GEOLOGY AND ENGINEERING GEOLOGY OF GRANITES AT GRIK-BALING ROUTE, NORTHERN PENINSULAR MALAYSIA

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ABSTRACT

Previous studies on the igneous rock in Grik and Baling area has classified the rock as a part of Bintang batholith, Main Range Granite Province of Peninsular Malaysia. This research is aimed to study the geology of the igneous rock along the route and its engineering geology. Petrographic, XRF and XRD analyses have been conducted to identify the geology of the igneous rock. Schmidt hammer rebound tests, uniaxial compressive strength and Brazillian tensile strength test were conducted to determine the engineering properties of the igneous rock. Discontinuity survey was conducted to collect discontinuity properties and to perform rock mass rating (RMR) and slope mass rating (SMR) determinations. Igneous rock in the study area is classified as coarse grain, porphyritic biotite granite (main rock type) which is the typical texture of Main Range Granite with minor equigranular granite. Strength test and rock mass classifications were conducted only on the main rock type: porphyritic biotite granite. The rock mass has Schmidt rebound value, uniaxial compressive strength and indirect tensile strength of 41, 50.19MPa and 7.58MPa respectively. RMR of the rock mass is 77 which classify the rock mass into a good rock. However, SMR of the rock mass is 26 which fall in the category of poor and unstable rock slope with wedge failure being the most critical type of failure.

Keywords porphyritic biotite granite; Rock mass rating (RMR); Slope mass rating (SMR).

INTRODUCTION

Igneous rocks are widely distributed in Grik and Baling area comprising of both volcanic and plutonic rocks [1]. Volcanic rocks occur as pyroclastics while plutonic rocks as batholiths and are known to be a part of the Main Range Granite. The granite of Triassic age intruded the Lower Palaeozoic rocks, resulting in the deformation as well as varying degrees of metamorphism. The granitic rocks in this area are affected by faults and significant amount of joint sets have developed throughout the igneous body [2].

The main factor controlling of engineering properties of rocks is the discontinuities within the rock mass [3]. Measurement of engineering properties of rocks requires a combination of laboratory testing of small samples together with field observation and description of the rock mass. Rock strength properties can be obtained from laboratory testing such as uniaxial compressive strength test and indirect tensile strength by Brazilian splitting test. Discontinuity survey conducted along scanline at the rock outcrop collects the details about the discontinuity, for instance the spacing, orientation, persistence, aperture and infill. Engineering properties of rocks are important elements that are applied in the rock mass classification to evaluate the rock mass condition and stability.

Previous studies available on Grik and Baling area are only on the general geology of the whole area. No previous study that has focused on the Grik-Baling route area, especially the igneous rock along the route.

Thus, this project is carried out to fulfil the following objectives:

i. To study the geology of igneous rock along the Grik-Baling route
ii. To identify and understand the engineering properties of igneous rock along Grik-Baling route

The scope of study covered in this project can be simplified as follows:

i. Reviews of previous research papers, journals and books related to the geology of the study area and engineering properties of rocks, focusing on igneous rocks.
ii. Geology of igneous body along Grik-Baling route area
ii. Engineering properties of igneous rock along the Grik-Baling route

LITERATURE REVIEW

Granites in Peninsular Malaysia are grouped into two granite provinces separated by Bentong-Raub suture zone: Western province (also known as Main Range Granite province) and Eastern province [4]. Ghani [5], [6] has divided the granite in the whole Western belt granite into three main groups: (i) biotite granite which are coarse to very coarse grained megacrystic granite, (ii) amphibole-bearing granite and (iii) felsic volcanic rocks. Later, another study has added microgranite and mesogranite associated with aplopegmatite as the fourth group of facies which are commonly associated with the individual granitic body [4] . Bintang batholith and Main Range batholith are the two main intrusive phases within the Main Range granite province which are complex and consists of its individual plutons [7]. Bintang batholith is located in the northern part of Main Range granite province, covering the area of north Perak and southeast Kedah. This batholith is divided into four main plutons, namely Taiping, Damar, Bubu and Selama [7]. Biotite granite are present in Bintang batholith but amphibole bearing granite are more common [8].

