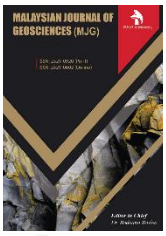
ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2521-0920 (Print)
ISSN: 2521-0602 (Online)
CODEN: MJGAAN

Malaysian Journal of Geosciences (MJG)

DOI: http://doi.org/10.26480/mjg.02.2020.96.102



CrossMark

RESEARCH ARTICLE

APPLICABILITY OF THE ROCK MASS RATING (RMR) SYSTEM FOR THE TRUSMADI FORMATION AT SABAH, MALAYSIA

Rodeano Roslee[a,b]*, Jeffery Anak Pirah[a,c], Mohd Fauzi Zikiri[a,d], Ahmad Nazrul Madri[a,d]

[a] *Universiti Malaysia Sabah, Faculty of Science and Natural Resources, UMS Road, 88400 Kota Kinabalu, Sabah, Malaysia.*
[b] *Universiti Malaysia Sabah, Natural Disaster Research Centre (NDRC), UMS Road, 88400 Kota Kinabalu, Sabah, Malaysia.*
[c] *Alamega Konsult, 2nd Floor, Block B, Lot 12-2, Plaza Utama, Jalan Penampang By Pass, 88300 Kota Kinabalu, Sabah, Malaysia.*
[d] *Department of Public of Work (Sabah State), Slope Branch, Sembulan Road, 88538 Kota Kinabalu, Sabah, Malaysia.*
**Correspondence Author Email: rodeano@ums.edu.my*

ARTICLE DETAILS

Article History:

Received 02 October 2020
Accepted 05 November 2020
Available Online 18 November 2020

ABSTRACT

Rock Mass Classification Systems (RMCS) can be of considerable use in the initial stage of a project when little or no detailed information is available. There is a large number of RMCS developed for general purposes but also for specific applications such as Rock Quality Designation (RQD), Rock Mass Rating (RMR), Rock Structure Rating (RSR), Geological Strength Index (GSI), Slope Mass Rating (SMR), etc. In this paper, we present the results of the applicability of the Rock Mass Rating (RMR) System for the Trusmadi Formation in Sabah, Malaysia. The RMR system is a RMCS incorporated with five (5) parameters: Strength of intact rock material, Rock Quality Designation (RQD), Spacing of joints, Condition of joints, and Groundwater conditions. A total of ten (10) locations were selected on the basis of exposures of the lithology and slope condition of the Trusmadi Formation. Trusmadi Formation is Paleocene to Eocene in aged. The Trusmadi Formation generally shows two major structural orientations NW-SE and NE-SW. Trusmadi Formation is characterized by the present of dark colour argillaceous rocks, siltstone and thin-bedded turbidite in well-stratified sequence. Some of the Trusmadi Formation rocks have been metamorphosed to low grade of the greenish-schist facies; the sediment has become slate, phyllite and metarenite. Cataclastic rocks are widespread and occur as black phyllonite enclosing arenitic and lutitic boudins with diameter up to a meter or demarcating thin to thicker fault zones or as flaser zones with hardly any finer grain matrix or as zones of closely spaced fractures. Quartz and calcite veins are quite widespread within the crack deformed on sandstone beds. The shale is dark grey when fresh but changes light grey to brownish when weathered. The RMR system for 10 outcrops ranges from 33.0 to 50.0 and its classified as “Fair” (Class III) to “Poor” (Class IV) rocks. The Fair Rock (Class III) recommended that the excavation should be top heading and bench 1.5 m – 3 m advance in the top heading. Support should be commencing after each blast and complete support 10 m from face. Rock bolts should be systematic with 4 m long spaced 1.5 m - 2 m in crown and walls with wire mesh in crown. Shotcrete should be 50 mm – 100 mm in crown and 30 mm in sides. While for the Poor Rock (Class IV), the excavation should be top heading and bench 1.0 m – 1.5 m advance in top heading. Support should be installed concurrently with excavation, 10 m from face. Rock bolt should be systematic with 4 m – 5 m long, spaced 1.5 m – 1.5 m in crown and walls with wire mesh. Shotcrete of 100 m – 150 mm in crown and 100 mm in sides. The steel sets should be light to medium ribs spaced 1.5 m only when required.

KEYWORDS

Rock Mass Rating (RMR) System, Rock Mass Classification Scheme (RMCS) & Trusmadi Formation.

