Journal of Sustainability Science and Management
Volume 10 *Number* 2, December 2015: 24-34

ISSN: 1823-8556

ASSESSMENT OF ROCKFALL POTENTIAL OF LIMESTONE HILLS IN THE KINTA VALLEY

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Abstract: Limestone hills are an astounding natural beauty to the landscape due to their unique features formed by the dissolution of carbonate by water (natural dissolution). However, depending on a hill's location, it may also pose danger to humans and properties due to the presence of extensive joints and fractures within the limestone hill. This study was conducted to assess the condition of seven limestone hills in Kinta Valley, Perak. They are Gunung Rapat, Gunung Datok, Gunung Lang, Gunung Paniang, Gua Kandu, Gunung Panjang, and Gua Tempurung. The significance of studying these hills are their locations that are close to roads, residential areas and the possible development as tourist attractions. A total of twelve assessment stations with two to three stations for each of the hills were set up to assess their stability using the Rock Mass Strength (RMS) system. The geological conditions of the hills were assessed by seven components in the RMS system for rockfall assessment: intact rock strength (using a Schmidt hammer), weathering, spacing of joints, joint orientations, width of joints, continuity of joints, and outflow of groundwater. Subsequently, the hills are classified into very strong, strong, moderate, weak, or very weak based on the sum of ratings for all the components. The assessment has revealed that the slopes at the assessment stations at Gunung Rapat and Gunung Lang are classified as weak whilst that at Gunung Datok is classified as moderate to weak. The main reasons are these hills are heavily jointed with smaller joint spacings (below 300 mm), joints daylighting steeply out of slopes (85-90˚), wider joint opening (larger than 20 mm) and very low Schmidt hammer rebound values (below 35 an average). Based on these factors, these hills were classified as weak (RMS: below 50) and highly susceptible to the occurrence of rockfalls. The remaining five hills have moderate susceptibility based on the RMS.

Keywords: Limestone, rock mass strength, geological condition, susceptibility, rockfall examination.

Introduction

The study area is located in the Kinta Valley in Perak where massive limestone hills are present in the midst of a highly urbanised area. The Kinta Valley is adorned by majestic high relief limestone hills and decorated with many limestone morphological features such as caves and dolines. Due to the magnificent landscape, it was proposed that Kinta Valley be developed as one of the national geoparks in Malaysia (Leman, 2013).

However, most of the limestone hills are mainly characterised by adverse structural conditions such as jointings and fractures and day lighting rock blocks. These characteristics are observable from the road side and may pose danger to the public and infrastructures near these hills. In view of this issue, the objective of this study is to assess the condition of seven limestone hills using a straightforward approach known as the Rock Mass Strength (RMS) scheme published by Selby (1980).

Rockfall History and Their Causal Factors

Reports on occurrences of rock slope failure in the study area have been documented as early as in 1927 (Shu & Lai, 1973). A massive slab of rock which detached from Gunung Cheroh caused the demise of 40 people on 18th of October 1973 (Shu & Lai, 1973). A rockfall with fallen rocks weighing 10,000 tonnes was reported to have occurred along the Ipoh-Changkat Jering Highway in April 1984 and within two months, another rockfall occurred at the same cliff (Muda, 1984). Other rockfall events include the one which occurred on the 29th December 1987 at the southern part of Gunung Tunggal where two rockfalls were reported on the same day (Chow & Sahat, 1988). There was one fatality and three persons were injured in this incident. Recent occurrences of rockfall were reported at Gua Tempurung in April 2012 where a 750 m^3 limestone block toppled down (Mohammed & Termizi, 2012a). Table 1 shows some of the rockfall occurrences in the Kinta Valley.

