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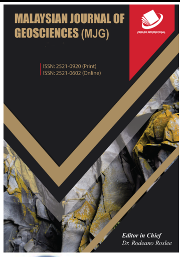

COMPARISON OF DIFFERENT TYPE OF FRICTION ANGLE IN KINEMATIC ANALYSIS

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ABSTRACT

The kinematic analysis is a method in determining the types of failure modes for a rock slope. This analysis is referring to the motion of bodies without reference to the forces that cause them to move and depending on the relationship between slope geometry and internal friction angle of discontinuity plane or failure. The selection of friction angle type for kinematic analysis is an important aspect in term of cost, availability and reliability of testing, equipment and result. Then, kinematic analysis has been conducted by using the peak, basic and conventional friction angles values from triaxial test, tilt test and assumption, respectively for ten (10) selected slopes. Finally, the cheaper, most available and reliable result was shown by the basic friction angle and recommended for kinematic analysis.

KEYWORDS

Basic friction angle, Tilt testing, Crocker Formation, Kinematic analysis.

1. INTRODUCTION

Slope stability analysis has been around for a long time for soil slopes such as limit equilibrium method to analyses the soil slope stability which was adapted to rock slope stability analysis. Methods such as kinematic analysis, finite element analysis and limit equilibrium analysis are widely used.

Markland and Hocking developed a test for identifying important pole concentrations of discontinuities. Kinematical analysis refers to the motion of bodies without reference to the forces that cause them to move and depending on the relationship between slope geometry and internal friction angle of discontinuity plane or failure. Kinematic analysis is based on Markland's test which is a technique to estimate the relative stability of the body and the potential rock slope failure based on stereonet (plane, wedge, toppling failures) [1].

Markland's test shows that, a plane failure is likely to occur when a discontinuity dips in the same direction (within 20°) as the slope face, at an angle gentler than the slope angle but greater than the friction angle along the failure plane; a wedge failure may occur when the line of intersection of two discontinuities, forming the wedge-shaped block, plunges in the same direction as the slope face and the plunge angle is less than the slope angle but greater than the friction angle along the planes of failure; a toppling failure may result when a steeply dipping discontinuity is parallel to the slope face (within 10°) and dips into it [1].

There are few types of usage for friction angles in kinematic analysis such as peak, residual, conventional and basic friction angles of discontinuities. The peak, residual and basic friction angle can be estimated from the triaxial test, uniaxial compressive test, direct shear test and tilt testing. The peak friction angle is a common input in estimating the mode of failure as well as the conventional friction angle (30°) as used by many researchers. The mode of failures by the usage of conventional friction angle in kinematic analysis for the Crocker, Temburung and Trusmadi formations are wedge, planar and toppling failures [2-12].

There is some aspect in selecting the type of friction angle that might be considered before conducting kinematic analysis. The cost of estimating friction value; the availability of testing equipment and the reliability of the mode of failure or result. In order to identify the safest and cost effective type of friction angle for kinematic analysis, ten (10) rock cut slopes of the Crocker formation around Menggatal-Tuaran area, Sabah (Figure 1 and 2) are selected.

The study area is mostly underlain by the Crocker formation of Late Eocene-late Early Miocene ages and Quaternary Alluvium along the river and tributaries and low land area. The Crocker formation is a turbidite of deep sea deposit. This formation consists of interbed sandstone, siltstone and shale units. Bouma sequence and sole mark can be found in some beds. The thickness of rock unit differs from one outcrop to another. The formation is highly folded and faulted to form a thrust-fold system in Sabah. The alluvium is observed in the stream bed and originated from different rocks around the study area. These deposits consist of gravel, sand, silt, clay and other materials.

2. MATERIAL AND METHOD

Generally, the methodology of this study consists of field study, laboratory test and data analysis. Field study includes geological mapping and rock sampling. The rock samples were taken from slope E because of weathering grade (grade I, fresh rock) and all selected slopes consists of same fine greywacke lithic sandstone [3]. Some of rock sample (hand specimen) is prepared for thin section before examined under polarized microscope (Nikon Axio-lab 10) for petrographic study. Discontinuities survey is conducted as an observation and measurement studies on given rock cut slope which involved discontinuities quantification based on ISRM before kinematic analysis [13]. The types of discontinuities parameters considered were the types, strike and dip of the discontinuities. The method used for discontinuities survey is random survey method and the data gathered were jotted down in a data sheet.

