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ROCK SLOPE STABILITY ASSESSMENT OF LIMESTONE HILLS, SOUTHERN KINTA VALLEY, IPOH, PERAK, MALAYSIA

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ABSTRACT

The uniqueness of the karst topography of Kinta Valley is the result of the spectacular shaped steep-sided limestone towers. The instability of these hillslopes however, may affect the vulnerability of the surrounding area. This paper presents the results of slope stability assessment by using kinematic analysis to investigate the possible failure modes of 7 slopes in Gua Naga Mas (GNM1, GNM2 and GNM3), Gua Kandu (GK1, GK2 and GK3) and Gua Tempurung (GT) located in the southern part of the Kinta Valley, Ipoh, Perak. From the results of the slope stability assessment, it was determined that planar failure and wedge failure were the main failure modes. The GNM1 slope of Gua Naga Mas consist of four wedge failures and a planar failure with dip directions/dip angles of $005^0/54^0$, $354^0/59^0$, $124^0/52^0$, $360^0/50^0$ and $063^0/70^0$ respectively. The GNM2 slope consists of a wedge failure with the dip direction/dip angle of $021^0/64^0$. Two wedge failures and a planar failure were identified on slope GNM3 with the respective dip directions/dip angles of $336^0/49^0$, $301^0/68^0$ and $270^0/71^0$. The GK1 slope for Gua Kandu consists of wedge and planar failures with dip directions/dip angles of $231^0/49^0$ and $217^0/49^0$ respectively. The mode of failure at GK2 slope was identified as wedge failure with the dip direction/dip angle of $154^0/44^0$. No mode of failure was identified on slope of GK3. Slope GT of Gua Tempurung was identified to have two wedge failures with dip directions/dip angles of $011^0/49^0$ and $321^0/48^0$ respectively.

1. INTRODUCTION

Karst topography in the Kinta Valley is characterized by the steep- sided limestone hills with many limestone morphological features such as caves and do lines. Kinta Valley was proposed to be developed as one of the national geoparks in Malaysia due to its beautiful landscape [1].

The literature study revealed that less research studies have been conducted on limestone hillslope stability assessment. The local researchers were focused on rock mass classification, landslides, rock fall and prediction of uniaxial compressive strength using ultrasonic velocities [2-10]. Some researcher characterized the discontinuity surface roughness by establishing a polynomial relationship between JRC with peak friction angles schist and granite [11-13]. A scientist, investigated the influenced of conditions of weathering to the geomechanical strength of Granites and Schists [14].

However, the geological structures such as jointing and fractures and daylighting of rock blocks that characterize the steep sided slopes may hasten the occurrence of geohazards such as rock slides and rock falls as stated [6]. According to a research, geological hazards will affect the vulnerability of development in the encompassing areas [15]. Generally, the main factor for rockfall events is due to structural failure [15]. Chemical weathering from water dissolution and quarry activities were also classified as the factors causing rockfalls such as the incident at Gunung Tunggal [16]. 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 also affect nearby buildings [17,15].

The instability of limestone hills such as at Gunung Cheroh in the Kinta Valley was investigated by the Geological Survey of Malaysia [18]. One of the incidents of rockfall tragedy that had occurred at Gunung Cheroh, Ipoh, Perak caused the death of 40 people in October 1973 [15]. Rock falls from Gunung Pondok, Perak were also reported in a research paper [19]. About these issues, this research was conducted to investigate the failure modes of 7 slopes of limestone hills in the Kinta Valley by using kinematic analysis as recommended by a researcher [20]. The recorded rockfall events occurrences in the Kinta Valley and the consequences are shown in Table 1.