Table 1 Examples of rockfall occurrences in the Kinta Valley in which some have caused a number of deaths and damages to vehicles and civil structuresSource: Modified from Aw & Ooi (1979); Ooi (1979); Chung (1981); Chow & Sahat (1988); Hashim (1991); Chow (1995); Aw (1996); Mohammed & Termizi (2012a & b)

Reports on the instability of limestone hills such as at Gunung Cheroh in the Kinta Valley have been a subject of investigation by the Geological Survey of Malaysia as early as in 1927 (Shu & Lai, 1973). Structural failure had been reported as the main causal factor of rockfalls at these limestone hills. The rockfall at the southern end of Gunung Lang for example, was caused by intersecting faults that caused numerous rock blocks with sizes of 1.5 m to 3 m across and big slabs of rocks to be detached from the cliff (Lai, 1974). The potential danger of rockfall at Gunung Lang was also highlighted by Wong (1979). This is due to intensively developed and widespread joints with sheared cliff faces found at Gunung Lang.

Apart from the presence of joints and faults, chemical weathering from dissolution by water and quarry activities were reported to be the main causal factors of rockfalls such as the incident at Gunung Tunggal (Chow & Sahat, 1988). Based on their report, chemical weathering had decreased the cohesive strength along joints and fractures, which might have been the reason for the rockfall. In this incident, two failures occurred at the northern and southern sections of the hill on the same day resulting in the disposal of rock debris of various sizes and with an estimated volume of 10,000 m^3. Active dissolution of the limestone in the Ipoh area is

Table 1: Examples of rockfall occurrences in the Kinta Valley in which some have caused a number of deaths and damages to vehicles and civil structures

Location	Date	Damage/fatalities
East of Gunung Cheroh, Ipoh	18 October 1973	A long house was destroyed by rock debris and caused 40 deaths
West of Gunung Rapat, Kg. Sengat	21 October 1976	Damage to vehicles but no fatalities
Northeast of Gunung Karang Besar, Keramat Pulai	Before 1981	No damage to structure or fatalities reported
Northwest of the Gunung Karang Besar, Keramat Pulai	Before 1981	No damage to structure or fatalities reported
West of Gunung Karang Kecil, Keramat Pulai	Before 1981	No damage to structure or fatalities reported
East of Gunung Tunggal, Gopeng	29 December 1987	Damage to structure (an office) and 1 fatality
North of Gunung Lang	Before 1993	No damage to structure or fatalities reported
Gunung Karang Besar, Keramat Pulai	5 June 2008	Damage to vehicle and 1 death
Yee Lee Edible Oils Factory (Gunung Lang, Ipoh)	13 February 2012	Damage to structure but no fatalities reported
Gua Tempurung, Kampar	11 April 2012	No damage to structure or fatalities reported

Source: Modified from Aw & Ooi (1979); Ooi (1979); Chung (1981); Chow & Sahat (1988); Hashim (1991); Chow (1995); Aw (1996); Mohammed & Termizi (2012a & b) indicated by the presence of numerous caves and caverns (Wong, 1979; Shu & Razak, 1984).

The most recent rockfall in Ipoh was reported to have occurred in April 2012 at Gua Tempurung where a 750 m^3 rock block toppled down (Mohammed & Termizi, 2012a). Based on their investigation, water flow from the top of the slope, mechanical weathering from roots of vegetation, and open fractures were identified as the main causes for the failure.

The impact of a rockfall can also affect its surrounding. Air blast resulting from the fallen rock debris can be felt at a distance that is much further from the disaster area which could also affect nearby buildings (Lai, 1974, Shu & Lai, 1974). In respect to this, development in an area close to the limestone hills may face grave consequences if a major rockfall occurrs (Shu & Lai, 1974).

The Study Area

The study area is located in the Kinta Valley, in the state of Perak. Overall, there are numerous massive limestone hills with an average size of 1.08km^2. Some of the hills are unnamed and the few known hills with their names are shown in Figure 1. Based on the topographic map, the maximum elevation of these hills reaches 546 m.