The orientation data of the discontinuities were then pole plotted on the stereogram to determine the types of discontinuity planes or sets via Dips 7.0 software [2]. Finally, the planes or sets of discontinuities analyzed kinematically to identify the modes of failure such as planar, wedge, toppling or circular failures [14].

The rock core and block samples preparation for triaxial testing and tilt testing are conducted in laboratory test, respectively. The rock samples collected for this study are rock blocks (at least 15mm x 10mm x 20mm dimension) for core and block samples. Samples of sandstone from Crocker formation were prepared in the form of fresh clean sawn surfaces obtained using a diamond core bit and saw.

The samples were cut with perfectly straight by carefully preparing and using polishing machine and sufficiently large slabs to come out complete contact. Occasionally, the contact occurs in a small zone in such a way that the upper slab rotates around an axis located in the center of the reduced contact zone.

Triaxial test was conducted according to ISRM in Hoek cell as shown in Figure 3 [15]. The tilt test is also following ISRM but the samples types and arrangement [16]. The test is called as 'square type' which performed on square base slabs with 50mm x 50mm x 20mm dimensions (Figure 4).

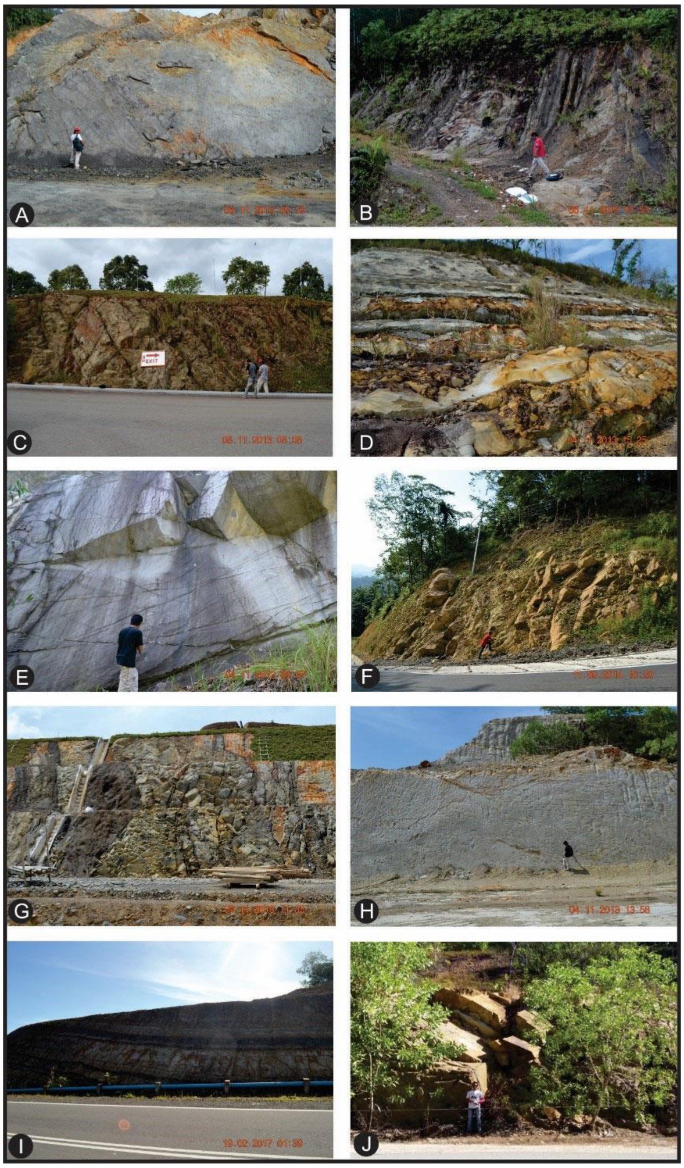

Figure 1: The selected slopes. Note: A-slope 1; B- slope 2; C- slope 3; D- slope 4; E- slope 5; F- slope 6; G- slope 7; H- slope 8; I- slope 9; J- slope 10.