The literature study revealed that less research studies have been conducted on the engineering properties of the granite body. The properties of rock mass are influenced by the properties of rock material, discontinuities and the condition of the rock masses when subjected to stress and groundwater [3]. ISRM [9] has listed ten main parameters to describe discontinuities within rock mass as: orientation, spacing, persistence, roughness, wall strength, aperture, filling, seepage, number of sets and block size. In terms of rock strength, unconfined compressive strength is the most common measurement for rock strength [10]. Numerous rock mass classifications have been developed for different purpose, including Rock Quality Designation (RQD), Rock Mass Rating (RMR), the Q-system and Geological Strength Index (GSI). This study will only implement RMR for the classification of the rock mass.

Slope failures are one of the major natural hazards throughout the world and are mostly controlled by the orientation and spacing of discontinuity planes with respect to the slope face. A single discontinuity, an intersection of two discontinuities or a combination of multiple discontinuities can be the cause of failures such as plane, wedge, toppling and rockfall [11]. Slope stability classifications such as Slope Mass Rating (SMR), Chinese Slope Mass Rating System (CSMR), rock slope rating (RSR), slope stability rating (SSR) and dump mass rating [12] can be used to evaluate a rock slope. This study will only apply SMR developed by [13] to analyze the rock slope stability.

STUDY AREA

The area covered in this study (Figure 4) is a part of the Grik-Baling route, lying between the longitudes of 100°55'E-100°58'E and latitudes of 5°29'N-5°32'N. Three igneous rock outcrops are identified as per location listed in Table 1.

Table 1 GPS coordinates of outcrops

Outcrop	GPS coordinate	
1	Latitude: 5.504° N	Longitude: 100.944° E
2	Latitude: 5.504° N	Longitude: 100.938° E
3	Latitude: 5.513° N	Longitude: 100.930° E

MATERIALS AND METHODOLOGY

The methodology of this study can be divided into geological fieldwork, laboratory analysis and rock mass and rock slope classifications:

Geological fieldwork

This study involved several fieldworks in the study area to collect data for the purpose of geological mapping as well other analysis. Observation and description of the rock were made during the fieldwork. GPS coordinates of the outcrops were recorded. Medium-sized rock samples were also collected for laboratory testing.

A discontinuity survey along scanline of 90m at Outcrop 3 was conducted to collect the parameters of the discontinuity: dip direction, dip angle, spacing, discontinuity length, aperture, surface roughness, infilling materials, groundwater condition, number of sets and block size [9]. The data collected was used in the rock mass classifications. The rock wall hardness was also tested using L-type Schmidt rebound hammer.

Laboratory analysis

Seven thin sections of rock samples were made to identify the mineral content

Three samples: porphyritic granite, equigranular granite and mafic microgranular enclaves were powdered to carry out x-ray diffractometry (XRD) and x-ray fluorescence (XRF). XRF was conducted to specify the elements concentration while XRD is to identify the mineral composition from the crystal structure.

Samples of porphyritic granite were cored to prepare three rock cores for uniaxial compressive strength test and five rock discs for Brazillian splitting tensile test.
Brazillian splitting tensile test was conducted on five rock discs according to [14] by applying increasing compressive load at constant rate on the rock discs until failure occurs. The splitting tensile strength was calculated as follows:

$$\boldsymbol{\sigma_t} = 2P/\pi LD$$

where σt = splitting tensile strength, Mpa
P = maximum applied load, N
L = thickness of specimen, mm
D = diameter of specimen, mm

Uniaxial compressive strength (UCS) test was conducted on three rock cores. The UCS was calculated by using the formula:

$$\textbf{UCS} = \text{Ultimate failure load / Area (MPa)}$$

where Area = $\pi(\text{core diameter})^2/4$

Rock mass and rock slope classifications

The discontinuity parameters and rock strength were used in rock mass classifications. This study evaluated the rock mass by using rock mass rating (RMR) and slope mass rating (SMR).

RMR was developed by [15]. Bieniawski has identified six main parameters to be used to classify a rock mass using RMR system:

i. Strength of intact rock. Uniaxial compressive strength is preferred but point load index is acceptable.
ii. Rock Quality Designation (RQD)
iii. Spacing discontinuities
iv. Condition of discontinuities
v. Groundwater conditions
vi. Orientation of discontinuities

Rock Quality Designation Index (RQD) is defined as the percentage of intact core pieces which is longer than 100mm from the total length of drill core logs. However, this study has no cores, therefore the RQD was estimated from the discontinuities traces on the exposed surface of rock mass. The RQD was calculated by using [16] estimation of RQD by using a parameter called discontinuity frequency which is the ratio of the number of discontinuities passed by a scanline, N and the length of the scanline, L. Thus, the RQD was calculated by using the following function:

Discontinuity frequency, $\lambda = N/L$ m-1
RQD = **100** (0.1 λ+1) e-0.1 λ

SMR that was used in this study for the rock slope classification is a system developed by [13] as an extension of RMR system. SMR involves RMR value, the three factors of the joint-slope relationship (F1, F2 and F3) and one adjustment factor for method of excavation (F4). The final value of SMR is obtained from the following expression:

$$SMR = RMR + (F1.F2.F3) + F4$$

where F1 is the parallelism between joints and slope face strike which ranges from 1 to 0.15. F2 is related to probability of discontinuity shear strength and depends on the discontinuity dip in the case of planar failure. F3 is the relationship between slope face and joint dip while F4 is a correction factor that depends on the excavation mode.

RESULT AND DISCUSSION

Geology of igneous rock

Three exposed outcrops have been identified at the roadside of the Grik-Baling route. All the three outcrops have a similar porphyritic texture with white euhedral to subhedral feldspar phenocryst and dark grey to black groundmass. The phenocrysts are aligned sub-parallel to each other in some area but mostly are scattered. The phenocrysts are white and cloudy. The sizes range from 0.5cm to 7.0cm but mostly are from 2.0cm to 4.0cm. Quartz crystals are also visible but most of the crystals are about 1.0 to 2.0cm. Quartz grains are clear and break in curvy and irregular shapes because of its conchoidal fractures. The groundmass grains are medium-grained and composed of major component biotite with feldspar and quartz. Other components of the groundmass are other mafic minerals such as amphibole (Figure 1).

However, some small and discontinuous igneous rock outcrops with equigranular texture are found near Outcrop 2. The boundary between the porphyritic and equigranular granite is not found during this study because of the vegetation as well as the limitation of access due to the hilly area. This equigranular granite has a low composition of mafic minerals. The percentage of quartz and feldspar made up almost 85% of the rock. Only a small percentage of mafic mineral is present, resulting in the colour of light grey of the fresh rock (Figure 1).

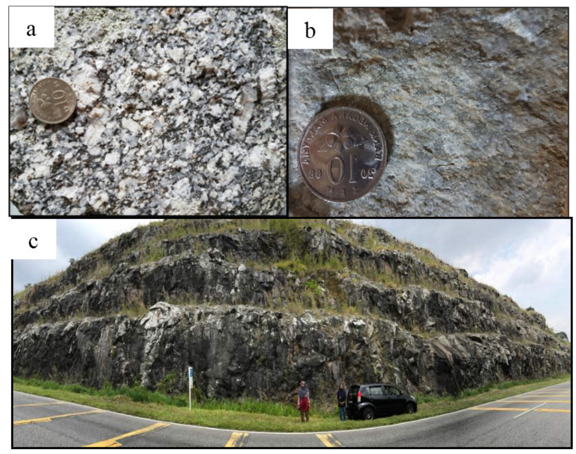


Figure 1 a) Texture of porphyritic biotite granite with large feldspar phenocryst in black biotite groundmass b) Texture of phaneritic granite with light grey color, showing high percentage of feldspars and quartz, low percentage of biotite. c) Outcrop 3 of porphyritic granite where discontinuity survey was conducted along a 90m scanline

Mafic microgranular enclaves (MME) are also observed at some of the porphyritic outcrops. The MME shows a sharp contact with the granite host and some are aligned with the feldspar phenocryst. It has a dark colour, fine grained components and formed in the shape of elongated patches. These are interpreted to be MME but not xenolith because of its visible igneous texture.

The rocks are also affected by some faults and significant amount of joint sets and will be presented and discussed in the discontinuity survey section. A large vein is also observed in Outcrop 1. The component of the vein is identified to be quartz with some feldspar. The contact between the vein and the host granite are not sharp. However, the extension and the size of the vein cannot be measured due to lack of accessibility.