2. MATERIALS AND METHODOLOGY

2.1 Geology of Study Areas

The study area is in the Kinta Valley, Perak as shown in Figure 1. The study areas cover the massive limestone bodies that are heavily jointed and fractured. The average size of limestone hills in the Kinta Valley are 1.08 km2 with the maximum elevation of up to 546 m based on the topographic map. The localized, highly weathered and poorly stratified schist was found at the bottom of a massive limestone body [18,21]. This limestone bodies were named as Kinta Limestone Formation with the age of Silurian to Permian [2
2]. The Kinta Valley is bordered by Trassic granite on both side. The limestone bodies were deposited on stable continental shelf in a marine environment [21]. The calcareous sedimentation during Late Paleozoic was interrupted by argillaceous sedimentation from the deeper ocean [21].

3. METHODOLOGY

Discontinuity surveys were conducted using the scan line method as suggested by two researchers and ISRM where 10 discontinuity parameters were considered [23,24]. The parameters are dip direction, dip of angle, discontinuity length (persistence), aperture, surface

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roughness, infilling, weathering, groundwater condition, number of joint set and block size.

The kinematic analysis was conducted by using Stereo32 software. The results were interpreted to identify the types of failure mode based on classification of failure modes [20]. The peak friction angle for each slope was determined by using the polynomial equation developed by a researcher [25].

Table 1: Examples of rockfall occurrences in the Kinta Valley that had caused many 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: [6]

4. RESULTS AND DISCUSSION

A total of three research stations were located at Gua Naga Mas, Gua Kandu, and Gua Tempurung. The slopes at Gua Naga Mas were labelled as GNM1, GNM2 and GNM3. The slopes at Gua Kandu and Gua Tempurung were labelled as GK1, GK2, GK3 and GT respectively. Figure 2 shows the locations of the study areas in the Kinta Valley.

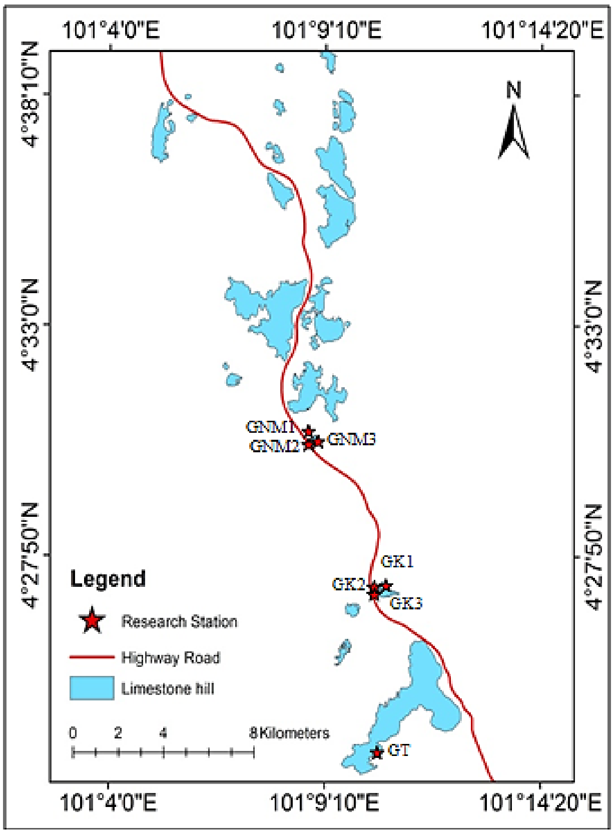

Figure 2: Location of study areas in southern Kinta Valley, Ipoh, Perak, Malaysia

Slopes of Gua Naga Mas; GNM1, GNM2, and GNM3 are composed of 4 to 5 major joint sets; slopes of Gua Kandu have 3 to 4 major joint sets; while the slope of Gua Tempurung, GT is composed of 4 major joint sets. The orientation of major joint sets and slope face for respective slopes are shown in Table 2.

