LITHOLOGICAL UNIT THICKNESS APPROACH FOR DETERMINING INTACT ROCK STRENGTH (IRS) OF SLOPE FORMING ROCK MATERIAL OF CROCKER FORMATION

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ABSTRACT. *The Intact Rock Strength (IRS) of slope forming rock material of the heterogeneous Crocker Formation has been determined using "Lithological Unit Thickness" approach in order to evaluate the slope stability. Four slopes in CPSB Stone Quarry were selected in this study namely slope B1, B2, B3, and B4. The "Lithological Unit Thickness" approach in this paper consists of slope geological mapping, slope geometry, lithological thickness measurement, petrographic analysis, intact rock strength testing and modeling. The intact rock strength was measured using Unconfined Compressive Strength test and Point Load test. The results show that the estimation of intact rock strength of the slope forming rock material by 'lithological unit thickness' approach is more representative and the value for slopes B1, B2, B3 and B4 are 129 MPa, 108 MPa, 117 MPa and 148 MPa, respectively. The intact rock strength for the slopes forming rock material in the study area can also be classified as 'strong' rock masses.*

KEYWORDS. Lithological unit, Intact Rock Strength, slope stability, Crocker Formation

INTRODUCTION

The study area is located in CPSB Stone Quarry, Tamparuli, Sabah, Malaysia (Figure 1). In this study, the quarry faces have been divided into four (4) sections denoted as B1, B2, B3 and B4 (Figure 2). Geology of the area is underlain by the Crocker Formation of Late Eocene to Early Miocene age. The Crocker Formation is a deep marine environment of flysch typed deposit. The sedimentary rock is characterized by rhythmic alteration of sandstone and fine-grained (pelitic) or shale layers. The Crocker Formation is also divided into sandstone facies, sandstone-shale interbedded facies and shale facies. The overall thickness is very large, even though it may have reduced considerably by erosion and thrusts.

Intact rock strength (IRS) is a basic rock property. IRS determines the strength of the intact rock block material and as such governs partially the strength of a rock mass. Standard determination of the IRS is by means of an Unconfined Compressive Strength (UCS) test. IRS is also an important parameter used in most of the rock mass classification systems, analytical and numerical calculations (Hack & Huisman, 2002).

