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Rock Slope Stability Assessment of Gunung Rapat Limestone Hills, Kinta Valley, Perak, Malaysia

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Abstract:* *Limestone hills are prone to chemical weathering such as dissolution which causes the formation of karst terrains. They also exhibit extensive geological discontinuities due to past tectonic history and also physical weathering. Therefore, limestone hills can pose danger to properties and human due to instability of the slopes. Physical weathering causes the rocks to undergo stress which opens existing geological discontinuities such as fractures. These geological discontinuities are the main factor which causes slope instability and rock fall. The main objective of this study is to investigate the failure modes of six slopes in the limestone hills of Gunung Rapat, Ipoh, Perak, Malaysia. Based on the kinematic analysis conducted, plane failures were identified on slope M1, M2 and T3. Wedge failures were identified on slopes M2, T2 and T3. However, no failure was identified on slopes M3 and T1. Slopes M1, M2, T2 and T3 all have high susceptibility to failure due to the intensity of discontinuities and unfavorable joint orientations.

***Index Terms*: Slope stability, Rock Fall, Kinematic Analysis, Modes of Failure.**

I. INTRODUCTION

The study area is located in Kinta Valley, Perak, Malaysia (Fig. 1). The Kinta Limestone which has an age ranging from Devonian to Permian underlies the tin-ore bearing alluvium of the study area. During the end of Permian, the limestone and schist of the study area have been folded and metamorphosed due to granite intrusion. This research focuses on the rock slope stability of the six slopes of the Gunung Rapat limestone hill. This is because, according to Simon et al.[1], the foot slope of Gunung Rapat is classified to be weak according to the Rock Mass Strength classification. Besides, wedge and planar failures have been ideitified at the western part of Gunung Rapat. However, there are no studies done to predict the possibility of rock fall occurring in the northern and southern part of the Gunung Rapat limestone hill. Since the limestone bodies are heavily jointed and fractured, it is vital to study the rock fall potential as the study area is facing residential estates and cave temples which are popular tourism sites. The Gunung Rapat limestone hill consists of caves, notches and pinnacles. The karstic features of this limestone hill are caused by dissolution process which has been initiated by the frequent flooding of the alluvial plain which causes swampy condition at the base of the hill (1). By sub-surface dissolution, the original limestone platforms of the study area have been reduced to pinnacle topography (1). In this study, the failure modes of three slopes of the iMix Quarry and three slopes of the Miaw Yuan Chan Lin Temple were investigated and quantified by using the kinematic analysis method.

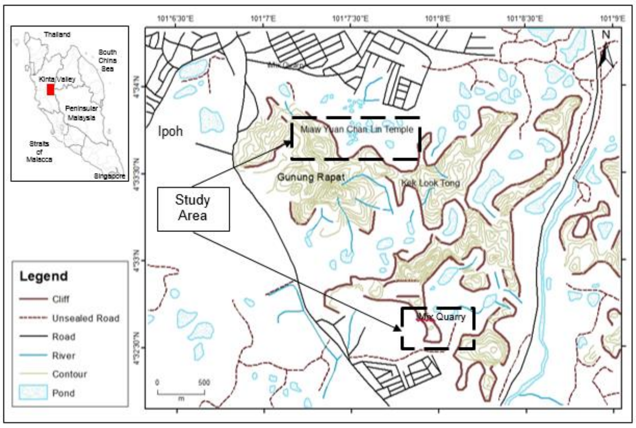

Fig. 1: Base map of the study area of the Gunung Rapat limestone hills, Perak, Malaysia

II. LITERATURE REVIEW

Kinta Valley has been intruded by two granitic intrusions namely the Main Range and the Kledang Range which occurred during the Late Triassic[2]. The cooling of the granite magma during these granitic intrusions have caused the country rocks such as limestone and shale to be metamorphosed into marble and schists (2) .Choong et al. (2) have also stated that the deformation of the Kinta Valley lithology such as folding was caused by a tectonic event which occurred during Triassic after the deposition of limestone. The granitic intrusions which have occurred during Late Triassic to Early Jurassic have caused a strong E-W compression. This compression causes all the pre-existing rocks to undergo compression which then results in folding and thrusting. Limestone of the Kinta Valley has been fractured and thrusted due to this compression event.