Significant developments are noticeable around some of the limestone hills. Residential,

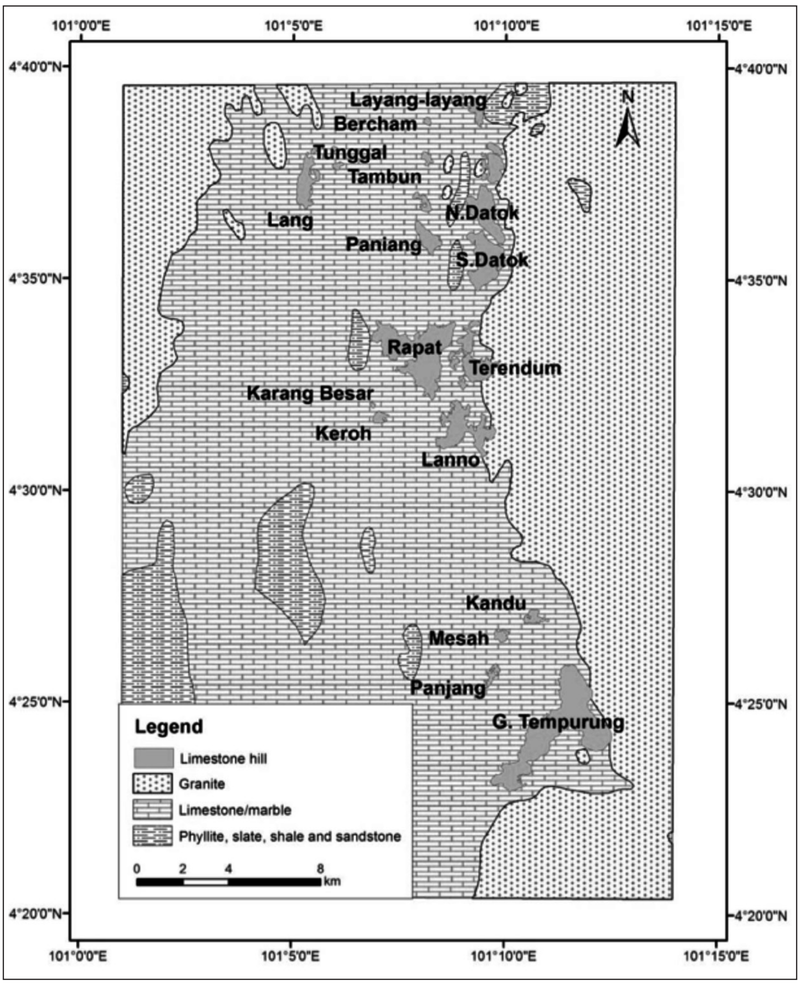

Figure 1: Geological map showing wide spread occurrences of limestone in the study area. Modified from Yin (1988)

industrial developments and temples are located nearby at the footslopes of some of these hills. Quarrying activities are also active in the study area as these limestone hills are sources of good quality limestone aggregates.

Geomorphology of the Study Area

The Kinta Valley has a wide spread occurrence of limestone. It is triangular in shape and is bounded by the Kledang Range in the west and the Main Range in the east (Yassin *et al*., 2013). It is featured with numerous limestone hills known as 'mogote' of various sizes, with caves and caverns that are adorned with beautiful karstic morphology such as giant stalactites and stalagmites. Steep sided limestone hills were formed from dissolution of carbonate rocks and these hills have many joint and fracture systems. The bases of the hills are usually swampy and notches are also visible due to dissolution.

Geology of the Study Area

The main lithology in the study area which is located in the Kinta Valley is the presence of massive limestone bodies that are heavily jointed and fractured. Localized highly weathered schist was also observed in a cave that is located at the Gunung Rapat area. The schist found was at the bottom of a massive limestone body. Joints and fractures are common features in the limestone bodies with two to four joint sets. The lithological map with wide occurrences of limestone hills in the Kinta Valley is shown in Figure 1.

The limestone in the Kinta Valley was named as the Kinta Limestone Formation by Foo (1983). Some of the names that were given by other researchers to describe the geological nature of this area are the Kanthan Limestone (Metcalfe, 2013), H.S. Lee Beds, Nam Long Beds, Kuan On Beds, Thye On Beds, and Kim Loong No.1 Beds (Suntharalingam,1968). The age of the Kinta Limestone is between Devonian to Permian and was deposited in a shallow marine environment (Sutharalingam, 1968).