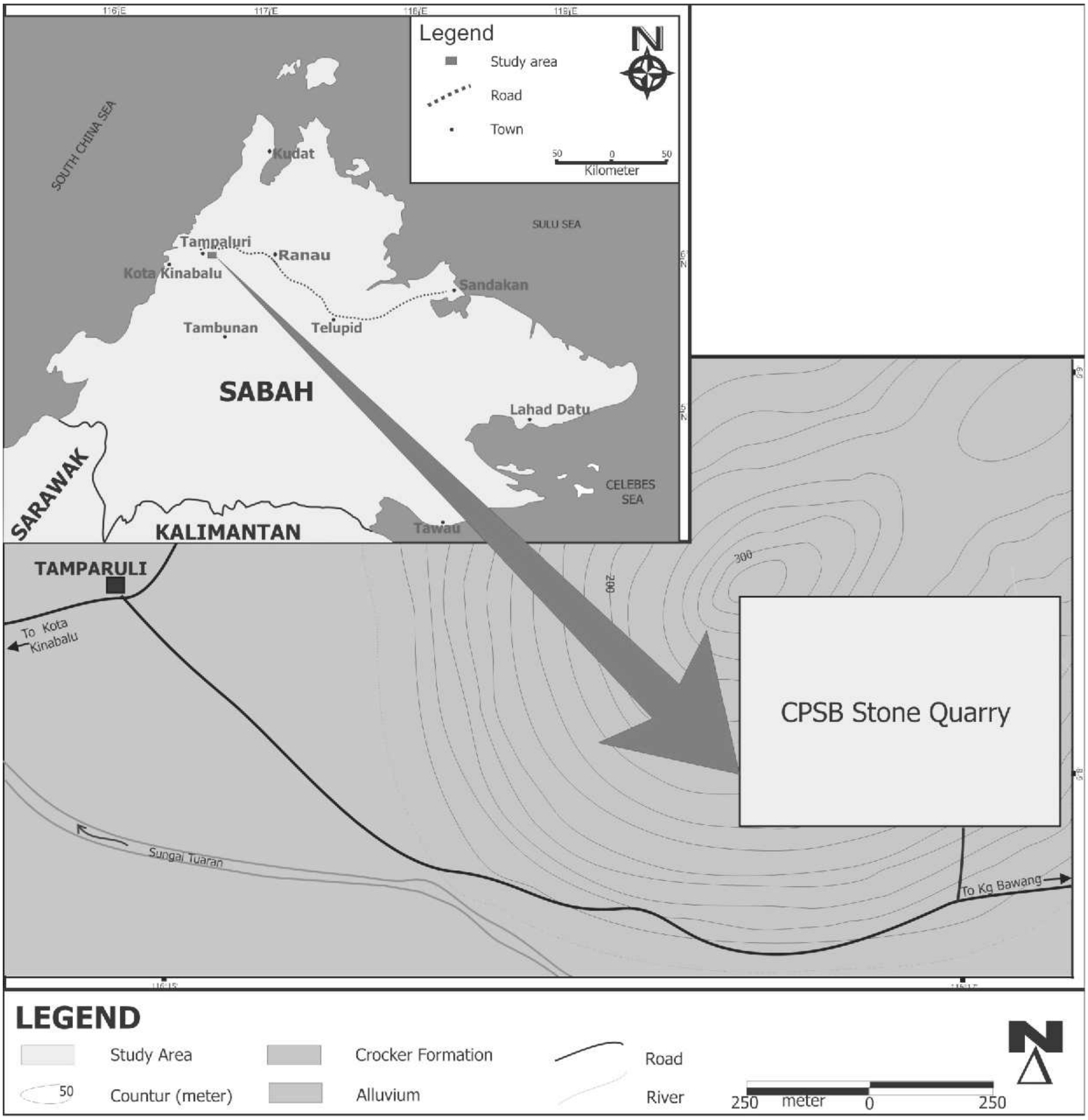


Figure 1. Location of the study area (reproduced from Yin, 1985).

Intact rock strength for the slope forming rock material can be represented by a single UCS value of intact rock samples for homogeneous rock masses but not for heterogeneous rock masses. Varied lithological unit in heterogeneous rock require the engineering geologists or geotechnical engineers to apply different approaches in determining representative intact rock strength for the slope forming rock material. There are four approaches to determine the intact rock strength for the slope forming rock material namely 'weighted average of strong layer', 'weighted average of strong and weak layer', 'thickness of strong and weak layer' and 'weighted average of weaker layer'.