1. INTRODUCTION

Rock Mass Classification Systems (RMCS) can be of considerable use in the initial stage of a project when little or no detailed information is available. There is a large number of RMCS developed for general purposes but also for specific applications. Most of the multi-parameter were developed from civil engineering case histories in which all of the components of the engineering geological characteristics of the rock mass were included in RMCS (Wickham et al ., 1972; Bieniawski, 1973; 1989; and Barton et al., 1974). The RMCS take into consideration several factors, which are believed to affect the stability. The parameters are therefore often related to the discontinuities such as the number of joint sets, joint distance, roughness, alteration and filling of joints, groundwater conditions, and sometimes also the strength of the intact rock and the stress magnitude.

Quick Response Code	Access this article online	
	Website: www.myjgeosc.com	**DOI:** 10.26480/mjg.02.2020.96.102

Cite the Article: Rodeano Roslee, Jeffery Anak Pirah, Mohd Fauzi Zikiri, Ahmad Nazrul Madri (2020). Applicability Of The Rock Mass Rating (RMR) System For The Trusmadi Formation At Sabah, Malaysia. *Malaysian Journal of Geosciences, 4(2): 96-102.*

RMCS is an indirect approach and does not measure the mechanical properties as well. The result is an estimate of the stability quantified in subjective terms such as e.g. bad, acceptable, good or very good. The value obtained by some of the RMCS is used to estimate or calculate the rock mass strength using a failure criterion. It can also be used to estimate necessary rock support. Therefore, it is important to understand that the use of a RMCS cannot replace some of the more elaborate design procedures. However, the use of these design procedures requires access to relatively detailed information on in situ stresses, rock mass properties and planned excavation sequence, none of which may be available at an early stage in the project. As this information becomes available, the use of the RMCS should be updated and used in conjunction with site specific analyses.

Bieniawski published the details of Rock Mass Rating (RMR) system (Bieniawski, 1976). Over the years, this system has been successively refined as more case records have been examined and the reader should be aware that Bieniawski has made significant changes in the ratings assigned to different parameters. In applying this RMR system, the rock mass is divided into a number of structural regions and each region is classified separately. The boundaries of the structural regions usually coincide with a major structural feature such as a fault or with a change in rock type. In some cases, significant changes in discontinuity spacing or characteristics, within the same rock type, may necessitate the division of the rock mass into a number of small structural regions.

2. Background of Study Area

Study area is located about 110km from Kota Kinabalu city center. It is bounded between longitude line E 116° 30' to E 116° 40' and latitude line N 06° 09' to N 06°15' (Figure 1). Due to this study only concentrated on the Trusmadi Formation, all activities such mapping, sampling, observation and monitoring is more focused on the slopes under this formation. The Trusmadi Formation consists of dark argillaceous rocks, siltstone, and sandstone with rare volcanic (Jacobson, 1970; Rodeano et al., 2010; Norbert et al., 2016; Rodeano et al., 2018). The age of the Trusmadi Formation ranges from late Paleocene to early Eocene (Table 1) (Jacobson, 1970). Low-grade metamorphism has occurred in some of the rocks of the Trusmadi Formation. The rocks are sheared and brecciate and cataclasites are common. The dark argillaceous rocks are thickly bedded or interbedded with sandstone and siltstone beds. The thickness of the argillaceous beds is about 30 m, whereas the sandstone beds are about 37 m in the Gunung Kinabalu area (Jacobson, 1970). Rare volcanic rocks, mainly spilite also occur in the Trusmadi Formation. Quartz veining is quite common in this Formation.

3. Determination of Rock Mass Rating (RMR) System

Field studies have been carried out to study the lithological and structural variations in rock slopes. A total of ten (10) locations were selected on the basis of exposures of the lithology and slope condition of the Trusmadi Formation (Figure 2). Slopes at these locations were studied and classified for their Rock Mass Rating (RMR) System were calculated by using below equation:

RMR = Parameter A + Parameter B + Parameter C + Parameter D + Parameter E (1) (Bieniawski, 1989)

Where,

Parameter A= Strength of intact rock material. Uniaxial compressive strength is preferred. For rock of moderate to high strength, point load index is acceptable.

Parameter B= Rock quality designation (RQD) which, as an attempt to quantify rock mass quality. RQD only represents the degree of fracturing of the rock mass. It does not account for the strength of the rock or mechanical and other geometrical properties of the joints.

Parameter C= Spacing of joints. Average spacing of all rock discontinuities is used.

Parameter D= Condition of joints. Condition includes joint aperture, persistence, roughness, joint surface weathering and alteration, and presence of infilling.

Parameter E= Groundwater conditions. It is to account for groundwater inflow in excavation stability.