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A. Rock fall history in Kinta Valley

There are many cases of rock falls in the Kinta Valley. There was a tragic rock fall which happened at Gunung Cheroh, Ipoh, Perak, Malaysia in 1973 causing the death of 40 people (1). Later in 1976, a tour bus was damaged due to the rock fall that occurred at the western tip of Gunung Rapat but without any loss of lives[3]. Rock falls are triggered by the instability of the slope or cliff. Rock falls happen at these limestone hills are primarily caused by structural failure (1). Numerous blocks with sizes of 1.5 meters to 3 meters across and big slabs of rocks that have detached from the cliff were triggered by the intersecting faults, thus results in rock fall at the southern end of Gunung Lang, Ipoh. Besides, Simon et al.(1) has mentioned that, extensive and widespread joints present in the cliff faces also trigger the formation of rock falls. Even though joints and fractures indicates a planar crack or break in rock without any displacement, there are other factors which causes them to be displaced from its original position and thus, causes slope failure. These factors include water infiltration and weathering (1).

III. METHODOLOGY/MATERIALS

Discontinuity survey was conducted using the scan line method to collect geological data of the cliff face. The parameters are dip direction, dip angle, discontinuity length, aperture, surface roughness, infilling material, weathering, groundwater conditions and rock wall strength. The roughness of the discontinuity surfaces were measured by using the Barton Comb to reproduce the true roughness profiles. The obtained profiles were compared to the corresponding standard profiles of Joint Roughness Coefficient (JRC) suggested by Barton & Choubey[4]. The joint roughness coefficient values were then used for the determination of peak friction angle of each slope as recommended by Ailie Sofyiana et al[5]. The modes of failure for each slope were determined by conducting kinematic analysis which is by plotting stereographic projections of each slope using the Dips 6.0 software by Rocscience. The results were interpreted to identify the types of failure modes based on study by Wyllie & Mah (6). The possible major types of slope failures are wedge failure, plane failure, toppling failure and circular failure.

IV. RESULTS AND FINDINGS

The three slopes at the iMix Quarry were labelled as M1, M2 and M3 whereas the three slopes at the Miaw Yuan Chan Lin Temple were labelled as T1, T2 and T3. Fig. 2 shows the locations of the study area while Fig. 3, 4, 5, 6, 7 and 8 show the photos of each slope. Based on the discontinuity survey conducted, stereographic projections were plotted and the orientation of major joint sets and slope face for slopes M1, M2, M3, T1, T2 and T3 were determined and shown in Fig. 9, 10, 11, 12, 13 and 14 respectively. Table 1 shows the summary of the kinematic analysis for all slopes.

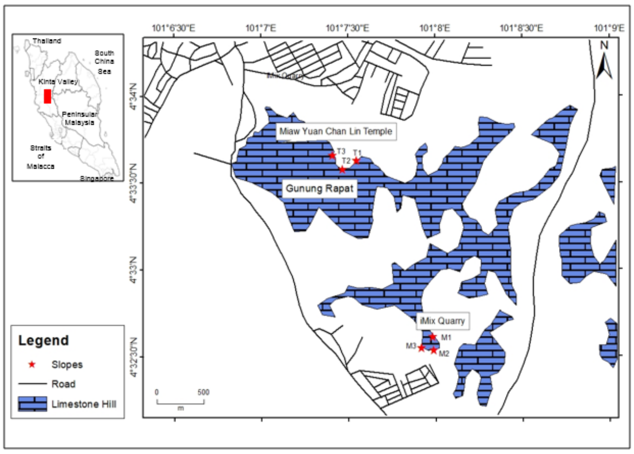

Fig. 2: Location map for the six slopes of the study area in Gunung Rapat limestone hills, Ipoh, Perak, Malaysia