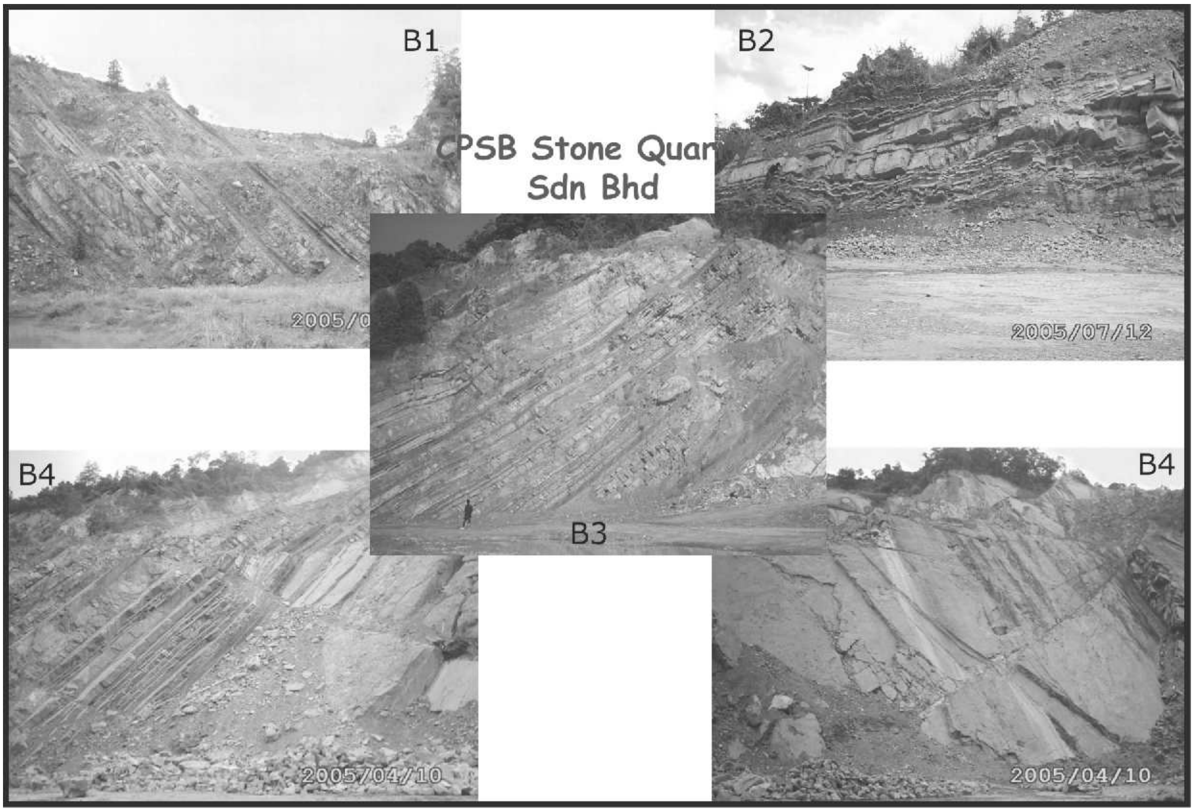


Figure 2. Four slope (B1, B2, B3 and B4) in the study area. B1, B2, B3 and B4 means slope B1, B2, B3 and B4, respectively.

'Weighted average of strong layer' approach has been practiced for a long time ago. In the case of sandstone and shale interbedded, the average value of UCS of intact sandstone was use as representing intact rock strength of the slope forming rock material. Nevertheless, it is not appropriate to use the properties of the sandstone alone to determine the overall intact rock strength or strength of the rock mass. On the other hand, using the 'intact' properties of the siltstone or shale is considered only too conservative since the sandstone skeleton certainly contributes to the overall strength of the rock mass (Marinos & Hoek, 2000).

Marinos & Hoek (2001) proposed the 'weighted average of strong and weak layer'. The proposed approach is restricted to flysch typed or heterogeneous rock masses which divided into eight facies based on lithology and structures of the rock. Both sandstone and siltstone or shale properties were used according to the facies type. Facies with predominant sandstone or shale will be using 100% strength value of sandstone or shale, respectively. Then, the interbedded facies will reduce sandstone value and should use full value of siltstone or shale following the proportion of sandstone.

The latest approach of 'thickness of strong and weak layer' has been introduced by Bell (2007). This approach is an improvement of Marinos & Hoek (2001) work. Thickness of sandstone and siltstone or shale will be converting into their proportion. The proportion is separated into seven divisions based on lithology, their abundance and thickness to produced seven sandstone and siltstone or shale percentages.

The 'weighted average of weaker layer' approach was introduced by Laubscher (1990) and used as a basic from Marinos & Hoek (2001) and Bell (2007) approached. This approach was designating for a zone or slope with the presence of weak and strong intact rock. The average value is assigning to the zone on the basis that the weaker rock will have a great influence on the average value. The relationship is non-linear and the value can be reads from an empirical chart of Laubscher (1990).

All of approaches mentioned above are still impractical for non-homogenous or heterogeneous rock mass. Every single lithological unit built up by specific major and accessory minerals and type of cement materials that effect the rock properties especially strength. In heterogeneous flysch deposit rock masses, not all sandstone units are petrographically equal. The particle size can be very coarse, coarse, medium, fine and/or very fine sandstones. The difference in grain size would influence the strength properties. Based on the current approach as mentioned above, this factor is not considered for the determination of intact rock mass properties, especially IRS. Therefore, this paper will discuss the new approach of IRS determination for slope forming rock material from heterogeneous rock masses of Crocker Formation.