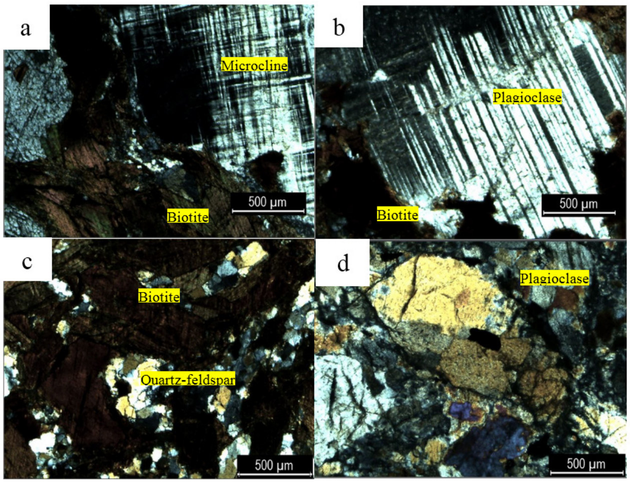


Figure 2 a) Thin section showing large k-feldspar (microcline with its distinctive cross-hatched twinning) phenocryst and smaller biotite grains as groundmass. b) Thin section showing large plagioclase phenocryst (with albite twinning) and biotite as groundmass. c) Groundmass of the porphyritic granite containing high percentage of biotite and low relief quartz grains. d) Equigranular granite with large K-feldspar grain and plagioclase

Thin section analysis (Figure 2) of the porphyritic granite shows that feldspars has the most abundant minerals in this porphyritic granite because it made up the large phenocrysts. The Plagioclase observed under thin sections varies from albite ($NaAlSi_3O_8$) to oligoclase $(Na,Ca)Al_1\text{-}_2Si_3\text{-}2O_8$ with visible albite polysynthetic twinning under cross-polarized. K-feldspars observed in thin sections are microcline and orthoclase. Quartz grains are mostly anhedral and low relief. The quartz grains occur as clusters, filling up the spaces between coarser biotite in the groundmass. Biotite shows a strong pleochroism from dark brown to greenish brown. Some hornblende grains are also found with strong pleochroism and have subhedral crystals.

Felsic minerals are the main component of the equigranular granite. Quartz, plagioclase and alkali feldspar are the most abundant minerals. Quartz grains are mostly anhedral and has a low relief. The quartz grains occur as clusters with anhedral K-feldspar and plagioclase. The sizes of feldspar grains are generally larger than quartz. Mafic minerals only occur as accessory minerals in this equigranular granite.

XRF resulted in the identification of Si (silicon), Fe (iron), K (potassium), Al (aluminium), Ca (calcium), Ti (titanium), Mg (magnesium), and P (phosphorus) as the major elements (Table 2). Other elements such as Ba, Na, Zr, Cl, Mn, Rb, Sr and S are present in quite significant amount while transition metals (Cr, Zn, Ni) are only present as trace elements. Equigranular granite has the highest Si concentration, which is 54.7% and this supports the rock sample observation and petrographic analysis. Fe and Mg is the highest in the MME and second highest in the porphyritic granite which is mostly in biotite and amphibole. In both granites, K-feldspars are higher in concentration compared to the plagioclase feldspar (Ca and Na feldspar). In terms of plagioclase feldspars, Ca-rich plagioclase is higher in concentration compared to Na-rich plagioclase.

Table 2 Comparisons of elements concentration based on XRF

Rock sample	**Porphyritic biotite granite**	**Equigranular granite**	**Mafic microgranular enclaves**
Elements	Concentration, %	Concentration, %	Concentration, %
Si	37.5	54.7	30.3
Fe	22.7	3.27	25.4
K	15.4	26.2	14.6
Al	8.4	8.36	6.61
Ca	7.18	2.64	14.4
Ti	3.12	1.33	2.24
Mg	2.17	0.215	3
P	1.13	1.29	1.05
Other elements	2.4	2.0	2.4

The result of XRD analysis (Figure 3) also supports the XRF analysis. XRD result of porphyritic granite has biotite with the highest peaks, followed by K-feldspar, plagioclase, quartz and amphibole. For equigranular granite, quartz and K-feldspar has almost similar peaks, followed by a lower peak of plagioclase and even lower peaks of biotite and amphibole. The peaks for MME sample are almost similar with the porphyritic granite. However, MME have higher peak for plagioclase compared to K-feldspar.