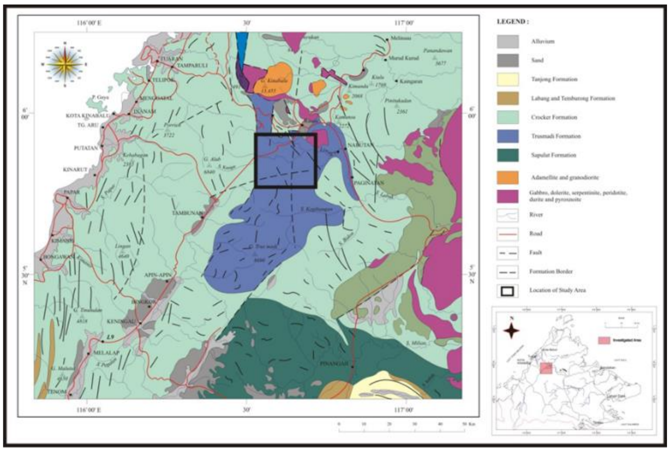


Figure 1: Location of study area

Table 1: Local Stratigraphic Column and their Water Bearing and Engineering Remarks for the Trusmadi Formation

Age	Unit	General Character	Water-Bearing Properties	Engineering Remarks
Paleocene to Eocene	Trusmadi Slate and Trusmadi Phyllite	Comprise of dark colour argillaceous rock either in thick bedded or interbedded with thin sandstone beds and siltstone.	Fractured sandstone has significant to groundwater.	Dangerous site for heavy structure. Improvement should be conducted before any project.

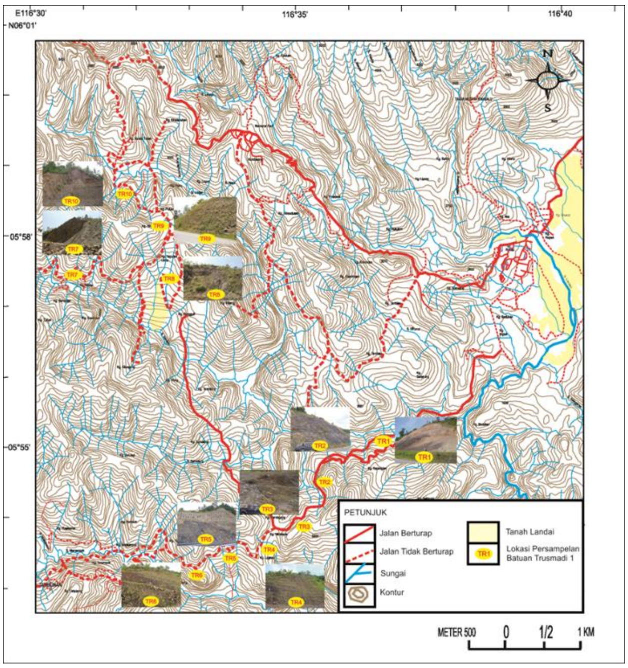


Figure 2: Selected rock slopes location with their photographs

Table 2 is the RMR system classification updated in 1989. Part A of the table shows the RMR system classification with the above 5 parameters. Individual rate for each parameter is obtained from the property of each parameter. The weight of each parameter has already considered in the rating. The overall basic RMR system rate is the sum of individual rates.

Influence of joint orientation on the stability of excavation is considered in Part B of the same table. Explanation of the descriptive terms used is given table Part C. With adjustment made to account for joint orientation, a final RMR system rating is obtained it can be also expresses in rock mass class, as shown in Tables 2 and 3. The tables also gives the meaning of rock mass classes in terms of stand-up time, equivalent rock mass cohesion and friction angle. Part D indicate the meaning of rock classes, Part E described the guidelines for classification of discontinuity conditions and Part F explained the effect of discontinuity strike and dip orientation in tunneling. Upon obtaining a RMR System, the value will be matched to a figure of recommended guidelines for support in tunnels and mine (Table 4).

Table 2: Rock Mass Rating (RMR) System (Bieniawski, 1989)

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10MPa	4 – 10MPa	2 – 4MPa	1 – 2MPa	For this low range – uniaxial compressive test is preferred		
		Uniaxial compression strength	>250MPa	100 – 250MPa	50 – 100MPa	25 – 50MPa	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 discontinuities		>2m	0.6 – 2m	200 – 600mm	60 – 200mm	<60mm		
	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 <1mm Slightly weathered walls	Slightly rough surfaces Separation <1mm Highly weathered walls	Slickensided surfaces or gouge <5mm thick or Separation 1-5mm continuous	Soft gouge >5mm thick or Separation >5mm continuous		
	Rating		30	25	20	10	0		
5	Ground water	Inflow per 10m 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 and mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	-60