Fig. 3: Slope M1, iMix Quarry, Ipoh, Perak, Malaysia

Fig. 4: Slope M2, iMix Quarry, Ipoh, Perak, Malaysia

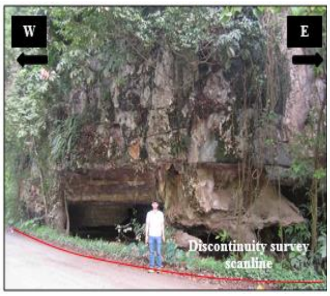

Fig. 5: Slope M3, iMix Quarry, Ipoh, Perak, Malaysia

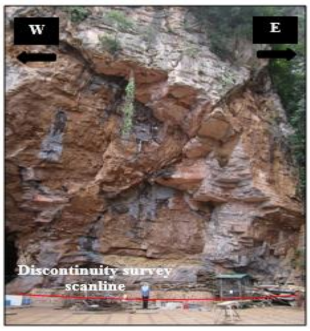

Fig. 6: Slope T1, Miaw Yuan Chan Lin Temple, Ipoh, Perak, Malaysia

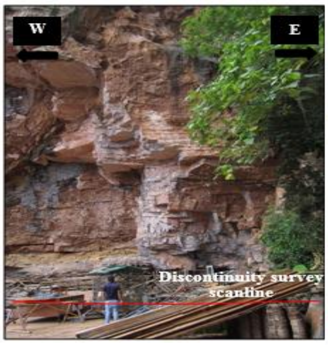

Fig. 7: Slope T2, Miaw Yuan Chan Lin Temple, Ipoh, Perak, Malaysia

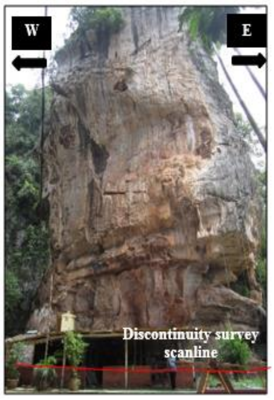

Fig. 8: Slope T3, Miaw Yuan Chan Lin Temple, Ipoh, Perak, Malaysia

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A. Kinematic Analysis

Kinematic analysis was done by plotting stereographic plots for each slope to determine the major joint sets and to predict the potential mode of failures. The values of the peak friction angles ($\emptyset_p$) for respective slopes were determined by using the polynomial equation developed by Ailie Sofyiana et al.(5). The equation is $\emptyset_p = -0.0635JRC^2 + 3.95JRC + 25.2°$ where JRC is the joint roughness coefficient value. Based on the calculation, the peak friction angle for slopes M1 and M2 is 43° with a JRC value of 5 while peak friction angle for slope M3 is 46° with a JRC value of 6. Meanwhile, the peak friction angle for slope T1, T2 and T3 is 46° with a JRC value of 6. Fig. 9, 10, 11, 12, 13 and 14 show the results of kinematic analysis for respective slopes.

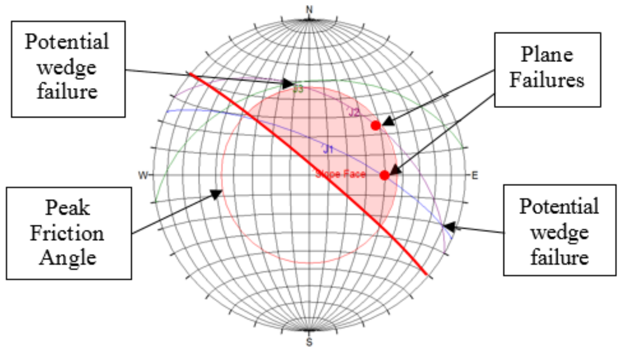

Fig. 9: Kinematic analysis for slope M1, using peak friction angle of 43°.