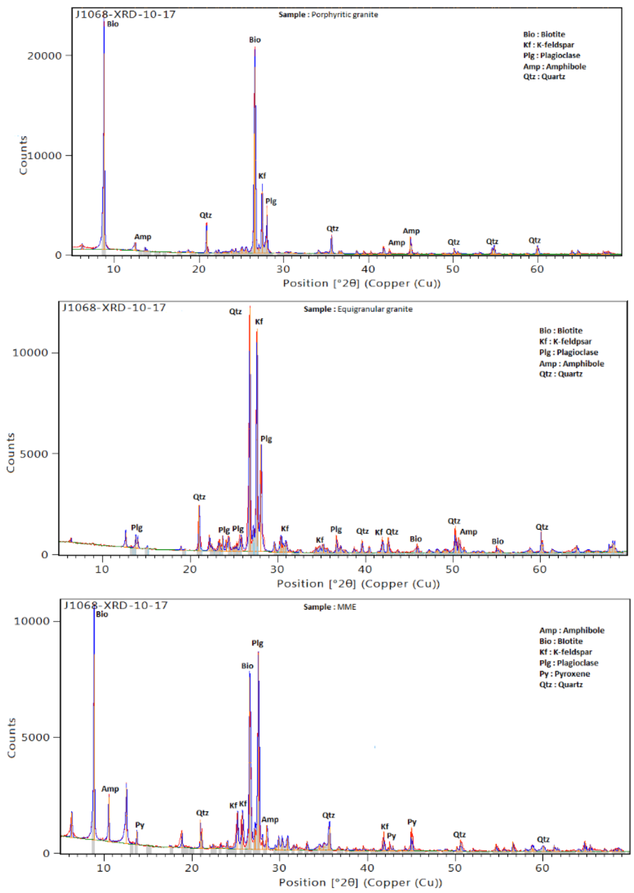


Figure 3 XRD charts showing series of identified peaks for the diffraction patterns a) porphyritic granite, b) equigranular granite and c) MME

Based on the field observations and laboratory analyses discussed, the two types of lithology are identified: coarse grained, porphyritic biotite granite and medium-grained equigranular granite. However, the equigranular granite only occurs as a small body in the study area, with the porphyritic granite as the main lithology. Therefore, the study of the engineering properties of the rock in the next part of this paper only involves the main rock type: porphyritic biotite granite.

Based on the location and properties, the granite in this area is a part of the Bintang batholith of the Main Range granite province, which agrees with the previous literatures. This granite is a part of the Selama pluton, which has a coarse porphyritic biotite granite as the main texture. The minor equigranular granite is interpreted to be part of the Damar pluton which has fine to medium-grained epigranular alkali granite as its main rock type. The emplacement of granite in this area is interpreted to be during Mesozoic orogeny, intruding the Lower Palaeozoic rocks [2] .

The geological observations in the study area are simplified in the geological map in Figure 4.

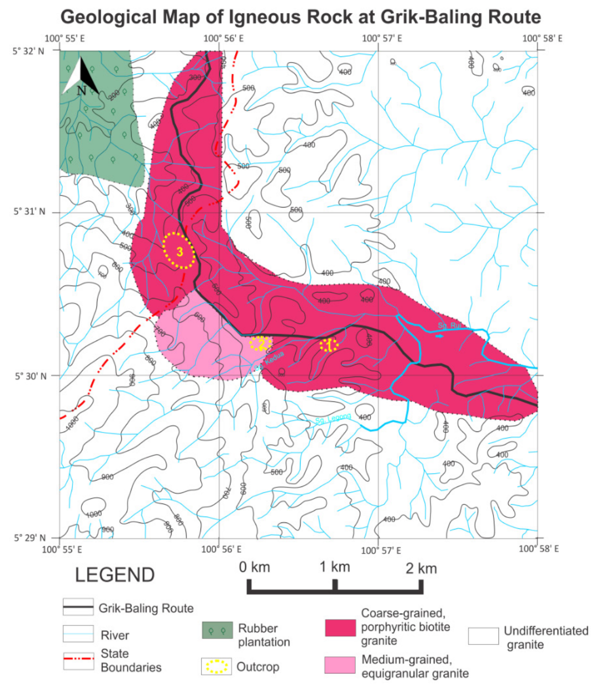


Figure 4 Geological map for igneous rock in Grik-Baling route

Engineering properties of igenous rock

The result of the rock strength test on porphyritic granite samples are presented in Table 3. Schmidt hammer rebound test was conducted at a few points on the surface of the outcrop during fieldwork. The rebound values differ at each point, therefore an average rebound value was calculated. The indirect tensile strength results range from 6.11MPa to 8.68MPa. The differences are not very large and resulted in average value of 7.58 MPa. The UCS results range from 41.51MPa to 64.46MPa. The variation in the values of the strength might be affected by the arrangement, percentage and size of the phenocryst. The inhomogeneity of the rock affects the rock strength as the grain contacts are different for large and small grain. The differences can also be noticed due to the fractures in the rock.