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 15m span	1 year for 10m span	1 week for 5m span	10 hrs for 2.5m span	30 min for 1m 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	<1m 6	1.3m 4	3 – 10m 2	10 – 20m 1	>20m 0
Separation (aperture) Rating	None 6	<0.1mm 5	0.1 – 1.0mm 4	1 – 5mm 1	>5mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling <5mm 4	Hard filling >5mm 2	Soft filling <5mm 2	Soft filling >5mm 0
Weathering Rating	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	

Table 3: Rock mass classes determined from total ratings and meaning (Bieniawski, 1989)

RMR Ratings	81 – 100	61 – 80	41 – 60	21 – 40	< 20
Rock mass class	A	B	C	D	E
Description	very good rock	good rock	fair rock	poor rock	very poor rock
Average stand-up time	10 year for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2.5 m span	30 minutes for 0.5 m span
Rock mass cohesion (KPa)	> 400	300 – 400	200 – 300	100 – 200	< 100
Rock mass friction angle	> 45°	35° – 45°	25° – 35°	15° – 25°	< 15°

Table 4: Guidelines for excavation and support of 10m span rock tunnels in accordance with the RMR System (Bieniawski, 1989)

Rock Mass Class	Excavation	Rock bolts (20mm diameter, fully grouted)	Shotcrete	Steel sets
I – Very good rock RMR: 81 – 100	Full face, 3m advance	Generally no support required except spot bolting		
II – Good rock RMR: 61 – 80	Full face, 1 – 1.5m advance. Complete support 20m from face.	Locally, bolts in crown 3m long, spaced 2.5m with occasional wire mesh	50mm in crown where required.	None
III – Fair rock RMR: 41 – 60	Top heading and bench 1.5 – 3m advance in top heading. Commence support after each blast. Complete support 10m from face	Systematic bolts 4m long, spaced 1.5 – 2m in crown and walls with wire mesh in crown	50 – 100mm in crown and 30mm in sides.	None
IV – Poor rock RMR: 21 – 40	Top heading and bench 1.0 – 1.5m advance in top heading. Install support concurrently with excavation, 10m from face	Systematic bolts 4 – 5m long, spaced 1 – 1.5m in crown and walls with wire mesh.	100 – 150mm in crown and 100mm in sides	Light to medium ribs spaced 1.5m where required
V – Very poor rock RMR: <20	Multiple drifts 0.5 – 1.5m advance in top heading. Install support concurrently with excavation. Shotcrete as soon as possible after blasting	Systematic bolts 5 – 6m long, spaced 1 – 1.5m in crown and walls with wire mesh. Bolt invert.	150 – 200mm in crown, 150mm in sides and 50mm on face	Medium to heavy ribs spaced 0.75m with steel lagging and forepoling if required. Close invert.

4. Estimation of Rock Mass Rating (RMR) System

4.1 Strength of intact rock material

The strength of intact rock material of the Trusmadi Formation was established by testing approximately 10 rock samples. There are 3 tests conducted to obtain the strength of intact rock material; Schmidt hammer rebound test, Point load test ($I_{s(50)}$) and Uniaxial compressive strength (UCS). However, the Point load test ($I_{s(50)}$) and UCS are chosen to determine the RMR System value because it has higher precision and according to the classification scheme introduced (Table 5) (Hoek et al., 1998).

Table 5: Strength of intact rock material results

Location		N5°55.053’, E116°36.859’	N5°54.521’, E116°35.703’	N5°53.901’ E116°35.105’	,N5°54.683’, E116°34.548’	N5°53.463’ , E116°33.856’
Depth (m)		0.30-0.50	0.30-0.50	0.30-0.50	0.30-0.50	0.30-0.50
Sample No.		TR1	TR2	TR3	TR4	TR5
Rock Strength tests						
Weathering Grade	-	III – IV	III – IV	III – IV	III – IV	III – IV
Point load test ($I_{s(50)}$)	mPa	0.4727	0.3800	0.4214	0.4694	0.4738
Uniaxial compressive strength (UCS)	mPa	5.849	5.289	5.645	5.847	5.283
Description		**Moderately weak**	**Moderately weak**	**Moderately weak**	**Moderately weak**	**Moderately weak**
Rating		**2.0**	**2.0**	**2.0**	**2.0**	**2.0**
Location		N5º53.139’, E116º33.173’	N5º57.472’, E116º30.908’	N5º57.411’, E116º32.893’	N5º58.105’, E116º32.289’	N5º58.648’, E116º31.815’
Depth (m)		0.30-0.50	0.30-0.50	0.30-0.50	0.30-0.50	0.30-0.50
Sample No.		TR6	TR7	TR8	TR9	TR10
Rock Strength tests						
Weathering Grade	-	III – IV	III – IV	III – IV	III – IV	III – IV
Point load test ($I_{s(50)}$)	mPa	0.3838	0.4849	0.4109	0.3852	0.5237
Uniaxial compressive strength (UCS)	mPa	5.497	5.225	6.143	5.894	5.362
Description		**Moderately weak**	**Moderately weak**	**Moderately weak**	**Moderately weak**	**Moderately weak**
Rating		**2.0**	**2.0**	**2.0**	**2.0**	**2.0**

