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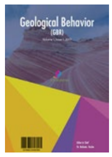

Rock Slope Stability Assessment of Limestone Hills in Northern Kinta Valley, Ipoh, Perak, Malaysia

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Limestone, failure modes, rock slope stability assessment

ABSTRACT

The uniqueness of karsttopography in Kinta Valley lies with the spectacular shape of the steep-sided limestone towers. However, theinstability ofthese hillslopes may affect the vulnerability of the surrounding area. Thus, this study was conducted with the objective to investigate the failure modes of 9 slopes in the vicinity ofnorthernKinta Valley, Ipoh, Perak. There were two types of failure modes identified in the study area,which are planar and wedge failures. Planar failures were identified on slope GL3of Gunung Lang and slope GR3of Gunung Rapat with the dip direction and dip angle of $280^0/79^0$ and $004^0/ 64^0$ respectively. Two wedge failures were identified on slope QXL1of Qing Xing Ling, Taman Saikat with dip direction and dip angle of $252^0/82^0$ and $302^0/74^0$ respectively. A wedge failure was identified on slope GL3 for Gunung Lang, slope GR1, slope GR3 for Gunung Rapat and slope QXL2 for Qing Xing Ling,Taman Saikat. The dip direction and dip angle for the respective wedges failure were $345^0/65^0$, $036^0/ 49^0$, $006^0/ 64^0$ and $025^0/60^0$. No failure was identified on slope GL1, and slope GL2,forGunung Lang and slope GR2, and slope GR4forGunungRapat.

1. INTRODUCTION

Karst topography in Kinta Valley is characterised by the steep- sided limestone hills and decorated with many limestone morphological features such as caves and dolines. Kinta Valley has been proposed to be developed as one of the national geoparks in Malaysia due to its impressive beautiful landscape (Leman, 2013).A literature study revealed that less research studies have been conducted on limestone hill's rock slope stability assessment. The local researchers were focused more on rock mass classification (Norbert et al. 2016), landslide (Norbert et al. 2013,Norbert et al. 2014, Norbert et al. 2015a), rock fall (Norbert et al. 2015b) and prediction of uniaxial compressive strength using ultrasonic (Goh et al. 2016, Goh et al. 2015a, Goh et al. 2015b, Goh et al. 2014b). Ghani Rafek et al. (2012), Ghani et al. (2011) and Goh et al. (2012a, 2014a) characterized the roughness of discontinuities surface by established a polynomial relationship between JRC with peak friction angles schist and granite. Goh et al. (2012b) investigated the influenced of conditions of weathering to the Geomechanical strength of Granites and Schists. Abdul Ghani Rafek et al. (2015) assessed the Kinta limestone based on slope mass rating.
Geohazard incidents like rock slab detachment and rock falls might occur as a result of weathering processes and discontinuity factors characterised mainly by geological structure conditions such as jointing, fractures and daylighting of discontinuities.These geological hazards will affect the vulnerability of development in the encompassing areas(Shu & Lai, 1974). The impact of a rockfall can also affects its surrounding in which the air blast resulting from the fallen rock debris can be felt at a distance that is much further from the catastrophe area which could affect nearby buildings (Lai, 1974, Shu & Lai, 1974).
As stated by Shu and Lai (1973), reports on the instability of limestone hills such as at Gunung Cheroh in the Kinta Valley have been a subject of investigations by the Geological Survey of Malaysia in early1927. One of the incidents of rockfall tragedy had occurred at Gunung Cheroh, Ipoh, Perak which caused the demise of 40 people in October, 1973 (Shu & Lai 1974). Rock fall incident at Gunung Pondok, Perak were also reported by Shu and Razak (1984).
Structural failure has been reported as the main causal factor of the rockfall events. Chemical weathering process also contributes to the decomposition of the rock mass.According to Chow and Sahat (1988) chemical weathering from water dissolution and quarry activities were reported to be the main causal factors of rockfalls such as the incident which occurred at Gunung Tunggal. It was reported that the cohesive strength along joints and fractures had decreased due to chemical weathering which possibly caused the rockfall.
With regard to these issues, this research was conducted to investigate the failure modes of eight limestone hills in the Kinta Valley by using kinematic analysis as recommended by Hoek and Bray (1981). The examples of rockfall events in the Kinta Valley that had caused a number of fatality and damages to vehicles and civil structures are shown in Table 1.