A detailed description of the procedures used for performing tilt tests as follows.

a) The specimens were cut according to the indicated dimensions using diamond core drill bits and saws.
b) The lower specimens were placed on the plane-tilting platform in the horizontal position and secured in place.
c) The upper specimens were placed on the fixed specimens in the horizontal position.
d) All the samples are marked to monitor the movement and rotation during tilting process.
e) The platform was progressively tilted at the rate of 0.4 mm/s until the upper specimens began to slide, and the tilt angle of the platform was recorded. Only tests corresponding to displacements of at least 10% of the sample length were taken into account.
f) Each test was repeated for five (5) times.
g) Results were calculated as the mean of the results for all the repetitions of each test.

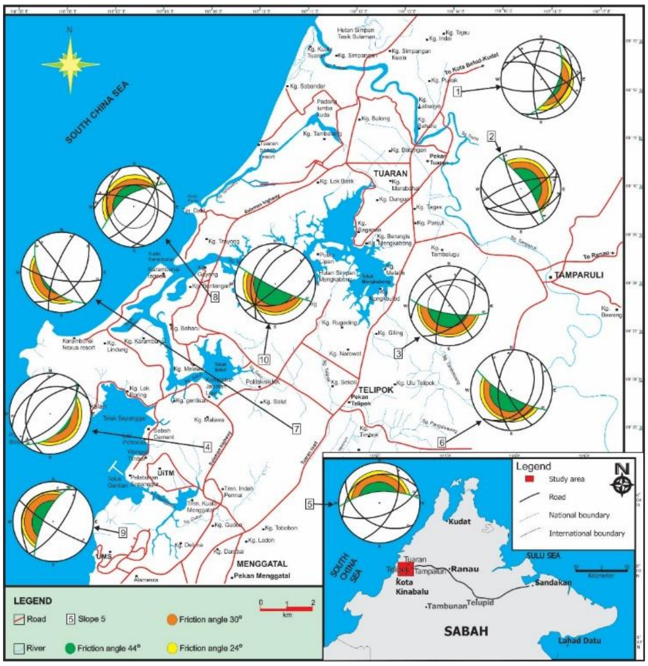

Figure 2: The slopes location and stereonet plots of Markland test.

Figure 3: The coring machine, polishing and Hoek cell for triaxial test.

Figure 4: The tilt testing of square types samples.

3. RESULT

The result and average peak friction angle and basic friction angle by triaxial test and tilt testing are shown in Table 1 and 2, respectively. The average peak friction angle and basic friction angle by triaxial test and tilt testing are 44^{o} and 24^{o}, respectively. But, for this study, the well-known conventional frictional angle of 30^{o} is also used in kinematic analysis as comparison. The results of kinematic analysis for these three (3) types of friction angle are shown in Table 3 and Figure

Table 1: The peak friction angle value by triaxial test.

Sandstone		Confining Pressure (MPA)	Stress (MPA)	Strain (%)	Peak friction angle, φ (degree)
Fine	DJ1A1	1.0	42.92	1.11	37
	DJ1A2	2.0	64.57	1.97	
	DJ1B1	1.0	150.66	1.46	51
	DJ1B2	2.0	171.70	2.13	
	DJ1B3	4.0	176.59	2.39	
Average					**44**

The result of kinematic analysis shows that the modes of failure are wedge, toppling and planar failures. There is no potential mode of failure in kinematic analysis by using peak friction angles, but the wedge failure has been found by conventional friction angles. The three modes of failure i.e. wedge, toppling and planar are identified as potential by using both conventional and basic friction angle.

Table 2: The basic friction angle value by tilt testing.

Sample	Basic friction angle, ϕ_b	Tests with rotation, sliding or resettlement (%)	Sample	Basic friction angle, ϕ_b	Tests with rotation, sliding or resettlement (%)
DJ1A	30	0	DJ1G	21	0
DJ1B	30	0	DJ1H	21	0
DJ1C	28	1	DJ1I	21	0
DJ3D	25	0	DJ1J	21	0
DJ1E	26	1	DJ1K	23	0
DJ1F	23	0	DJ1L	23	1
AVERAGE	**24**	**25**			

Table 3: Kinematic analysis result for three (3) type's friction angle.