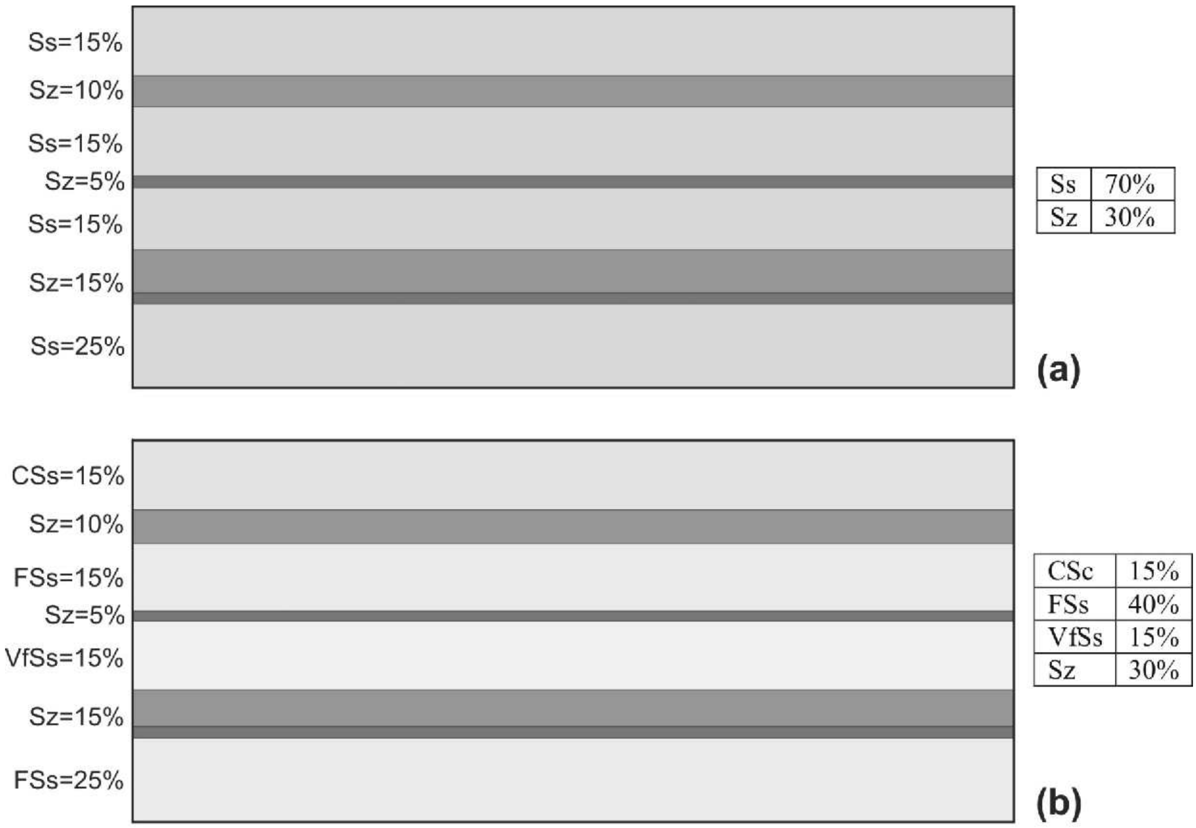
METHODOLOGY

This study involves field work study, laboratory analysis and modeling. Lithological type identification and thickness measurements, irregular rock block sampling and Point Load test have been conducting during the field study. Collected of blocks or small irregular pieces of sandstone and siltstone were testing by Point Load machine (ISRM, 1981). Point Load Index of sandstone and siltstone is then converting into UCS value by assuming siltstone strength equal to siltstone and shale strength following Marinos & Hoek (2001) and Bell (2007).

The laboratory analysis includes petrographic study and UCS test. The irregular rock block samples from the field are then prepared for thin section and coring. The core samples have been prepared into 53mm diameter and 10cm height (ISRM, 1981) and polished by conventional Polishing Machine at the top and bottom surfaces before tested in a Hoek cell at the Geotechnical Department, Universiti Teknologi Malaysia, Skudai, Johor. Data from UCS test is then analyzed to determine UCS for IRS of the rock material. The analyses consist of three fine sandstone samples.