Table 1: Examples of rockfall occurrences in the Kinta Valley thathad 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	13 February 2012	Damage to structure but
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: Simon et al.(2015)

MATERIALS AND METHODOLOGY

Geology of Study Areas

The study area is located in the Kinta Valley, Perak as shown in Figure 1. The study areas covered the massive limestone bodies that are heavily jointed and fractured. As stated by Simon et al. (2015), there arenumerous massive limestone hills with an average size of 1.08

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km2with maximum elevation of these hills reaching 546 m based on the topographic map.The localized, highly weathered schist was found at the bottom of a massive limestone bodywhich can be observed in a cave located at Gunung Rapat. This limestone bodies were named by Foo (1983) as Kinta Limestone Formation with age of Silurian to Permian.

Methodology

Discontinuity surveys wereconducted by using the scan line method as suggested by Priest and Hudson (1976) and ISRM (1978) where 10 discontinuity parameters were considered. The parameters are dip direction, dip angle, discontinuity length (persistence), aperture, surface roughness, infilling, weathering, groundwater conditions, number of joint sets and block size.

The kinematic analysis was conducted by using Stereo32 software (Ruhr University Bochum, 2016). The results were interpreted to identify types of failure mode based on Hoek and Bray (1981). According to them, the possible major types of block failures on slopes and structural geology conditionsare plane failure, wedge failure, toppling failure and circular failure.The joint roughness coefficient values were used for the determination of peak friction angle as recommended by Ghani Rafek et al. (2012).

RESULTS AND DISCUSSION

A total of 9 slopes at the Northern Kinta Valley were assessed and labeled as GL1, GL2, and GL3 for Gunung Lang, GR1, GR2, GR3 and GR4 for Gunung Rapat and QXL1 and QXL2 for Qing Xing Ling, Taman Saikat as shown in Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10 and Figure 11, respectively. The locations of respective slopes are shown in Figure 2. The stereographs of respective slope were shown in Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, Figure 18, Figure 19 and Figure 20, respectively. GL1, GL2, and GL3of Gunung Lang are composed of 5 major joint sets. GR1, GR2, GR3 and GR4 for Gunung Rapat were composed of 4 major joint sets. 4 major joint sets were identified on slope QXL1 and QXL2 for Qing Xing Ling, Taman Saikat. The orientation of major joint sets and slope face of the respective slope are shown in Table 2.

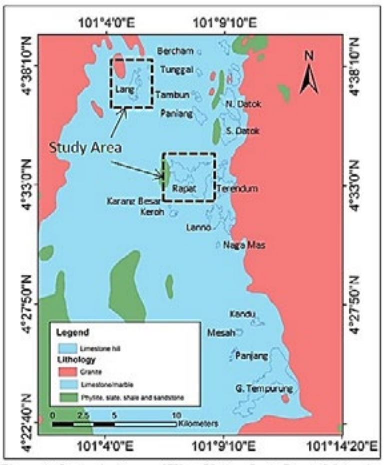

Figure 1: Geological map of Kinta Valley, Ipoh, Perak, Malaysia.

Source: Modified from Norbert *et al.* (2015b)

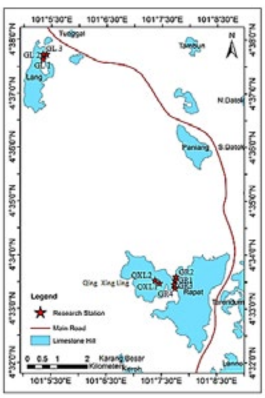

Figure 2: Location map for 9 slopes of study areas in the Northern Kinta Valley, Ipoh, Perak, Malaysia

Figure 3:Slope GL1, Gunung Lang, Ipoh, Perak, Malaysia.

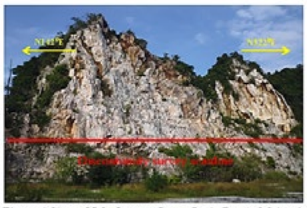

Figure 4:Slope GL2, Gunung Lang, Ipoh, Perak, Malaysia

Figure 5: Slope GL3, Gunung Lang, Ipoh, Perak, Malaysia

Figure 6:Slope GR1, Gunung Rapat, Ipoh, Perak, Malaysia.

Figure 7: Slope GR2, Gunung Rapat, Ipoh, Perak, Malaysia.

Figure 8.Slope GR3, Gunung Rapat, Ipoh, Perak, Malaysia.

Figure 9:Slope GR4, Gunung Rapat, Ipoh, Perak, Malaysia.

Figure 10: Slope QXL1, Qing Xing Ling, Taman Saikat, Ipoh, Perak, Malaysia.

