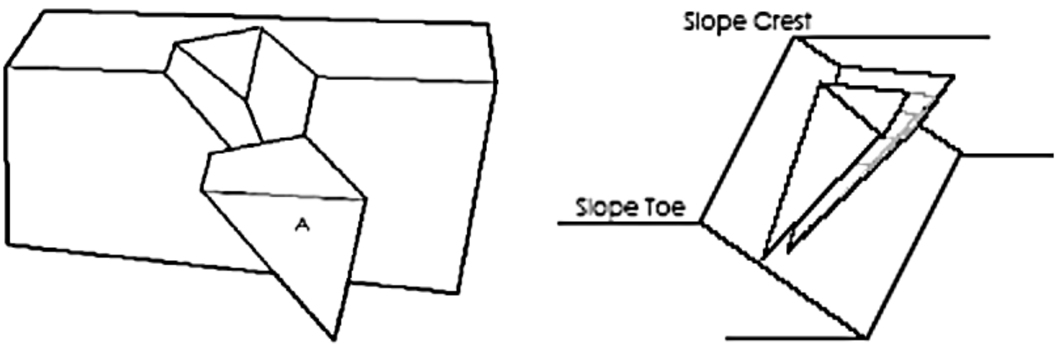

Figure 2.6: Typical View of Wedge Failure (*Admassu, 2012)*

Toppling Failures happen if the collumn of the rock, formed by steeply dipping discontinuities in the rock rotates about an essentially fixed point at or near the base of the slope followed by slippage between the layers There are further categorised depend on the mode like example flexural toppling, block toppling and block flexural toppling as Figure2.7.

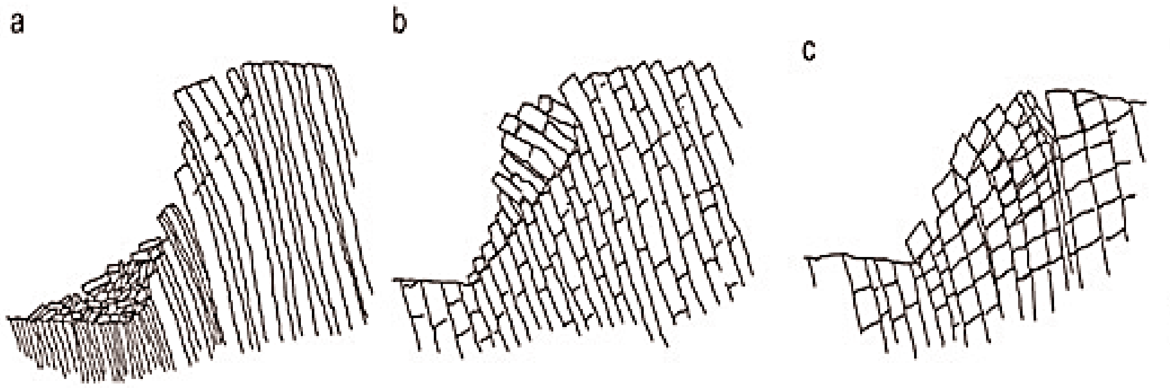

Figure 2.7: Mode of Toppling Failure. a) Flexural toppling b) Block toppling c)Block-flexural toppling modified *(Goodman and Bray 1976)*

Rock fall happens when a rock mass in any size is detached from a steep slope or cliff along a surface on which little or no shear displacement takes place and descends mostly through the air either by free fall, bouncing, leaping or rolling as Figure2.8 below. It is initiated by some biological or climatic event due to a change in the force acting on a rock.