Table 3 Rock strength parameters for porphyritic granite

Type of rock strength test	Strength parameter	
Schmidt hammer test	Rebound number	41
Indirect tensile test	Tensile strength	7.58MPa
Uniaxial compressive strength test	Uniaxial compressive strength	50.19MPa

Fracture distribution have been plotted (Figure 5) from joints data of the discontinuity surveys. Based on the density plots, seven sets of joints are identified (Table 4). Set 1 to Set 3 is interpreted to be the major joint sets while Set 4 to Set 7 is the minor joint sets. The maximum density recorded is 7.21% which is in Joint Set 1. The joint sets have an aperture ranging from very narrow to tight with rough surfaces. Set 3 has the smallest true spacing which is 0.88m while Set 7 has the largest true spacing of 3.82m. The major joint sets have higher dip angles than the minor sets (>70°dip).

Estimation of RQD was done by using the correlations of RQD with joint frequency, λ by [16]:

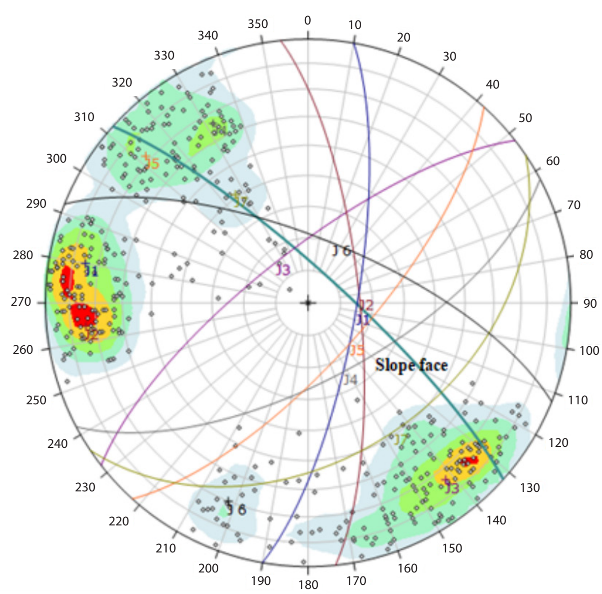
$$\lambda = N/L\ m^{-1}$$

$$\lambda = 406/90 = 4.51 m^{-1}$$

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

$$\mathbf{RQD} = 100\ (0.1 * 4.51 + 1)\ e^{-0.1 * 4.51} = \mathbf{92.43\%}$$

The value RMR= 77 (Table 5) indicates that the rock mass is good and it is in Class II. In the case of tunneling excavation, the rock mass has an average stand-up time of about six months for 8m span. The stand-up time refers to the time period where the tunneled rock mass can retain without collapsing and without any support installed. The rock mass cohesion is high, which falls in the range of 300-400 KPa. The rock mass friction angle is between 35°-45°, which is high. Friction angle is a measurement of the ability of a rock unit to withstand shear stress. The angle is measured between normal force (N) and resultant force (R).



Color	Density Concentrations
	0.00 - 1.30
	1.30 - 2.60
	2.60 - 3.90
	3.90 - 5.20
	5.20 - 6.50
	6.50 - 7.80

Maximum density	7.21%
Minimum density	0.00%
Contour distribution	Fisher
Hemisphere	Lower
Projection	Equal area

Figure 5 Intensity plots with seven identified sets of discontinuity

Table 4 Summary of joints data collected during discontinuity survey

Joint set	1	2	3	4	5	6	7
Dip direction/Dip angle	100/75	084/74	322/74	152/66	132/72	022/70	146/41
Average spacing, m	1.23	1.26	0.88	2.49	1.82	1.38	3.82
Average length	1.45	1.76	1.68	1.96	2.06	0.84	0.80
Aperture	Extreme narrow (<2mm)	Very narrow (2-6mm)	Extreme narrow (<2mm)	Tight	Tight	Tight	Tight
Fill material	Non-cohesive	Non-cohesive	Non-cohesive	Clean	Clean	Clean	Clean
Roughness	Rough	Rough	Rough	Rough	Rough	Rough	Rough
Water condition	Dry	Dry	Dry	Dry	Dry	Dry	Dry