The petrographic analysis was used Ziess's polarizing microscope. The classification of sandstone for petrographical study is conducting according to Pettijohn (1975).

The intact rock strength of the slope forming rock material model as called 'lithological unit thicknesses' approach was designed with the consideration of the lithological heterogeneity of Crocker Formation. The 'lithological unit thickness' approached involve the conversion of lithological unit and thickness into percentages values. The IRS value from field and laboratory tests for every single lithological unit and their calculated percentage is then converting to IRS in MPa unit. The final intact rock strength of the slope forming rock material is represented by the sum of strength of all lithological units in that particular slope (Figure 3).



Lithology	Thickness (m)	Thickness %	Strength (UCS) MPa	Strength by lithology (MPa)	Strength of the SFRM (Mpa)
MSs	k	15.00	100.00	15.00	107.85
FSs	l	40.00	165.00	66.00	
VfSs	m	15.00	105.00	15.75	
Sz	n	30.00	37.00	11.10	
	Total	100.00			Very strong

(c)

Note: k, l, m and n - measured thickness (?); SFRM - the slope forming rock material

Figure 3. The 'lithological unit thickness' models (Figure 3b) and comparison of intact rock strength determination and calculation from Figure 3a, 3b and 3c.

RESULTS AND DISCUSSION

Results of the petrographic study on eight (8) thin sections from the study area are presented in Figure 4. The sandstones consist of more than 15% matrix and can be classified as fine (0.125-0.25mm) and very fine (0.0625-0.125mm) lithic wacke, fine feldspathic wacke and quartz wacke. The siltstone is identified by its very fine grain size (<0.0625mm) (Figure 5).

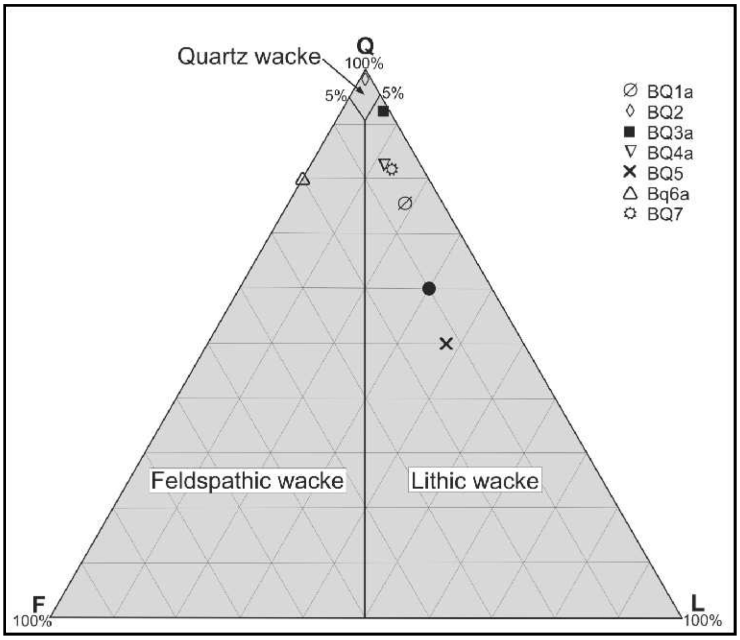


Figure 4. The QFL plot of the greywacke sandstone from the study area (Pettijohn, 1975).