The dip/dip direction of the slope face is 85°/ 40°. The shaded region shows the zone of critical area. The mode of failure identified is plane failure. There are also potential wedge failures outside the zone of critical area.

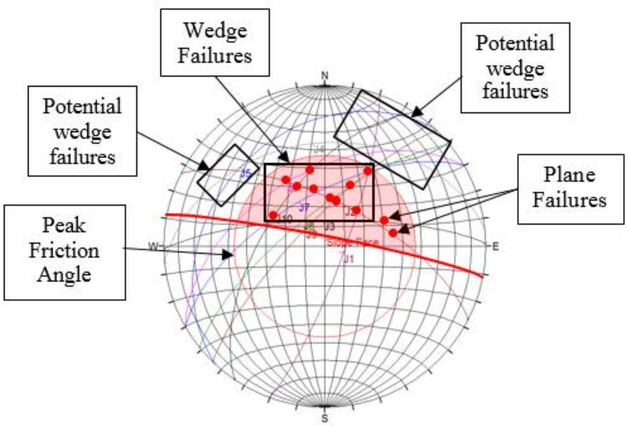

Fig. 10: Kinematic analysis for slope M2, using peak friction angle of 43°.

The dip/dip direction of the slope face is 85°/ 11°. The shaded region shows the zone of critical area. The modes of failures identified are plane and wedge failures. There are also potential wedge failures outside the zone of critical area.

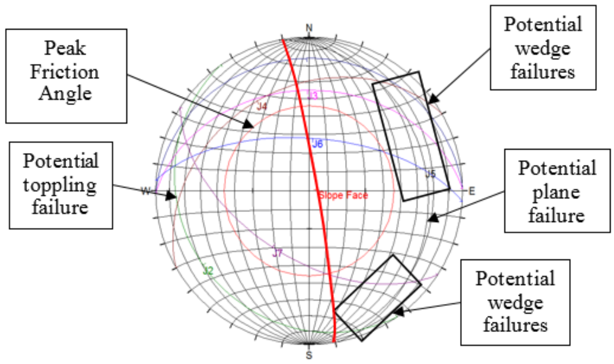

Fig. 11: Kinematic analysis for slope M3, using peak friction angle of 46°.

The dip/dip direction of the slope face is 85°/ 80°. There are potential plane and wedge failures identified on the eastern and south-eastern part of the stereonet while the potential toppling failure is identified on the western part of the stereonet.

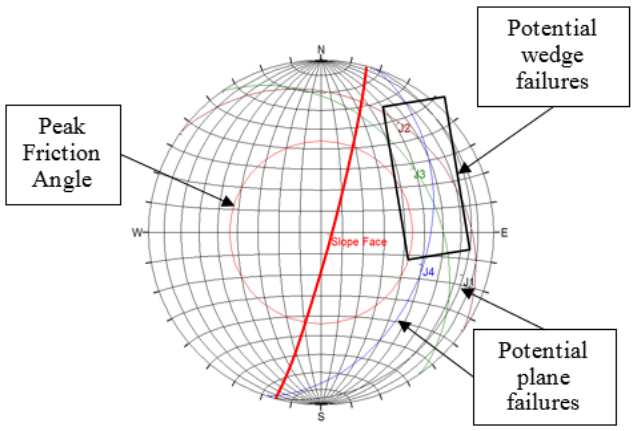

Fig. 12: Kinematic analysis for slope T1, using peak friction angle of 46°.

The dip/dip direction of the slope face is 85°/ 105°. There are potential plane and wedge failures identified on the eastern and south-eastern part of the stereonet.