Table 5 RMR value and rating (based on after Beniawski, 1989)

Item	Value	Rating
Uniaxial compressive strength	50.19 MPa	7
RQD	92.43%	20
Spacing of discontinuities	1.84m	15
Condition of discontinuities	Note 1	20
Groundwater	Completely dry	15
RMR		**77**

Note 1. The rating is the sum of: 4 (1-3m discontinuity length), 4 (separation/aperture of 0.1-1.0mm), 5 (rough surface), 2 (soft filling <5mm) and 5 (slightly weathered) = 20.

SMR involves the evaluation of the rock mass in terms of the rock slope stability. The discontinuity sets are evaluated for the possibility for rock slope failures such as planar failure, toppling failure and wedge failure. Planar and toppling failure depends on the dip direction and dip amount of each joint set plane with respect to the slope face. Wedge failure on the other hand needs evaluations of any possible rock wedge, formed by the intersection of two joint sets. Wedge failure depends on the dip direction and dip amount of the wedge and the slope face (Figure 6).

The friction angle used is 35°. Any intersection of joint sets that falls within the critical zone, which is considered as a possible wedge. The wedge that falls in the critical zone are dipping in the similar direction with the slope face but are less steep compared to the slope face. Eight wedges that are located in the critical zone for wedge sliding are identified and the adjustment factors (F1, F2, and F3) are evaluated. Adjustment factors for each discontinuity set are also calculated for both planar and toppling failures (Table 6).

The calculated SMR values are in the range between 26 to 73 which is in Class IV to Class II. However, the total adjustment factors for wedge failures are large which results in low SMR value. The four critical wedges are identified: I13, I23, I16 and I26 with SMR values of 35, 35, 26, and 27 respectively. These four critical wedges result in the SMR values of Class IV rock slope. Class IV rock slopes are poor and are unstable with possible wedges or planar failures. The probability of failure is 0.6.

Since the sums adjustment factors for wedge failure are the highest among the three types of failures, it is concluded that the wedge failure is more critical along the rock slope. This condition should be considered as the worst state with the lowest SMR=26. The most critical wedge is the intersection between one major joint set (Set 1) and a minor joint set (Set 6). Since Set 6 is only a minor set with intensity of 3% and average length=0.84m, smaller-sized rock wedge is expected to form and therefore is less critical compared to larger wedges. Nevertheless, this condition has to be put in consideration for the safety of Grik-Baling route user. Romana et al.[13] had suggested some support guidelines for unstable slopes based on the SMR classification. For this rock slope, the first remedial measure is suggested to develop a good surface and deep drainage for the groundwater as well as the meteoric water. If any indicators of the large rock failures are found, re-excavation or retaining walls can be built for safety purposes.