4.1 Gua Naga Mas

Three slopes were investigated at Gua Naga Mas which were labelled as GNM1, GNM2 and GNM3. The outcrops of the slopes are shown in Figure 3. The stereographs of respective slopes are shown in Figure 4. The peak friction angle for GNM1 was 55^0. The peak friction angle for both GNM2 and GNM3 was 49^0. Figure 5 shows the results of kinematic analysis for respective slopes. Based on the kinematic analysis, four wedge failures and a planar failure were identified at slope GNM1 and the dip directions/dip angles for respective wedge and planar failures were $005^0/54^0$, $354^0/59^0$, $124^0/52^0$, $360^0/50^0$ and $063^0/70^0$, respectively. The mode of failure identified at slope GNM2 was wedge failure with the dip direction/dip angle of $021^0/64^0$ whereas two wedge failures and a planar failure were identified at slope GNM3. The dip directions/dip angles for respective wedge and planar failures at slope GNM3 were $336^0/49^0$, $301^0/68^0$ and $270^0/71^0$, respectively. Table 3 shows the summary of rock slope assessment at Gua Naga Mas according to failure mode, failure direction, peak friction angle and joint roughness coefficient.

Table 2: The orientation of major joint sets and slope face for GNM1, GNM2 and GNM3, Gua Naga Mas, Simpang Pulai, slope GK1, GK2, GK3, Gua Kandu,; Gopeng and slope of GT, Gua Tempurung, Gopeng, Perak, Malaysia.

Slope	Major Joint set/Slope Face	Dip Direction (^{0})	Dip Angle (^{0})
GNM1	Slope face (SF)	068	82
	J1	063	79
	J2	286	77
	J3	320	63
	J4	157	56
GNM2	Slope face (SF)	024	86
	J1	061	69
	J3	314	79
	J4	204	21
	J5	010	38
GNM3	Slope face (SF)	260	80
	J1	040	69
	J2	270	71
	J3	336	71
	J4	148	30
GK1	Slope face (SF)	218	82
	J1	331	38
	J2	217	49
	J3	135	35
	J4	099	59
	J5	279	60
GK2	Slope face (SF)	172	78
	J1	322	59
	J2	211	60
	J4	091	65
GK3	Slope face (SF)	284	70
	J1	360	51
	J2	194	70
	J3	135	75
	J4	080	64
GT	Slope face (SF)	306	82
	J1	350	51
	J2	180	59
	J3	036	52
	J4	240	82

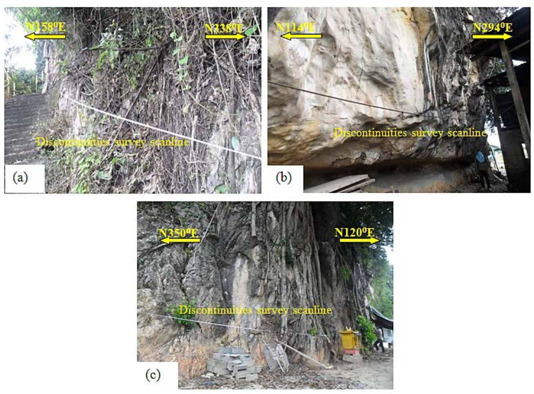

Figure 3: Discontinuity survey scanlines at the outcrop of (a) slope GNM1, (b) GNM2 and (c) GNM3 for Gua Naga Mas, Simpang Pulai, Perak.

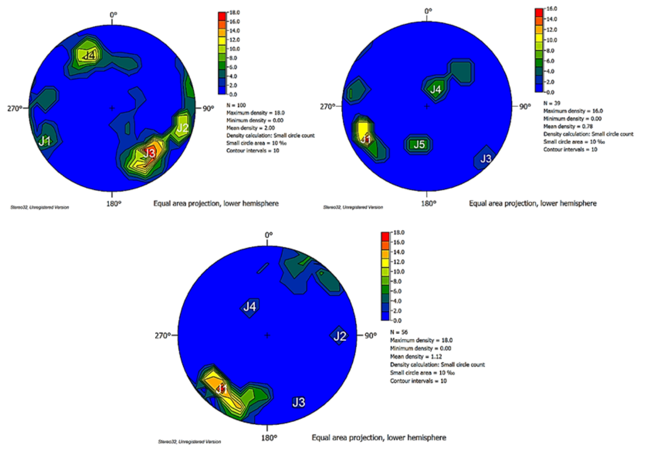

Figure 4: Stereographs for slopes of (a) GNM1, (b) GNM2 and (c) GNM3 for Gua Naga Mas, Simpang Pulai, Perak.