Slope (face = S/D)	Friction angle	DC (S/D)	Failure	DC or DC intersection	Slope (face = S/D)	Friction angle	DC	Failure	DC or DC intersection
1 (25/55)	Peak	B (79/58) J1 (324/86) J2 (30/19) J3 (295/60) J4 (282/21) J5 (331/86)	-	-	6 (120/70)	Peak	B (20/38) J1 (150/73) J2 (71/82) J3 (183/53)	-	-
	C		W	BJ2		C		W W	BJ1 J1J2
	Basic		W W W	BJ2 BJ1 J1J2		Basic		W W W	BJ1 J1J2 BJ3
2 (333/85)	Peak	B (60/68) J1 (253/70) J2 (64/30) J3 (153/75)	-	-	7 (152/50)	Peak	B (40/60) J1 (110/75) J2 (332/70) J3 (215/50)	-	-
	C		-	-		C		-	-
	Basic		W	BJ1		Basic		W	BJ3
3 (100/75)	Peak	B (199/75) J1 (45/58) J2 (324/85) J3 (250/25)	W	J1J2	8 (225/68)	Peak	B (39/66) J1 (288/71) J2 (162/23) J3 (266/34)	-	-
	C		-	-		C		-	-
	Basic		W W	J1J2 BJ1		Basic		W W W	J1J2 J1J3 J2J3
4 (40/40)	Peak	B (225/75) J1 (45/58) J2 (324/85) J3 (250/25)	-	-	9 (209/77)	Peak	B (35/78) J1 (217/22) J2 (36/75) J3 (123/77)	-	-
	C		-	-		C		-	-
	Basic		T	B		Basic		P T	J1 B
5 (266/72)	Peak	B (25/50) J1 (123/34) J2 (70/55) J3 (255/30)	-	-	10 (115/84)	Peak	B (48/78) J1 (76/35) J2 (205/60) J3 (190/40)	-	-
	C		P T	J3 B		C		W W	BJ1 BJ2
	Basic		P T	J3 B		Basic		W W W W W	BJ1 BJ2 J1J3 BJ3 J2J3

Note: S/D-strike/dips; C-conventional; DC-discontinuity; W-wedge; P-planar; T-toppling

4. DISCUSSION

In order to highlight the safest and cost-effective type of friction angle for kinematic analysis, there is few aspects must be considered. First, the cost for conducting the testing in the determination of friction angles. Second, the availability of testing equipment and finally, the reliability of the result.

In this study, the peak and basic friction angle have been obtained by triaxial and tilt tests, respectively. The triaxial test is using the costly 'Hoek cell' machine compare to tilt testing. This shows that, the cost for basic friction angle is cheaper than peak friction angle. The availability of testing equipment is depending on their price, where the cheaper tilting machine can be found in many laboratories compares to Hoek cell. This has showing that the basic friction angle is easier to recover compare to peak friction angle. The price and availability for conventional friction angle is ignore because it is just an assumption or without any testing.

There are huge differences in the mode of failure from kinematic analisis for these three (3) types of friction angle as shown in Table 3. The expensive and difficult to recover peak friction angle is not showing any potential mode of failure except the wedge failure in slope 3. This means, the selected slopes are kinematically stable and doesn't need protection and stabilization measures or cost in term of slope design.

The most commonly used conventional friction angle has been showing potential wedge, toppling and planar failures except in slope 2, 3, 4, 7, 8 dan 9. The slopes are partly stable or 60% of the slope is stable and without protection and stabilization measures. This shows that, the usage of conventional friction angle is moderately recommended because the value is only assumption and questionable in representing real friction angle value for a discontinuity plane in the rock mass. But, it is suitable as an alternative in early design, low cost, fast or temporary projects.

The wedge, toppling and planar mode of failures are also potential kinematically when using basic friction angles for the selected slopes. This shows that the slopes are considered unstable. The potential mode of failure by conventional and peak friction angle is includes in this simple and cheap basic friction angle as shown in slope 1, 3, 5, 6 and 10. The results can be interpreted as comprehensive and reliable in term of safety and cost. For the purposes of safety, the more identified potential mode failure is better than less, even though the cost for stabilization and protection are high. Investing high cost for protection and stabilization measures in construction phase are better than repairing and reconstructing the slopes in the future.

5. CONCLUSION

The modes of failure for selected slopes by kinematic analyses are wedge, toppling and planar failures. The basic friction angle is recommended for kinematic analysis due to its operational cost, availability of testing equipment and reliability of result.

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