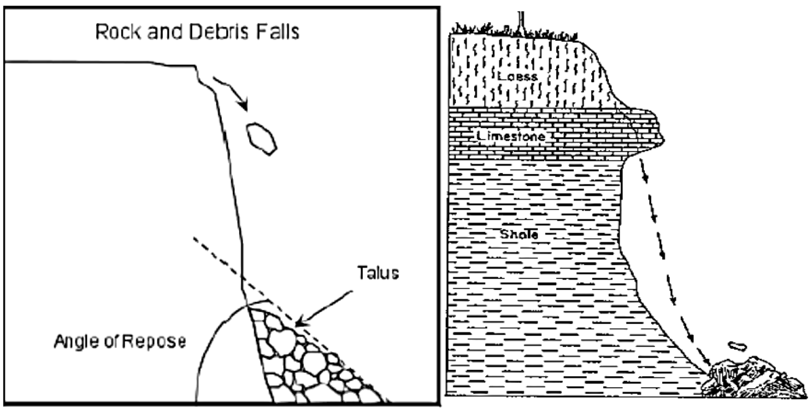

Figure 2.8: Rock Fall view *(A. Franklin and Dusseault, 1992)*

The rotational type of slope failure mainly occurs in soil, very weak rock, heavily jointed or fractured rock mass and mine dump. It also divides into two type whether it is circular or non-circular slips with non-homogeneous conditions (Figure 2.9). This failure can occur in rock structures that exhibit no plane of weakness, and may not be associated with any underlying critical discontinuity. They involve factors such as moisture content, cohesive or shear strength of the materials, and various triggering events.

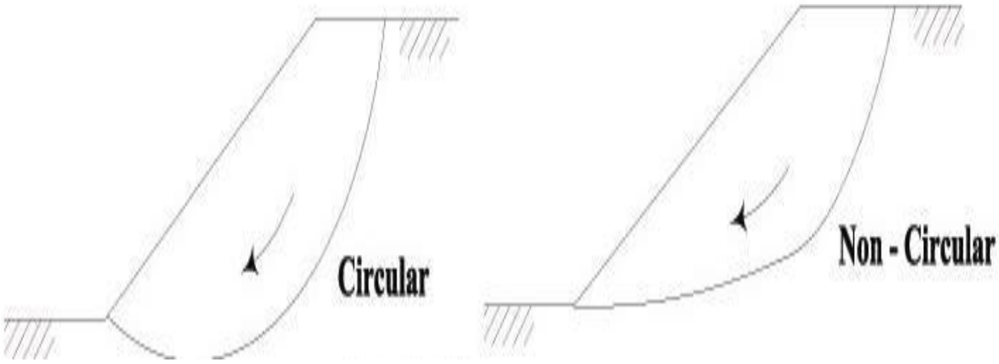

Figure 2.9: Rotational Failure *(Wyllie and Mah, 2017)*

2.6 Condition of Failure

i. Circular Failure (Figure 2.10):

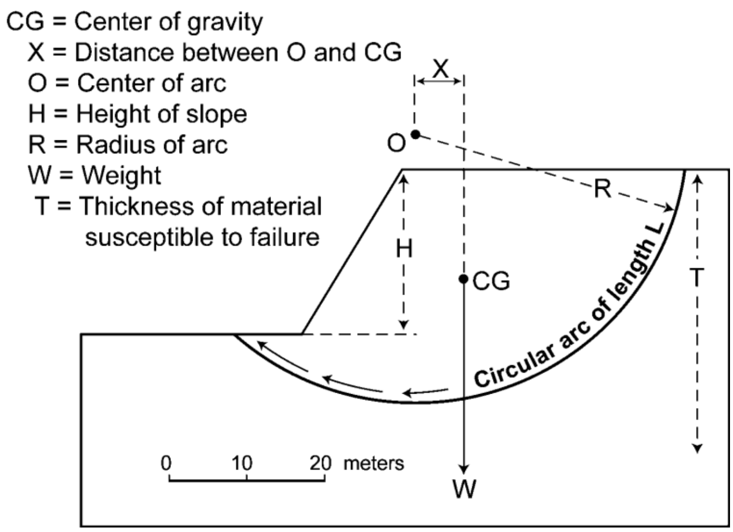

Figure 2.10: Condition of Circular Failure *(Grover and Nash, 2018)*

The individual particle in a soil or rock mass are very small compared with the size of the slope and the broken rock is behave as a soil, then it fails in a circular shape. The presence of an adjacent stratum of significantly different strength and the adjacent stratum is at a relatively shallow depth below the surface of the slope where the failure surface tends to be a plane and roughly parallel to the slope.

ii. Planar Failure(Figure2.11):