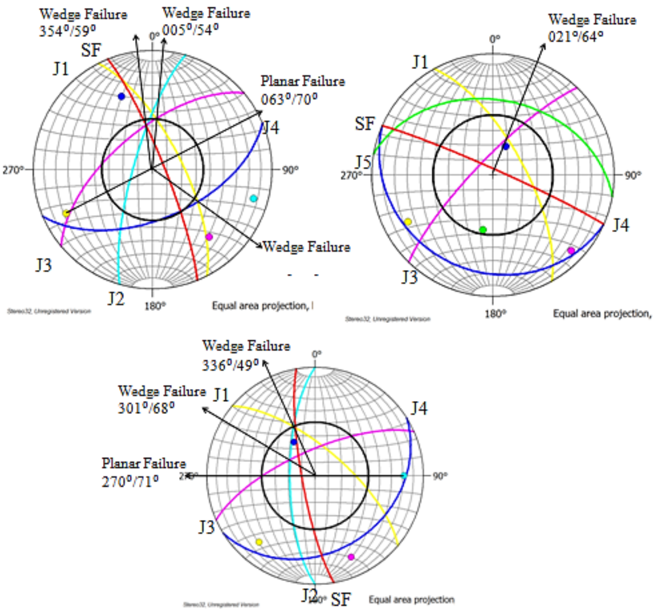

Figure 5: Kinematic analysis of (a) slope GNM1, (b) GNM2 and (c) GNM3 for Gua Naga Mas, Simpang Pulai, Perak.

Table 3: Summary of rock slope stability assessment at Gua Naga Mas according to failure mode, failure direction, peak friction angle and joint roughness coefficient.

Slopes	Failure mode	Failure direction	Peak friction angle	Joint roughness coefficient
GNM1	Wedge failure	$005^0/54^0$ $354^0/59^0$ $124^0/52^0$	55	9
	Planar failure	$063^0/70^0$		
GNM2	Wedge failure	$021^0/64^0$	49	7
GNM3	Wedge failure	$336^0/49^0$ $301^0/68^0$	49	7
	Planar failure	$270^0/71^0$		

4.2 Gua Kandu

Three slopes were investigated at Gua Kandu and were labelled as GK1, GK2 and GK3. The locations of the respective slopes are shown in Figure 6. The stereographs of the respective slopes where are shown in Figure 7. The peak friction angle for slope GK1, GK2 and GK3 were 49˚, 36˚ and 55˚ respectively. Figure 8 shows the results of kinematic analysis for the respective slopes. The mode of failure for slope GK1 were wedge and planar failures with the dip directions/dip angles for wedge and planar failures as $231^0/49^0$ and $217^0/49^0$, respectively. The mode of failure at slope GNM2 was wedge failure with the dip direction/dip angle of $154^0/44^0$. No mode of failure was identified at slope GK3. Table 4 shows the summary of rock slope stability assessment at Gua Kandu according to failure mode, failure direction, peak friction angle and joint roughness coefficient.