The other common lithologies in the Kinta Valley are schist and granite that flank the eastern and western sides of the valley (Hutchison & Tan, 2009). Based on their studies, the schist is poorly stratified and weathered and can be found occasionally in old tin mines due to its poor exposure. In terms of structure, a straight 26 km long scarp is found on the eastern flank of the Kledang Range which is suggestive of a major fault. Several smaller faults have been observed at the eastern side of the Kinta Valley.

Method

The Rock Mass Strength (RMS) method was used to assess the condition of rock slope in the field based on the presence of discontinuities in the rock mass. This method was developed by Selby (1980) and has several components:

a) Intact rock strength (I_r);
b) Weathering (W)
c) Joints spacing (J_s);
d) Joints orientation (J_o);
e) Joints width (J_w);
f) Continuity of joints (J_c);
g) Outflow of groundwater (G_w).

The intact rock strength is obtained by using the N-type Schmidt hammer and the range of 'R' values from 10 to 100 is used to classify the intact rock strength. In terms of weathering, only five classes of weathering grade are used in this RMS system (unweathered, slightly weathered, moderately weathered, highly weathered and completely weathered). However, to determine the characteristics of each weathering grade in the field, the authors used the weathering characteristics suggested by ISRM (1981). The RMS system classifies joint spacing of less than 50 mm as very weak and more than 3 m as competent. For joint orientation, the system classifies joints that dip steeply out of a slope as very unfavourable. This study considers any joint with a dipping angle that exceeds 45° as steep. Joints that are continuous with thick infill and with wide opening (> 20 mm) are classified as not favourable. This condition could be worsened if water flows through these joints.

These components in the RMS are summed up to determine the favourability of the rock

Table 2: The rating for each class in each of the RMS components

Components	Classes	Rating
Intact rock strength ('R' value) (I_r)	100 – 60	20
	60 – 50	18
	50 – 40	14
	40 – 35	10
	35 – 10	5
Weathering (W)	Unweathered	10
	Slightly weathered	9
	Moderately weathered	7
	Highly weathered	5
	Completely weathered	3
Joints spacing (J_s)	> 3 m	30
	3 – 1 m	28
	1 – 0.3 m	21
	300 – 50 mm	15
	< 50 mm	8
Joints orientation (J_o)	Very favourable. Steep dips into slope, cross joints interlocked	20
	Favourable. Moderate dips into slope	18
	Fair. Horizontal dips, or nearly vertical (hard rocks only)	14
	Unfavourable. Moderate dips out of slope	9
	Very unfavourable. Steep dips out of slope	5
Joints width (J_w)	< 0.1 mm	7
	0.1 – 1.0 mm	6
	1 – 5 mm	5
	5 – 20 mm	4
	> 20 mm	2
Continuity of joints (J_c)	None continuous	7
	Few continuous	6
	Continuous, no infill	5
	Continuous, thin infill	4
	Continuous, thick infill	1
Outflow of groundwater (G_w)	None	6
	Trace	5
	Slight (<25l/min/10m^2)	4
	Moderate (25-125l/min/10m^2)	3
	Great (>125l/min/10m^2)	1
Total Rating (RMS)	Very strong	100 – 91
	Strong	90 – 71
	Moderate	70 – 51
	Weak	50 – 26
	Very Weak	< 26

Source: Adapted from Selby (1980)

mass. The rating for the classes in each of the components is given in Table 2. The final score to obtain the rock mass strength of the assessed slope is calculated based on the equation below:

$$RMS = I_r + J_s + J_o + J_w + J_c + G_w$$

For the rock slope assessment, a total of one to three assessment stations were set up for each hill depending on their accessibility. The significance of these stations is their close proximity to roads and developed areas. Each