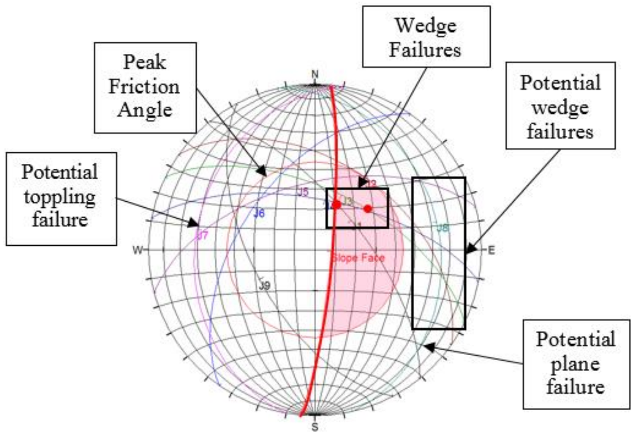

Fig. 13: Kinematic analysis for slope T2, using peak friction angle of 46°.

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The dip/dip direction of the slope face is 82°/ 95°. The shaded region shows the zone of critical area. There is one mode of failure identified, which is the wedge failure. There are also potential wedge, and plane failures on the eastern and south-eastern part of the stereonet while the potential toppling failure is identified on the western part of the stereonet.

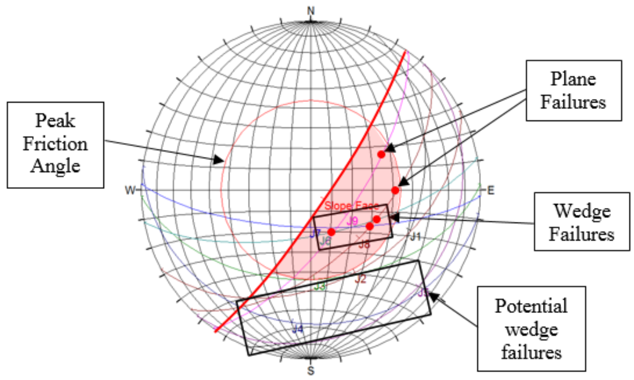

Fig. 14: Kinematic analysis for slope T3, using peak friction angle of 46°

The dip/dip direction of the slope face is 82°/ 124°. The shaded region shows the zone of critical area. There are two modes of failure identified, which are the plane and wedge failures. There are also potential wedge failures identified on the south-eastern and southern part of the stereonet.

Table I: Summary of Kinematic Analysis for slopes M1, M2, M3, T1, T2 and T3

Slope	Mode of Failure	Friction Angle	Joint Roughness Coefficient (JRC)
M1	Plane failure (72°/024°)	43°	5
M2	Plane failure (48°/030°)	43°	5
	Plane failure (67°/027°)	43°	5
	Plane failure (71°/ 359°)	43°	5
	Wedge failure (23°/224°)	43°	5
	Wedge failure (33°/ 203°)	43°	5
	Wedge failure (22°/ 188°)	43°	5
	Wedge failure (36°/151°)	43°	5
	Wedge failure (38°/169°)	43°	5
	Wedge failure (30°/116°)	43°	5
	Wedge failure (27°/172°)	43°	5
	Wedge failure (32°/156°)	43°	5
M3	-	46°	6
T1	-	46°	6
T2	Wedge failure (63°/239°)	46°	6
	Wedge failure (24°/204°)	46°	6
T3	Plane failure (57°/135°)	46°	6
	Plane failure (82°/124°)	46°	6
	Wedge failure (23°/329°)	46°	6
	Wedge failure (33°/301°)	46°	6

V. CONCLUSION

From the kinematic analysis assessment, planar failures were identified on slope M1, M2 and T3. Besides, wedge failures were also identified on slope M2, T2 and T3. This is due to the high intensity of discontinuities and unfavourable dip orientations of the slope faces. Even though slope M3 of the iMix Quarry and slope T1 of the Miaw Yuan Chan Lin temple do not show any mode of failures in the critical zone of the kinematic analysis, many potential wedge, planar and toppling failures were identified[6]. Generally, all the limestone slopes exhibit hazardous geological features that may contribute to slope failure and rock fall. The friction angle values used in this study is relatively high due to its high Joint Roughness Coefficient value. However, future physical and chemical weathering can decrease the Joint Roughness Coefficient and peak friction angles of the slopes. Thus, the potential failures identified may undergo failure in the future.

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