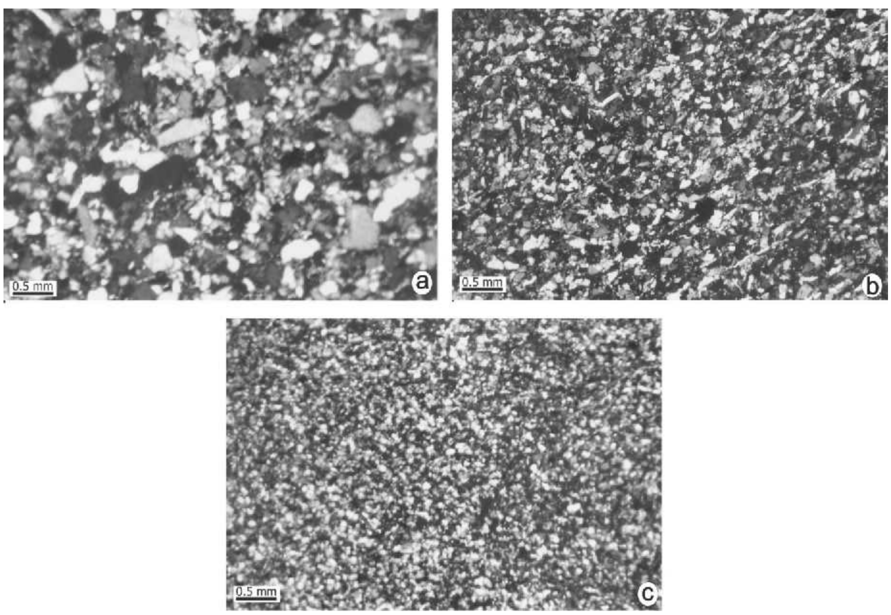


Figure 5. Photomicrographs of (a) fine lithic wacke, (b) very fine lithic wacke and (c) siltstone.

The result of the point load test and UCS test are given in Table 1. Both point load test and UCS test were conducting on fine sandstone for the controlled sample and classified as 'very strong' rock mass, whereas the siltstone is classified as medium strong. The UCS test for very fine sandstone and siltstone is not be able to measured due to the difficulties of core sample preparations.

Table 1. The classification of rock masses based on the Point Load Index and UCS tests.

Lithology	Point Load Index	UCS	UCS test	Classification (ISRM, 1981)
	MPa		MPa	
Fine sandstone (FSs)	7.82	165	130	Very strong
Very fine sandstone (VfSs)	5.36	105	NA	Very strong
Siltstone (St)	2.24	37	NA	Medium strong

Note: Point Load test (FSs–101 samples; VfSs-78 samples; St-27 samples); UCS test (FSs-3 samples): NA-not available

The model of this study is shown in Figure 3. Figure 3a shows sandstone and siltstone or shale interbedded without particular attention on sandstone lithological unit. Figure 3b shows the nature of heterogeneous rock masses with medium, fine and very fine sandstone interbedded with siltstone or shale as applied in this study. The conversions of thickness and lithological unit into percentages value are shown in Figure 3c (3rd Column). Figure 3c also shows the calculation of IRS using "lithological unit thickness" in Figure 3b.

Table 2 shows the result of the intact rock strength (IRS) of the rock slope forming material calculation and value by "lithological unit thickness" approach for interbedded Crocker Formation in the study area. All the slope is classified as 'very strong' rock masses.

Table 2. Intact rock strength of the slope forming rock masses model calculation and value by 'lithological unit thickness' approach for the study area. Strength value following ISRM (1981).

Slope	Lithology	Thickness (m)	Thickness %	Strength (UCS) MPa	Strength by lithology (MPa)	Strength of SFRM (MPa)
B1	FSs	49.21	67.35	165.00	111.12	129.15 (129)
	VfSs	6.39	8.75	105.00	9.18	
	Sz	17.47	23.91	37.00	8.85	
	Total	73.07	100.00			Very strong
B2	FSs	6.27	53.27	165.00	87.90	108.19 (108)
	VfSs	0.52	4.42	105.00	4.64	
	Sz	4.98	42.31	37.00	15.66	
	Total	11.77	100.00			Very strong
B3	FSs	33.48	59.71	165.00	98.52	116.66 (117)
	VfSs	2.66	4.74	105.00	4.98	
	Sz	19.93	35.54	37.00	13.15	
	Total	56.07	100.00			Very strong
B4	FSs	93.42	85.80	165.00	141.57	147.61 (148)
	VfSs	1.26	1.16	105.00	1.22	
	Sz	14.2	13.04	37.00	4.83	
	Total	108.88	100.00			Very strong

Note: FSs-Fine sandstone; VfSs-Very fine sandstone; Sz-siltstone&shale; SFRM-slope forming rock material

Table 3 shows the example of intact rock strength calculation by using data from Figure 3a for classical 'weighted average of strong layer' approach. The 'weighted average of strong layer' approach will come out with either case 1, case 2 or case 3 in table 2. If the selection is pointed at specific single lithological unit then the IRS become either one of the strength values in 2nd, 3rd or 4th row and 4th column in Table 3.