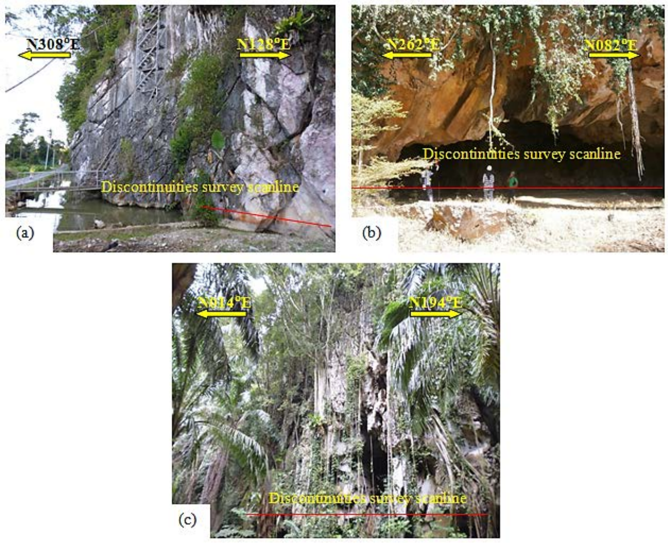

Figure 6: Discontinuity survey scanlines at the outcrop of (a) slope GK1, (b) GK2 and (c) GK3 for Gua Kandu, Gopeng, Perak

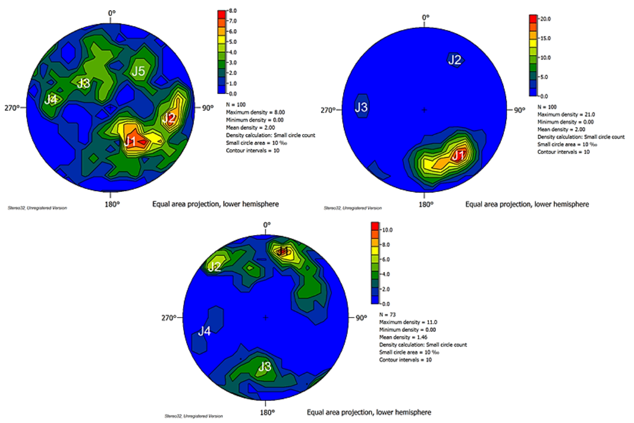

Figure 7: Stereograph of (a) slope GK1, (b) GK2 and (c) GK3 for Gua Kandu, Gopeng, Perak

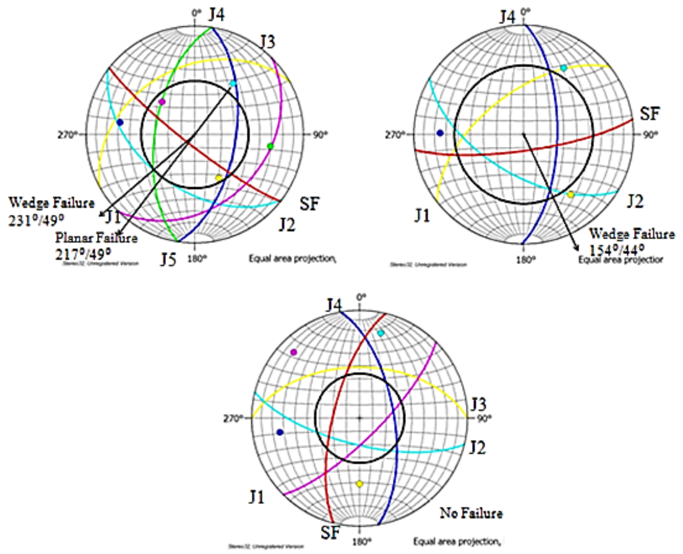

Figure 8: Kinematic analysis of (a) slope GK1, (b) GK2 and (c) GK3 for Gua Kandu, Simpang Pulai, Perak

Table 4: Summary of rock slope assessment at Gua Kandu according to failure mode, failure direction, peak friction angle and joint roughness coefficient.