Table 3: The number of assessment stations for each of the limestone hills

Name of limestone hill	No. of Stations	Station indicator
Gunung Rapat	3	R1, R2, R3
Gunung Datok	2	D1, D2
Gunung Lang	2	L1, L2
Gunung Paniang	1	Pi1
Gunung Kandu	2	K1, K2
Gunung Panjang	1	Pj1
GuaTempurung	1	T1

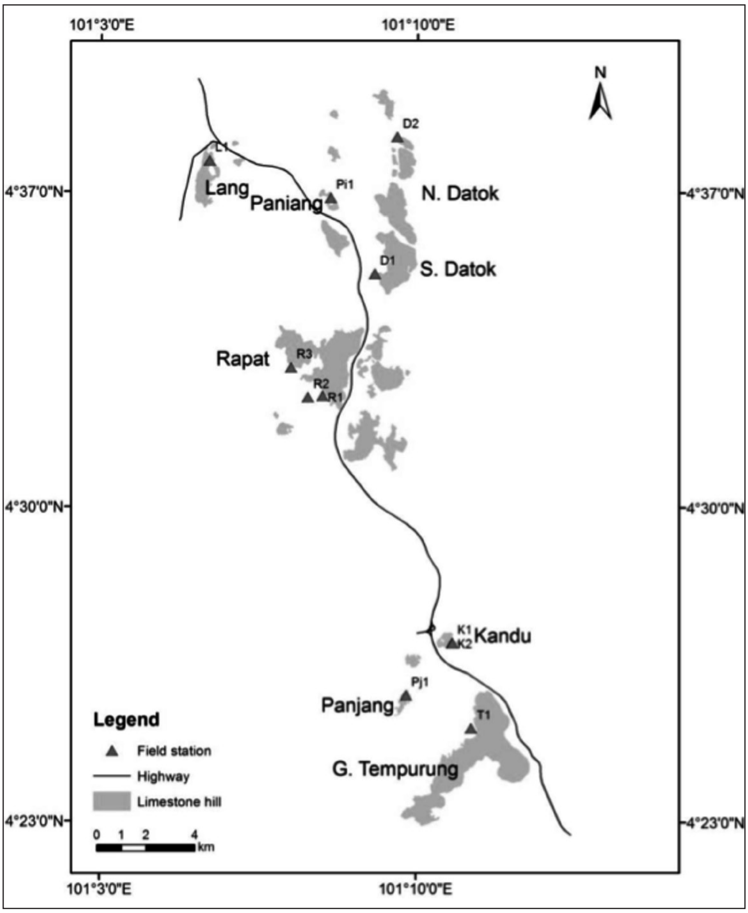

Figure 2: Locations of the assessment stations for each of the limestone hills as stated in Table 2

station was assessed along a 20-30 m scan line depending on the accessibility of the site. The results obtained from the field were averaged and the rating was later acquired from the RMS.

Results and Discussion

The Rock Mass Strength assessment was carried out on seven limestone hills, namely, Gunung Rapat, the southern and northern parts of Gunung Datok, Gunung Lang, Gunung Paniang,

Table 4: The rating for each RMS parameter on the different assessment stations in the study area

Station Max rating	Intact rock strength ('R' value) (I_r)	Weathering (W)	Joints spacing (J_s)	Joints orientation (J_o)	Joints width (J_w)	Continuity of joints (J_c)	Outflow of groundwater (G_w)
R1	5	7	21	5	2	5	5
R2	5	7	15	5	4	5	5
R3	5	7	21	9	4	1	5
D1	5	5	21	5	2	5	6
D2	5	9	21	14	4	4	6
L1	5	9	15	5	2	5	6
L2	5	7	15	9	2	5	6
Pi1	5	9	15	14	2	4	6
K1	5	7	21	5	4	4	5
K2	5	9	21	5	2	5	5
Pj1	5	7	21	5	2	5	5
T1	5	7	21	9	2	4	4