Cite the Article: Rodeano Roslee, Jeffery Anak Pirah, Mohd Fauzi Zikiri, Ahmad Nazrul Madri (2020). Applicability Of The Rock Mass Rating (RMR) System For The Trusmadi Formation At Sabah, Malaysia. *Malaysian Journal of Geosciences, 4(2): 96-102.*

Based on the results in Table 5, the ranges of point load strength index ($I_{s(50)}$) significantly from 0.3800 MPa to 0.5237 MPa (moderately weak). While UCS results also indicated the similar category moderately week, which is varies from the lowest 5.225 MPa to the highest 6.143 MPa. Both the experimental results show that the rocks exhibit very high grade of weathering features such as chemical weathering and influences from rainfall. Moreover, a new foliated/sheared rock mass category of the Trusmadi Formation has thus been considered to better represent thinly foliated and structurally sheared weak rocks. In these rock masses the foliation is the predominant structural feature which prevails over any other discontinuity set, resulting in complete lack of blockiness.

4.2 Rock Quality Designation (RQD)

Due to unable to obtain a drill core sample for the selected outcrops, other method has been used in determining the value of Rock Quality Designation (RQD). By using the method that was introduced by Priest & Hudson (1976), RQD value has been estimated from the average of joint spacing. The value of RQD later was used in classification of GSI (Hoek & Karzulovic, 2000). The value of RQD for the 10 selected slopes in the study area is shown in Table 6. Based on the RQD results, the rock mass quality in the study area can be categorised as fair where the RQD values is ranging between 50.37 to 65.18 %. This result indicates that the value of RQD is directly influenced by the presence of discontinuity characteristics in the intact rock. This condition is proved by the presence of the lower intensity of joint sets or shale unit, the value of RQD will be higher.

Table 6: Results for rock quality designation (RQD)

Location No.	Rock Quality Designation, $100e^{-0.1\lambda}(0.1\lambda+1)$	Rock Quality Description	Rating
TR1	61.51	Fair rock	13.0
TR2	54.49	Fair rock	13.0
TR3	50.37	Fair rock	13.0
TR4	53.90	Fair rock	13.0
TR5	61.52	Fair rock	13.0
TR6	52.49	Fair rock	13.0
TR7	65.18	Fair rock	13.0
TR8	60.26	Fair rock	13.0
TR9	55.42	Fair rock	13.0
TR10	58.25	Fair rock	13.0

4.3 Spacing of discontinuities

Discontinuity spacing is a basic measurement of the distance between one discontinuity and another. Priest stated three forms of discontinuity spacing measurements: total spacing, set spacing, and normal set spacing (Priest, 1993). Total spacing is the distance between two adjacent discontinuities, measured along a sampling line but with a specified location and orientation. Set of spacing is the distance between adjacent discontinuities from a particular discontinuity set measured along a sampling line but with a specified location and orientation. Normal set spacing is the set spacing measured along a sampling line that is normal to the mean orientation of a particular set.

Discontinuity spacing determines the dimensions of the blocks of rocks in a slope which influences the overall stability of the rock slope. Therefore, it is an important parameter in designing appropriate stabilization measures for rock slopes such as rock bolts and rock fall barriers (Priest and Hudson, 1976). Similarly, discontinuity spacing is one of the most important parameters to describe the quality of a complete rock mass. It is widely used in the rock mass classification system such as the rock mass rating system (Priest, 1993). A total of 1,258 discontinuity of fractures (joints) were measured from the study area. From the data obtained, the occurrences of discontinuity spacing were recorded and divided into two (2) categories; 60-200 mm (rating = 8) and 200-600 m (rating = 10) (Table 7).