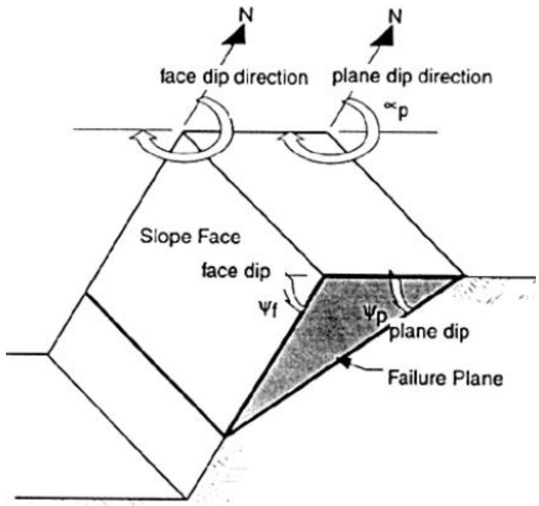

Figure 2.11: Condition of Planar Failure *(Aksoy and Ercanoglu, 2007)*

The sliding plane must strike parallel or nearby parallel (±20º) to the slope face, sliding plane must "daylight" in the slope face where the dip of the sliding plane must be less than the dip of the slope face, $\psi_p < \psi_f$, the dip of sliding plane is greater than the angle of friction, $\psi_p > ø$, The upper end of the sliding surface, intersects the upper slope or terminates in a tension crack and presence of release surface is to define the boundaries of the slide.

*iii. Wedge Failure (*Figure 2.12)*:*

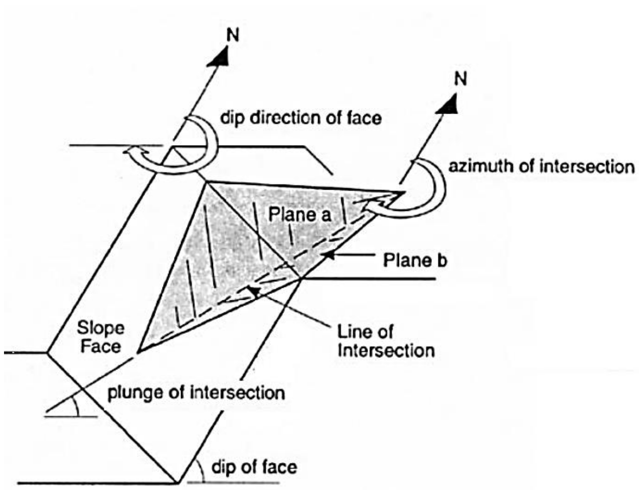

Figure 2.12: Condition of Failure for Wedge Failure (*Aksoy and Ercanoglu, 2007)*

The two planes will always intersect in a line on the stereonet, the line of the intersection point where 2 great circles of the plane intersect, then the orientation of the line is defined as trend ($\propto_i$) and plunge (ψ_i) and sliding may occur if the intersection point lies within the shaded area, The plunge of the line intersection must be flatter than the dip of the face, steeper than the average friction angle, $\psi_{fi} > \psi_i > \phi$. *The inclination of the slope face,* ψ_{fi} is measured in the view at right angles to the line of the intersection and the sliding to feasible it needs to the line of intersection must dip in the direction out of the face with possible range trend of the line if the intersection is between $\propto_i$ and $\propto'_i$.

iv. *Toppling Failure (Figure 2.13) :*

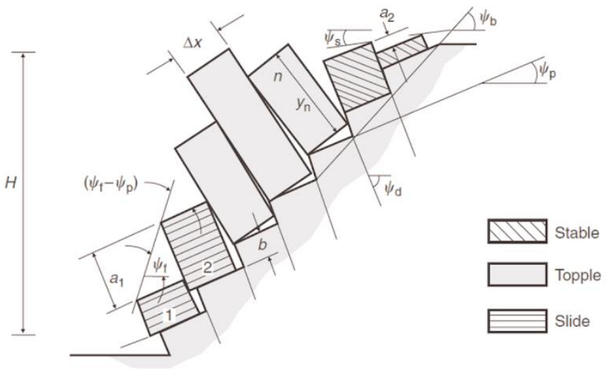

Figure 2.13: Model of Toppling Failure
(*Goodman and Bray 1976, Wyllie and Mah,2005)*

According to Goodman (1989), a toppling failure involves inter-layer slip movement. The requirement for the occurrence of a toppling failure according to Goodman (1989) is "If layers have an angle of friction Φj, the slip will occur only if the direction of the applied compression makes an angle greater than the friction angle with the normal to the layers. Thus, a pre-condition for the interlayer slip is that the normal be inclined less steeply than a line inclined Φj above the plane of the slope. If the dip of the layers is σ, then toppling failure with a slope inclined α degrees with the horizontal can occur if $(90 - \sigma) + \Phi j < \alpha$".