Figure 11: Slope QXL2, Qing Xing Ling, Taman Saikat, Ipoh, Perak, Malaysia.

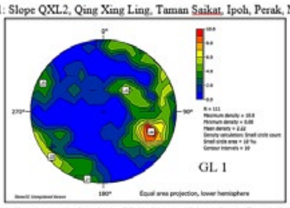

Figure 12: Stereograph for slope GL1, Gunung Lang, Ipoh, Perak, Malaysia.

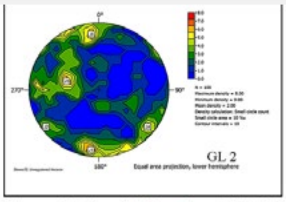

Figure 13: Stereograph for slope GL2, Gunung Lang, Ipoh, Perak, Malaysia.

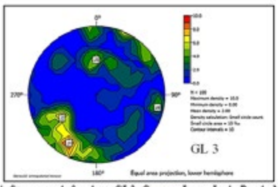

Figure 14: Stereograph for slope GL3, Gunung Lang, Ipoh, Perak, Malaysia.

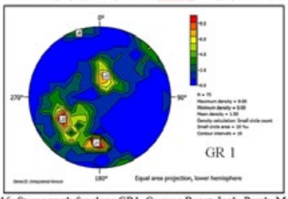

Figure 15: Stereograph for slope GR1, Gunung Rapat, Ipoh, Perak, Malaysia.

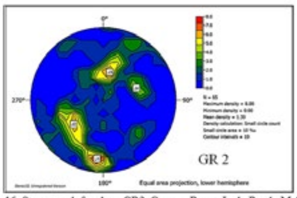

Figure 16: Stereograph for slope GR2, Gunung Rapat, Ipoh, Perak, Malaysia.

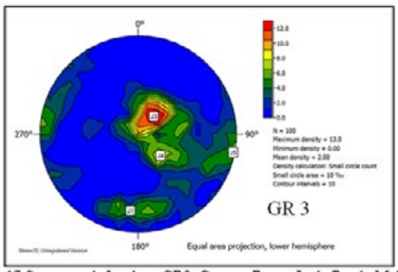

Figure 17:Stereograph for slope GR3, Gunung Rapat, Ipoh, Perak, Malaysia.

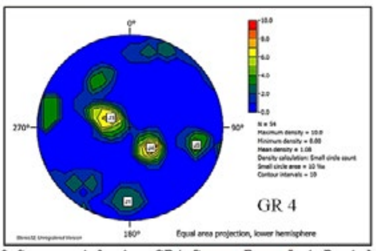

Figure 18: Stereograph for slope GR4, Gunung Rapat, Ipoh, Perak, Malaysia.

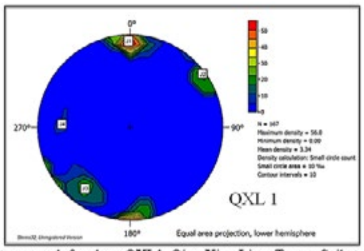

Figure 19: Stereograph for slope QXL1, Qing Xing Ling, Taman Saikat, Ipoh, Perak, Malaysia.

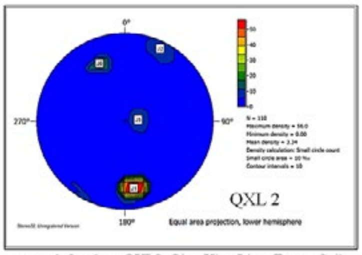

Figure 20: Stereograph for slope QXL2, Qing Xing Ling, Taman Saikat, Ipoh, Perak, Malaysia.

Table 2: Orientation of major joint set and slope face for slopes GL1, GL2 and GL3, for Gunung Lang, Ipoh; GR1, GR2, GR3 and GR4, for Gunung Rapat, Ipoh; QXL1 and QXL2, for Qing Xing Ling, Taman Saikat, Ipoh, Perak, Malaysia.