Table 7: Results for spacing of discontinuities

Location No.	Spacing of discontinuities	Rating
TR1	≈ 75-105mm	8.0
TR2	≈ 480-560mm	10.0
TR3	≈ 65-155mm	8.0
TR4	≈ 450-580mm	10.0
TR5	≈ 114-135mm	8.0
TR6	≈ 240-480mm	10.0
TR7	≈ 106-180mm	8.0
TR8	≈ 88-176mm	8.0
TR9	≈ 450-575m	10.0
TR10	≈ 425-550m	10.0

4.4 Condition of discontinuities

A discontinuity of fractures (joints) is an interface face of two contacting surfaces. The surfaces can be smooth or rough; they can be in good contact and matched, or they can be poorly contacted and mismatched. The condition of contact also governs the aperture of the interface. The interface can also be filled with intrusive or weathered materials. Joint surface roughness is a measure of the inherent surface unevenness and waviness of the discontinuity relative to its mean plane. The roughness is characterised by large scale waviness and small scale unevenness of a discontinuity. It is the principal governing factor the direction of shear displacement and shear strength, and in turn, the stability of potentially sliding blocks.

Roughness can be distinguished between small scale surface irregularity or unevenness and large scale undulation or waviness of the discontinuity surface. A classification of discontinuity roughness has been suggested, and is reproduced in Table 2 for RMR system. It describes the roughness first in meter scale (step, undulating, and planar) and then in centimeter scale (rough, smooth, and slickensided) (Bieniawski, 1989). The result of condition of discontinuities from the field observation is presented in Table 8. Based on the results, the condition of discontinuities of the slopes in the study area can be categorized as:

a. Slightly rough surfaces, separation <1mm and highly weathered walls.

b. Slickensided surfaces with gouge <5mm thick and separation 1-5mm continuous.

The classification is useful to describe the joint surface but does not give any quantitative measure. Moreover, filling is material in the rock discontinuities. The material separating the adjacent rock walls of discontinuities. The wide range of physical behaviour depends on the properties of the filling material. In general, filling affects the shear strength, deformability and permeability of the discontinuities.

Table 8: Results for condition of discontinuities

Location No.	Condition of discontinuities	Rating
TR1	Slightly rough surfaces, separation <1mm and highly weathered walls	20.0
TR2	Slickensided surfaces with gouge <5mm thick and separation 1-5mm continuous	10.0
TR3	Slightly rough surfaces, separation <1mm and highly weathered walls	20.0
TR4	Slickensided surfaces with gouge <5mm thick and separation 1-5mm continuous	10.0
TR5	Slickensided surfaces with gouge <5mm thick and separation 1-5mm continuous	10.0
TR6	Slightly rough surfaces, separation <1mm and highly weathered walls	20.0
TR7	Slickensided surfaces with gouge <5mm thick and separation 1-5mm continuous	10.0
TR8	Slightly rough surfaces, separation <1mm and highly weathered walls	20.0
TR9	Slickensided surfaces with gouge <5mm thick and separation 1-5mm continuous	10.0
TR10	Slickensided surfaces with gouge <5mm thick and separation 1-5mm continuous	10.0

4.5 Groundwater conditions

Groundwater occupying the fractures within a rock mass can significantly reduces the stability of a rock slope. Water pressure acting within a discontinuity reduces the effective normal stress acting on plane, thus reducing the shear strength along the plane. Water pressure within discontinuities that run roughly parallel to a slope face also increase the driving forces acting on the rock mass. In the study area, groundwater occurs and moves through interstices or secondary pore openings in the rock formations in wet to flowing (Table 9). Such openings can be the pore spaces between individual sedimentary and meta-sediment grains, open joints and fractures or solution and cavernous opening in brecciated layers and cataclasites.

The direction of groundwater movement is generally under the influence of gravity. The rock formations exhibit a high degree of weathering and covered by thick residual soil that extends to more than 25 meters in thickness. Evaluation of more than 60 boreholes in the study area indicated that the groundwater table is shallow and ranges from 2 meters to about 15 meters (Rodeano, 2020). It's also seen that the water table follows the topography from highland toward the road and the valley side. The weathered materials are weak due to high fractures porosity and high pore-water pressures that generated by both shallow and deep groundwater.

Table 9: Results for groundwater conditions

Location No.	Groundwater conditions			
	Inflow per 10m tunnel length (l/m)	**(Joint water press)/ (major principal, σ)**	**General conditions**	**Rating**
TR1	10 – 25	0.1 – 0.2	Wet	7.0
TR2	> 125	> 0.5	Flowing	0.0
TR3	> 125	> 0.5	Flowing	0.0
TR4	25 – 125	0.2 – 0.5	Dripping	4.0
TR5	10 – 25	0.1 – 0.2	Wet	7.0
TR6	25 – 125	0.2 – 0.5	Dripping	4.0
TR7	> 125	> 0.5	Flowing	0.0
TR8	25 – 125	0.2 – 0.5	Dripping	4.0
TR9	10 – 25	0.1 – 0.2	Wet	7.0
TR10	25 – 125	0.2 – 0.5	Dripping	4.0