Table 5: The classification of the rock slopes for each of the assessment stations based on the the total sum of the RMS parameters

Stations	Total rating	RMS classification
R1	50	**Weak**
R2	46	**Weak**
R3	52	Moderate
D1	49	**Weak**
D2	63	Moderate
L1	47	**Weak**
L2	49	**Weak**
Pi1	55	Moderate
K1	51	Moderate
K2	52	Moderate
Pj1	50	Moderate
T1	52	Moderate

Gunung Kandu, Gunung Panjang and Gunung Tempurung. The number of assessment stations and the respective hills where they are located are summarised in Table 3 and the locations of these assessment stations are given in Figure 2.

Based on field observation, the rating for each component in the RMS for each station is given in Table 4. Based on the RMS assessment in Table 4, five out of the twelve are classified as weak, while the other seven stations are in the moderate class (Table 4).

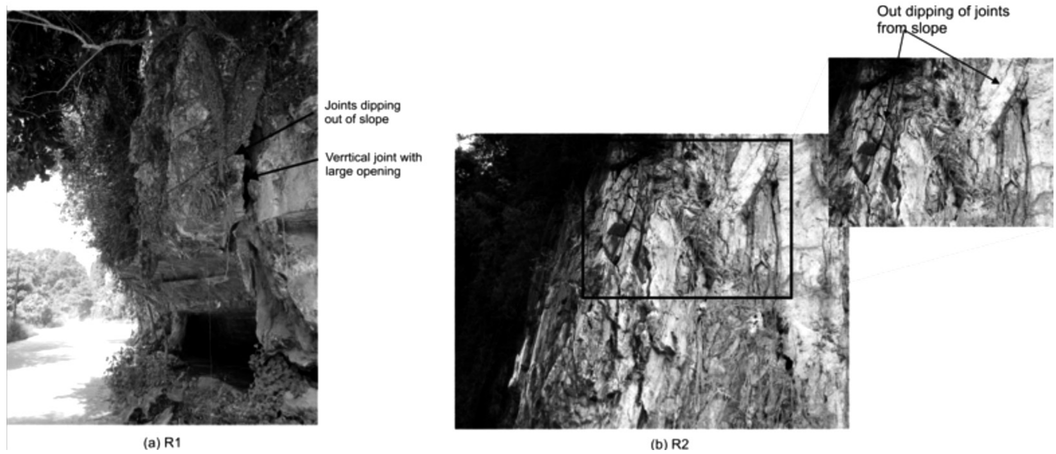

Figure 3: Very unfavourable jointings at Stations R1 and R2 result in the two stations being classified in the weak group of the RMS. (a) Vertical joints with wide opening and moderate dipping of daylighting joints (b) sub-vertical to vertical dipping of joints

Gunung Rapat

The Stations R1, R2, and R3 are located at the foot slope of Gunung Rapat. These stations are easily accessible by road. Based on Table 3, Stations R1 and R2 exhibit signs of weakness in the slope such as very unfavourable dipping of joints out of the slope and visible opening of joints which are wider than 30 mm. In the RMS scheme, these observations have the lowest ratings. Both of these stations also have very low average intact rock strength (25) as indicated by the Schmidt hammer test. Intersections of joints dipping out of the slope are clearly visible in both stations and plant roots filling the gaps of the vertical joints may widen the joints' opening (Figure 3). The susceptibility of rock failure may be increased by vibrations generated from movement of heavy vehicles such as lorries that use roads close to these hills. Although the slope at Station R3 does not exhibit the same level of susceptibility as that at Stations R1 and R2, its condition cannot be taken lightly as the calculated final score is just slightly over the margin of the weak group, which is 50.