Slopes	Failure mode	Failure direction	Peak friction angle	Joint roughness coefficient
GK1	Wedge failure Planar failure	$231^0/49^{00}$ $217^0/49^0$	49	7
GK2	Wedge failure	$154^0/44^0$	49	3
GK3	No failure		55	5

4.3 Gua Tempurung

The slope investigated at Gua Tempurung was labelled as GT. The location of the slope is shown in Figure 9. The stereograph of the slope is shown in Figure 10. The peak friction angle for GT was 49^0. Figure 11 shows the results of kinematic analysis for slope GT. Two wedge failures were identified on slope GT with dip directions/dip angles of $011^0/49^0$ and $321^0/48^0$. Table 5 shows the summary of rock assessment at Gua Tempurung according to failure mode, failure direction, peak friction angle and joint roughness coefficient.

Figure 9: Discontinuity survey scanlines at the outcrop of slope GT for Gua Tempurung, Gopeng, Perak

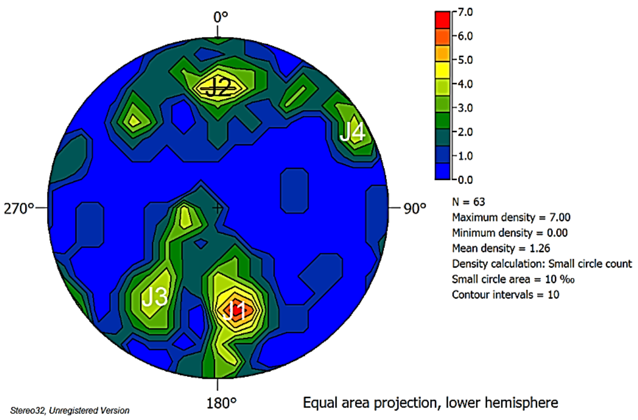

Figure 10: Stereograph of slope GT for Gua Tempurung, Gopeng, Perak

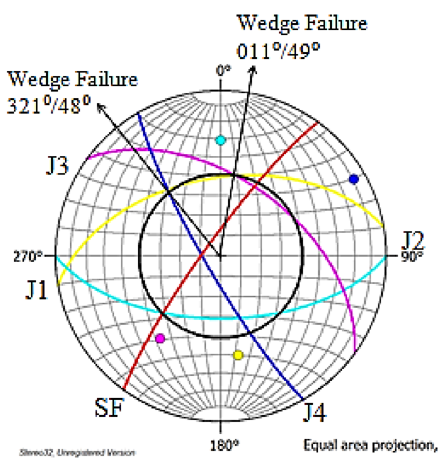

Figure 11: Kinematic analysis of slope GT for Gua Tempurung, Gopeng, Perak

Table 5: Summary of rock slope assessment at Gua Tempurung according to failure mode, failure direction, peak friction angle and joint roughness coefficient.

Slope	Failure mode	Failure direction	Peak friction angle	Joint roughness coefficient
GT	Wedge failure	$011^0/49^0$ $321^0/48^0$	49	7

5. CONCLUSION

The slope stability assessment using kinematic analysis revealed that there were wedge failures and planar failures at both Gua Naga Mas and Gua Kandu. Only wedge failure was identified at Gua Tempurung. Slope GNM1 consist of four wedge failures and planar failure with failure directions of $005^0/54^0$, $354^0/59^0$, $124^0/52^0$, $360^0/50^0$ and $063^0/70^0$ respectively. Slope GNM2 consist of a wedge failure with the dip direction/dip angle of $021^0/64^0$. Two wedge failures and a planar failure were identified on slope GNM3. The dip directions/dip angles for respective wedge and planar failures on slope GNM3 were $336^0/49^0$, $301^0/68^0$ and $270^0/71^0$ respectively. Slope GK1 consist of wedge and planar failure with dip direction/dip angle of $231^0/49^0$ and $217^0/49^0$ respectively. The mode of failure on slope GNM2 was wedge failure with the dip direction/dip angle of $154^0/44^0$. No mode of failure was identified on slope GK3. Slope GT was identified to have two wedge failures with dip direction/dip angle of $011^0/49^0$ and $321^0/48^0$ respectively.

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