Slope	Major Joint set/Slope Face	Dip Direction (°)	Dip Angle (°)
GL1	**Slope face (SF)**	**148**	**82**
	J1	013	84
	J2	050	83
	J3	115	81
	J4	293	59
	J5	229	36
GL2	**Slope face (SF)**	**052**	**78**
	J1	007	80
	J2	055	84
	J3	106	39
	J4	309	77
	J5	174	70
GL3	**Slope face (SF)**	**270**	**82**
	J1	030	71
	J2	054	51
	J3	179	42
	J4	280	79
GR1	**Slope face (SF)**	**316**	**82**
	J1	003	55
	J2	060	51
	J3	196	25
	J6	162	88
GR2	**Slope face (SF)**	**262**	**82**
	J1	007	77
	J2	052	43
	J3	193	33
	J4	250	40
GR3	**Slope face (SF)**	**082**	**88**
	J1	004	64
	J3	220	19
	J4	315	25
	J5	280	88
GR4	**Slope face (SF)**	**120**	**84**
	J1	001	66
	J3	115	18
	J4	313	25
	J5	285	63
QXL1	**Slope face (SF)**	**279**	**83**
	J1	360	82
	J2	238	83
	J3	040	60
	Major joint set /J4	093	64
QXL2	**Slope face (SF)**	**040**	**82**
	J1	354	64
	J2	207	79
	J5	271	14
	J6	157	60

The peak friction angles for respective slopes used in kinematic analysis were determined based on the tilt test method suggested by Abdul Ghani Rafek and Goh (2012). The peak friction angle for slope GL1, GL2, and GL3 for Gunung Lang was 43^0. The peak friction angles for slope GR1, GR2, GR3 and GR4 for Gunung Rapat were 43^0, 70^0, 33^0 and 49^0 respectively. The peak friction angle for slope QXL1 and QXL2 for Qing Xing Ling was 49°.

Figure 21, Figure 22, Figure 23, Figure 24, Figure 25, Figure 26, Figure 27, Figure 28 and Figure 29 shows the results of kinematic analysis for respective slopes. Table 3 shows the summary of kinematic analysis for the respective slopes. Wedge and planar failures were identified on slope GL3 for Gunung Lang. The dip direction/dip angle for respective wedge and planar failures were $345^0/65^0$ and $280^0/79^0$. No mode of failure was identified on slope GL1 and GL2 for Gunung Lang.

A wedge failure was identified on slope GR1 with the respective dip direction/ dip angle of $036^0/49^0$.A wedge failure and planar failure was identified on slope GR3 for Gunung Rapat with the respective dip direction/ dip angle of $004^0/64^0$ and $006^0/64$. No mode of failure was identified on slope GR2 and GR4 for Gunung Rapat. There were two wedge failures identified on slope QXL1 and one wedge failure on slope QXL2 for Qing Xing Ling, Taman Saikat. The respective dip direction/dip angle of wedge failures were $252^0/82^0$, $302^0/74^0$ and $025^0/60^0$.

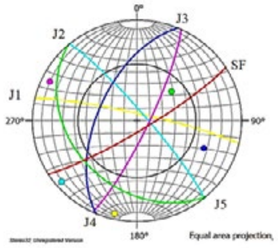

Figure 21: Kinematic analysis for slope GL1, Gunung Lang using friction angle of 43^0. No mode of failure on this slope.

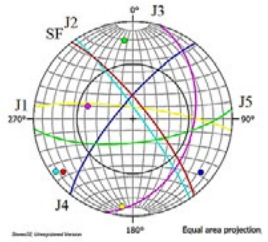

Figure 22: Kinematic analysis for slope GL2, Gunung Lang using friction angle of 43^0. No mode of failure on this slope.

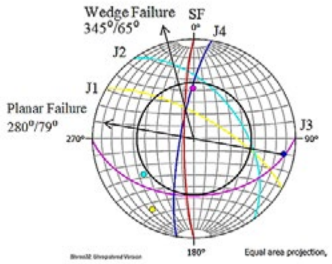

Figure 23: Kinematic analysis for slope GL3, Gunung Lang using friction angle of 43^0. From the kinematic analysis, a planar and a wedge failure were identified. The dip direction/dip angle for respective wedge and planar failure were $345^0/65^0$and $280^0/7$.

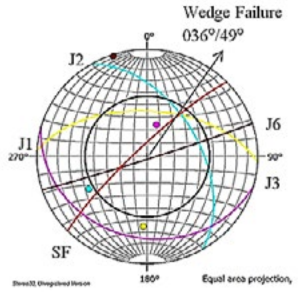

Figure 24: Kinematic analysis for slope GR1, Gunung Rapat using friction angle of 43^0. From the kinematic analysis, a wedge failure was identified. The dip direction/dip angle for the wedge failure was $036^0/ 49^0$.