5. Summary Result of Rock Mass Rating (RMR) Classification System

The summary result of Rock Mass Rating (RMR) System are shown in Table 10. Based on the Table 10, the strenght of intact rock rating for all ten rock sample from the outcrop is 2.0. For RQD ratings, it shows that all of the samples has 13.0 which indicates that the rock RQD quality ranges from 50% - 75%. For TR1, TR3, TR5, TR7 and TR8, the spacing of joint rating is 8.0 which indicicates 60 mm – 200 mm spacing of discontinunity, while TR2, TR4, TR6, TR9 and TR10 spacing of joints is 10.0 indicating a 200mm – 600mm discontinuity spacing. For the condition of joints rating, TR2, TR4, TR5, TR7, TR9 and TR10 rate is 10.0, which means the condition of discontinuity on the outcrop has slickensided surface or gouge with less than 5 mm thick and seperation of 1 mm – 5 mm continuously.

Meanwhile TR1, TR3, TR6 and TR8 has condition of joint rating of 20.0 indicating that the condition of discontinuities on respective outcrops has slightly rough surfaces with seperation of less than 1mm and slightly weathered walls. Groundwater conditions rating for TR2, TR3 and TR7 is 0.0 indicating that the general condition for the outcrops are completely dry, TR4, TR6, TR8 and TR10 has 4.0 rating for groundwater condition indicating a dripping water on outcrops while TR1, TR5 and TR9 has 7.0 groundwater conditions rating indicating a flowing water on the outcrops. Therefore, the RMR ratings for 10 outcrops ranges from 33.0 to 50.0 and classified as "Fair" to "Poor" rocks.

Table 10: The total summarizes rating for the Rock Mass Rating (RMR) System results.

Station	**TR1**	**TR2**	**TR3**	**TR4**	**TR5**	**TR6**	**TR7**	**TR8**	**TR9**	**TR10**
Strength of intact rock material rating	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
RQD rating	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
Spacing of joints rating	8.0	10.0	8.0	10.0	8.0	10.0	8.0	8.0	10.0	10.0
Condition of joints rating	20.0	10.0	20.0	10.0	10.0	20.0	10.0	20.0	10.0	10.0
Groundwater conditions rating	7.0	0.0	0.0	4.0	7.0	4.0	0.0	4.0	7.0	4.0
TOTAL RMR rating	50.0	35.0	43.0	39.0	40.0	49.0	33.0	47.0	42.0	39.0
RMR System Classification	**Fair rock**	**Poor rock**	**Fair rock**	**Fair rock**	**Fair rock**	**Fair rock**	**Poor rock**	**Fair rock**	**Fair rock**	**Poor rock**

6. Application of Rock Mass Rating (RMR) System For The Trusmadi Formation

Table 3 shows the rock mass classes determined from total ratings and its meaning. According to Tables 2 and 3, TR2, TR3, TR4, TR5, TR7, TR9 and TR10 falls in rock mass class D. Rock mass class D are generally poor rocks with average stand- up time of 10 hours for 2.5m span with mass cohesion ranges between 100 kPa – 200 kPa and rock mass friction angle ranges from 15° to 35°. Meanwhile, TR1, TR6 and TR8 falls on rock mass class C. For rock mass class C, the rock from this class are generally fair rock. A class C rock has average stand-up time of 1 week for 5 m span. The rock mass cohesion for this class ranges from 200 kPa – 300 kPa with friction angle ranges from 25° to 35°.

The Rock Mass Rating (RMR) System of the Trusmadi Formation is classified as Class III (fair rock) and Class IV (poor rock) (Table 4). The guideline for excavation and support of 10m span rock tunnels on Table 4 indicate that for fair rock (Class III), the excavation should be top heading and bench 1.5 m – 3 m advance in the top heading. Support should be commencing after each blast and complete support 10 m from face. Rock bolts should be systematic with 4 m long spaced 1.5 m - 2 m in crown and walls with wire mesh in crown. Shotcrete should be 50 mm – 100 mm in crown and 30 mm in sides.

For poor rock (Class IV), the excavation should be top heading and bench 1.0 m – 1.5 m advance in top heading. Support should be installed concurrently with excavation, 10 m from face. Rock bolt should be systematic with 4 m – 5 m long, spaced 1.5 m – 1.5 m in crown and walls with wire mesh. Shotcrete of 100 m – 150 mm in crown and 100 mm in sides. The steel sets should be light to medium ribs spaced 1.5 m only when required (Table 4).