Table 3. The calculation and selection of intact rock mass strength for available intact rock mass strength approach.

Case	Lithology	Thickness %	Strength of Slope (MPa) 'weighted average of strong layer'	'weighted average of strong and weak layer' (Marinos & Hoek, 2001)	'thickness of strong and weak layer' (Bell, 2007)
1	MSs	70.00	100.00	117.00	81.10
2	FSs	70.00	165.00	167.00	126.60
3	VfSs	70.00	105.00	121.60	84.60
4	Average Ss	70.00	123.33	135.66	97.43
	Sz	30.00	37.00		

Note: Ss-sandstone; MSs-Medium sandstone; FSs-Fine sandstone; VfSs-Very fine sandstone; Sz-siltstone&shale

For the 'weighted average of strong and weak layer', the result of intact rock strength using data in Figure 3a is represented in column 4 and either one of row 2, 3 or 4 (case 1, case 2 or case 3) in Table 3. However the final IRS value is the sum of 20% reduced sandstone value and using full value of siltstone (Sz) (facies C of Marinos & Hoek, 2001) as given in column 5 and either one of raw 2, 3 or 4 (case 1, case 2 or case 3).

By using data in Figure 3a, the 'thickness of strong and weak layer' approach is as good as 'weighted of strong and weak layer' approach (Bell, 2007), but the value of intact rock strength was not reduced and depend on selected sandstone (Ss) unit. For example, if medium sandstone is selected (70% Ss and 30% Sz) the intact rock mass strength will become 81.10 MPa (column 6 and row 2 in Table 3).

The result of IRS by 'weighted average of weaker layer' approach (Laubscher, 1990) by using data in Figure 3a is shown in Table 4. The IRS value is represented by 8th column and either 2nd, 3rd, 4th or 5th raw.

Table 4. Example of the calculation and selection of intact rock mass strength for 'weighted average of weaker layer' approach (Laubscher, 1990).

Case	Lithology	Thickness %	Strength (MPa)	Weak rock IRS as % of strong rock (%)	Weak rock IRS (%)	Average IRS (%)	Average IRS as % of strong rock IRS (MPa)
1	MSs	70.00	100.00	37	30	61	61.00
2	FSs	70.00	165.00	22	30	50	82.50
3	VfSs	70.00	105.00	35	30	59	58.80
4	Average Ss	70.00	123.33	30	30	56	69.06
	Sz	30.00	37.00				

Occurrence of thick 'medium strong' Sz (siltstone and shale) layers with 13 to 42 percent of distribution is expected controlling the overall stability of the slope in the study area. The failure always occurs at this weaker material (Sz layer). But, this paper is only focusing in determining IRS for the slope without considering slope stability analysis.

Based on the IRS calculation, it is concluded that the 'lithological unit thickness' approach is the most practical in determining IRS for an area or slope with the consideration for lithological unit in heterogeneous rock masses. Occurrences of fine, very fine, etc sandstone in the Crocker Formation should be measuring in term of their thickness and strength as well as Sz (siltstone and shale) to produce the sum of lithological unit strength that represents better IRS value for the area or slope forming rock material.

CONCLUSIONS

1. The value of Intact Rock Strength (IRS) of the slope forming rock material Crocker Formation for slopes B1, B2, B3 and B4 are 129 MPa, 108 MPa, 117 MPa and 148 MPa, respectively and classifying as 'strong' rock masses.

2. 'Lithological unit thickness' approach is the most practical method in the determination of intact rock strength of the slope forming rock material for the heterogeneous Crocker Formation in Tamparuli area.

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