Gunung Datok

Two assessment stations were set up at the northern (D1) and southern (D2) parts of Gunung Datok. This was done to observe if there is any difference in terms of joint properties if the stations are far apart. From the assessment, it is indicated by the RMS score that the slope at Station D1, which is located at the northern part is categorised as weak and that at Station D2 which is located at the southern end of the hill is classified as moderate. The limestone at Station D1 is highly weathered and jointed. As observed and measured, most joints at Station D1 dip moderately out of the slope as compared to that at Station D2 which has joints almost dipping horizontally and the rock is only slightly weathered. Apart from these factors, Station D1 has an average joint width around 25-50 mm compared to that at Station D2 which has an average joint width of 5-20 mm. However, both stations show low rebound Schmidt hammer readings (R: < 35).

Gunung Lang

The slopes at both Stations L1 and L2 are classified as weak based on their RMS final scores. Joints on both hills were noticeably clear but joint patterns were difficult to recognise due to blasting activities (Figure 4). However, the joint spacings are closely spaced and the joints dip moderately to steeply out of the slope. In addition, the width of the joints is also wide with openings of more than 20 mm. Most of these features were observed at the foot slope.

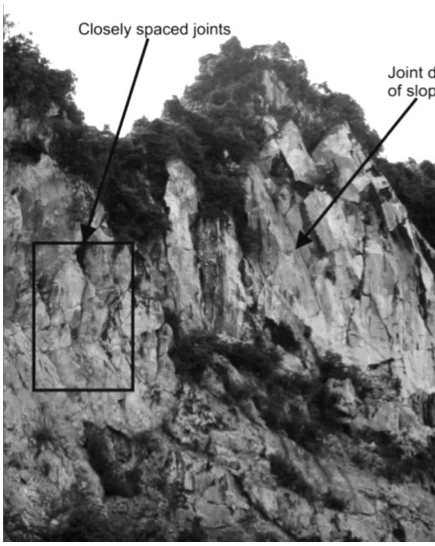

Figure 4: The condition of the exposed rock slope at Station L2 where joints are closely spaced, dipping out of the slope and the major of orientation is difficult to be determined due to the high joints density

Figure 5: Joints dipping out of slope in Station Pj1 increases its susceptibility to failure

Gunung Paniang, Gunung Kandu, Gunung Panjang & Gua Tempurung

All the slopes at the assessment stations at Gunung Paniang, Gunung Kandu, Gunung Panjang and Gua Tempurung were categorised as moderate. However, it is good to note that these slopes are all in the marginal or lower part of the moderate scoring range especially for Station K1 (Gunung Kandu) and Pj1 (Gunung Panjang). These stations were found to be susceptible due to their joint orientations that are dipping moderately to steeply out of the slope. This condition may pose great danger to passersby if rock blocks are dislodged from the slope (Figure 5). The contributing factors that put these slopes into the moderate group are that the rocks are slightly to moderately weathered, the spacings between joints are wide and the joints are either horizontal or moderately dipping.

Conclusion

Based on the seven components in the RMS system, namely, intact rock strength, weathering, joint spacing, joint orientation, joint width, continuity of joint and outflow of groundwater, assessment of the seven limestone hills has been conducted successfully. Out of the seven hills, the slopes at the assessment stations at Gunung Rapat, Gunung Datok, and Gunung Lang are classified as weak, while the slopes at the stations at the other four hills are classified as moderate. These four sites however have unfavourable joint orientations, where joints are dipping steeply out of the slope. As the fieldwork was conducted in the dry season, only traces of water outflow were observed in most of the hills classified as moderate. Therefore, the rating of these hills may change if the assessment is conducted during the wet season.

Over a longer period of time, mechanical weathering such as widening of joints due to in-growth of roots of vegetation and dissolution of carbonate rock by rain water along the joint openings may increase the susceptibility of rockfall at the study sites. These conditions can be aggravated by vibration from blasting activities in the nearby quarries and the movement of heavy vehicles in close proximity to the limestone cliffs which could easily trigger off rockfalls. Therefore, it is important to monitor regularly the condition of the slopes that are classified as weak to minimise the possibility of a rockfall occurring.

Acknowledgements

This research was funded by Sciencefund Grant (06-01-02-SF1140) & FRGS (FRGS/1/2014/STWN06/UKM/03/1).

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