7. Conclusion

In light of available information, the following conclusions may be drawn from the present study:

1. The RMR system for 10 outcrops from the Trusmadi Formation ranges from 33.0 to 50.0 and its classified as "Fair" (Class III) to "Poor" (Class IV) rocks.

2. The Fair Rock (Class III) recommended that the excavation should be top heading and bench 1.5 m – 3 m advance in the top heading. Support should be commencing after each blast and complete support 10 m from face. Rock bolts should be systematic with 4 m long spaced 1.5 m - 2 m in crown and walls with wire mesh in crown. Shotcrete should be 50 mm – 100 mm in crown and 30 mm in sides.

3. For the Poor Rock (Class IV), the excavation should be top heading and bench 1.0 m – 1.5 m advance in top heading. Support should be installed concurrently with excavation, 10 m from face. Rock bolt should be systematic with 4 m – 5 m long, spaced 1.5 m – 1.5 m in crown and walls with wire mesh. Shotcrete of 100 m – 150 mm in crown and 100 mm in sides. The steel sets should be light to medium ribs spaced 1.5 m only when required.

Acknowledgements

Deep gratitude to Universiti Malaysia Sabah (UMS) for providing easy access to laboratories and research equipment. Highest appreciations also to Ministry of Higher Education of Malaysia (MOHE) for the research grant award (*Engineering Properties of The Trusmadi Formation Rocks and Soils in Ranau Area, Sabah, Malaysia-FRG0095-ST-1-2006*) to finance all the costs of this research.

References

Barton, N., Lien, R., Lunde, J., 1974. Analysis of rock mass quality and support practice in tunneling and a guide for estimating support requirements. Internal report No. 106. Norwegian Geotechnical Institute, Oslo.

Bieniawski, Z.T., 1973. Engineering classification of jointed rock masses. South African Inst. Civil Eng., 15, Pp. 335 – 344.

Bieniawski, Z.T., 1976. The point load test in geotechnical practice. Engineering Geology, 9, Pp. 1 – 11.

Bieniawski, Z.T., 1989. Engineering rock mass classification. New York: Jonh Wiley & Sons.

Hoek, E., Karzulovic, A., 2000. Rock mass properties for surface mines. In: Hustralid WA, McCarter MK, van Zyl DJA (eds). Slope stability in surface mining. Society for Mining, Metallurgical and Exploration (SME), Littleton.

Hoek, E., Marinos, P., Benissi, M., 1998. Applicability of the geological strength index (GSI) classification for weak and sheared rock masses—the case of the Athens schist formation. Bull Eng Geol Env., 57 (2), Pp. 151–160.

Jacobson, G., 1970. Gunong Kinabalu area, Sabah, Malaysia. Geological Survey Malaysia. Report 8.

Norbert, S., Rodeano, R., Abdul, G.R., Goh, T.L., Noran, N.N.A., Kamilia, S., Nightingle, L.M., Azimah, H., Lee, K.E., 2016. Rock Mass Assessment using Geological Strength Index (GSI) along the Ranau-Tambunan Road, Sabah, Malaysia. Research Journal of Applied Sciences, Engineering and Technology, 12 (1), Pp. 108-115.

Priest, S.D., 1993. Discontinuity analysis for rock engineering. Chapman & Hall, London, Pp. 473.

Priest, S.D., Hudson, J.A., 1976. Discontinuity spacings in rock. International Journal of Rock Mechanics and Mining Sciences & Geomechanics, 13, Pp. 135–148.

Rodeano, R., 2020. Geological Assisted on Water Resources Planning in Mountainous Catchments In Kundasang, Sabah, Malaysia. Malaysian Journal of Geosciences, 4 (1), Pp. 26-31.

Rodeano, R., Sanudin, T., Baba, M., Omang, S.A.K.S., 2010. Geological inputs for Landslide Hazard Identification (LHI) in the Trusmadi Formation slopes, Sabah, Malaysia. Borneo Science, 26, Pp. 37-51.

Rodeano, R., Felix, T., 2018. Engineering Geological Mapping on Slope Design in the Mountainous Area of Sabah Western, Malaysia. Pakistan Journal of Geology, 2 (2), Pp. 01-10.

Wickham, G.E., Tiedemann, H.R., Skinner, E.H., 1972, Support determination based on geologic predictions, In: Lane, K.S.a.G., L. A., ed., North American Rapid Excavation and Tunneling Conference: Chicago, New York: Society of Mining Engineers of the American Institute of Mining, Metallurgical and Petroleum Engineers. Pp. 43-64.