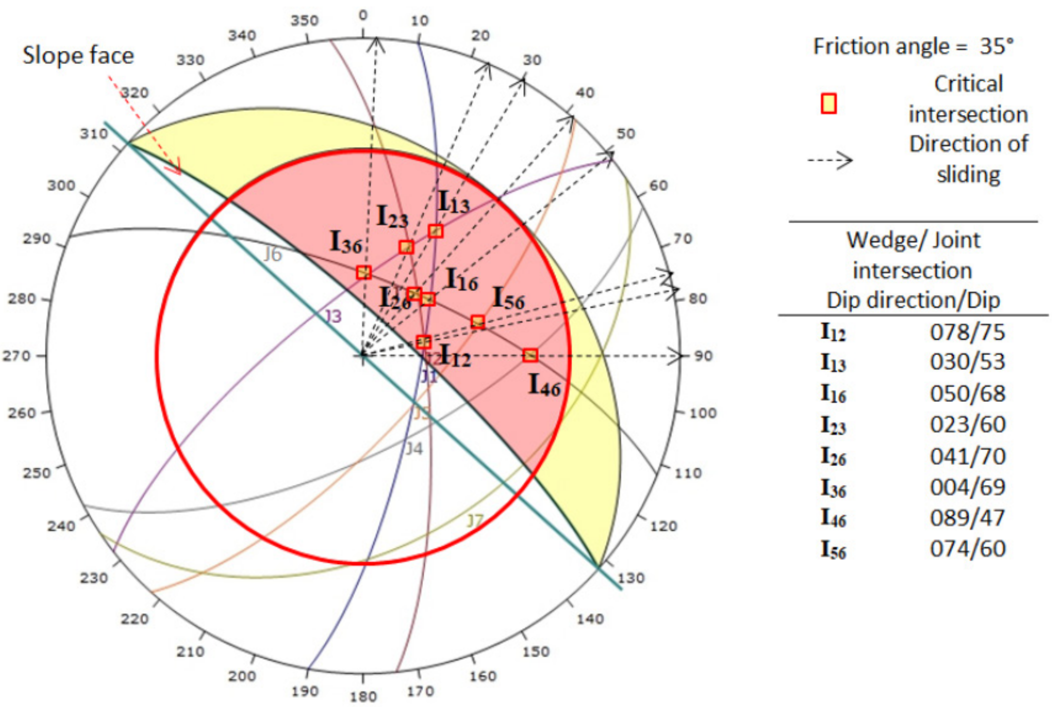


Figure 6 Critical intesections of joints resulting in eight wedges which are prone to wedge failure

Table 6 SMR adjustment factors and SMR values of all joint sets and wedges

Plane/Wedge	Dip direction/Dip angle	Dip	Type of failure	F1	F2	F3	F4	SMR	Class
J1	100/75	75	PLANAR	0.15	1	-50	0	69.5	II
			TOPPLING	0.15	1	-25	0	73.25	II
J2	084/74	74	PLANAR	0.15	1	-50	0	69.5	II
			TOPPLING	0.15	1	-25	0	73.25	II
J3	322/74	74	PLANAR	0.15	1	-50	0	69.5	II
			TOPPLING	0.15	1	-25	0	73.25	II
J4	152/66	66	PLANAR	0.15	1	-60	0	68	II
			TOPPLING	0.15	1	-25	0	73.25	II
J5	132/72	72	PLANAR	0.15	1	-50	0	69.5	II
			TOPPLING	0.15	1	-25	0	73.25	II
J6	022/70	70	PLANAR	0.4	1	-50	0	57	III
			TOPPLING	0.15	1	-25	0	73.25	II
J7	146/41	41	PLANAR	0.15	0.85	-60	0	69.35	II
			TOPPLING	0.15	1	-25	0	73.25	II
I23	023/60	60	WEDGE	0.7	1	-60	0	35	IV
I13	030/53	53	WEDGE	0.7	1	-60	0	35	IV
I12	078/75	75	WEDGE	0.15	1	-50	0	69.5	II
I56	074/60	60	WEDGE	0.15	1	-60	0	68	II
I46	089/47	47	WEDGE	0.15	1	-60	0	68	II
I26	042/70	70	WEDGE	1	1	-50	0	27	IV
I16	050/68	68	WEDGE	0.85	1	-60	0	26	IV
I36	004/69	69	WEDGE	0.15	1	-60	0	68	II

CONCLUSION

The study was conducted to identify the geology and engineering geology of the igneous rock in the study area. Geological fieldwork, petrographic analysis and geochemical analyses (XRF and XRD) shown that the igneous rock in the study area is made up of grain porphyritic biotite granite with minor equigranular granite. The porphyritic granite is similar to the typical texture of Main Range granite, which confirms that the granite in this area is a part of Bintang batholith, Main Range Granite Province of Peninsular Malaysia. The porphyritic granite is classified as part of the Selama pluton while the equigranular is part of the Damar pluton, both from the Bintang batholith.

The engineering geological properties were only measured for the porphyritic granite due to limitations. Schmidt rebound number and UCS of the intact rock is 41 and 50.19MPa respectively, indicating that the rock is moderately strong with average tensile strength of 7.58MPa. Discontinuity survey of 90m scanline was conducted on a slope with a dip direction/dip angle of 042/80° resulted in the identification of seven joint sets affecting the rock mass. RMR value of the rock mass is 77 which indicates that this rock mass lies in good quality with respect to its strength and discontinuities properties. However, the SMR value is 26 which indicates a poor and unstable rock with possible wedges or planar failure. The most critical failure is identified as the wedge failure with failure dip direction/dip angle of 050/68°, resulting from the intersection of major joint Set 1 and minor joint Set 6.

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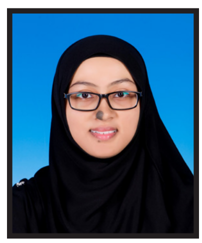

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