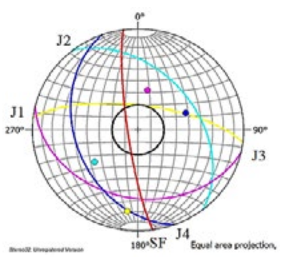

Figure 25 Kinematic analysis for slope GR2, Gunung Rapat using friction angle of 70^0. No mode of failure on this slope.

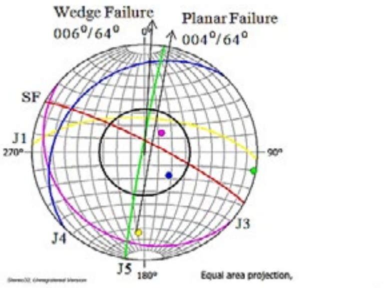

Figure 26: Kinematic analysis for slope GR3, Gunung Rapat using friction angle of 33^0. From the kinematic analysis, a planar and a wedge failure were identified. The dip direction/dip angle for respective wedge and planar failure were $006^0/ 64$ and $004^0/ 64^0$.

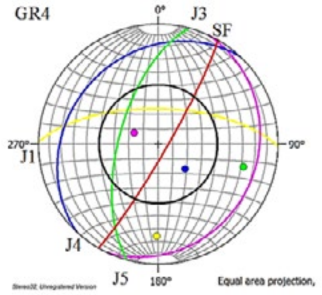

Figure 27: Kinematic analysis for slope GR4, Gunung Rapat using friction angle of 49^0. No mode of failure on this slope.

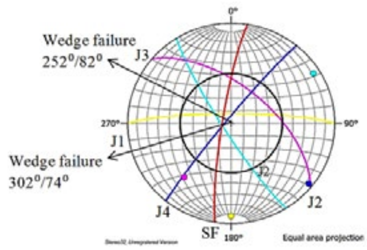

Figure 28: Kinematic analysis for slope QXL1, Qing Xing Ling using friction angle of 49^0. From the kinematic analysis, two wedge failures were identified. The dip direction/dip angle for the respective wedge failures were $252^0/82^0$ and $302^0/74^0$.

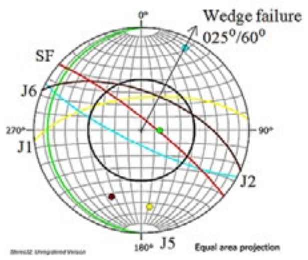

Figure 28: Kinematic analysis for slope QXL2, Qing Xing Ling using friction angle of 49^0. From the kinematic analysis, a wedge failure was identified. The dip direction/dip angle for the wedge failure was $025^0/60^0$.

Table 3: Summary of kinematic analysis for slopes GL1, GL2 and GL3, for Gunung Lang, Ipoh; GR1, GR2, GR3, GR4 and GR5, for Gunung Rapat, Ipoh; QXL1 and QXl2, for Qing Xing Ling, Gunung Rapat, Ipoh.

Slope	Friction angle ϕ	Joint Roughness Coefficient (JRC)	Failure Mode
GL1	43	5	No failure
GL2	43	5	No failure
GL3	43	5	Wedge failure: $345^0/65^0$
			Planar failure: $280^0/79^0$
GR1	43	5	Wedge failure: $036^0/ 49^0$
GR2	70	15	No failure
GR3	33	9	Wedge failure: $006^0/ 64^0$
			Planar failure: $004^0/ 64^0$
GR4	49	7	No failure
QXL1	49	7	Wedge failure: $252^0/82^0$
			Wedge failure: $302^0/74^0$
QXL2	49	7	Wedge failure: $025^0/60^0$

CONCLUSION

From the kinematic analysis assessment,a wedge failure was identified at on slope GL3, for Gunung Lang. The dip direction and dip angle of the wedge failureswas $345^0/65^0$.There are no modes of failureson slope GL1 and GL2 for Gunung Lang. A wedge failure was identified onslope GR1 for Gunung Rapat with the dip direction and dip angle of $036^0/ 49^0$. No modes of failure were identified on slope GR2 for Gunung Rapat. A wedge and planar failure were identified on slope GR3 for Gunung Rapat. The dip direction and dip angle for the respective wedge and planar failure were $006^0/ 64^0$ and $004^0/ 64^0$. No modes of failurewere identified on slope GR4 for Gunung Rapat. Two wedge failures were identified on slope QXL1 for Qing Xing Ling, while a wedge failure was identified on slope QXL2 for Qing Xing Ling. The dip direction and dip angle for the respective wedge failures were $252^0/82^0$, $302^0/74^0$ and $025^0/60^0$.

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