Geological Behavior (GBR)

DOI: http://doi.org/10.26480/gbr.01.2020.13.17

ISSN: 2521-0890 (Print)
ISSN: 2521-0491 (Online)
CODEN: GBEEB6

RESEARCH ARTICLE

SLOPE STABILITY ASSESSMENT USING MODIFIED D-SLOPE METHOD OF WESTERN PART OF SANDAKAN, SABAH

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ARTICLE DETAILS

Article History:

Received 01 January 2020
Accepted 06 February 2020
Available online 04 March 2020

ABSTRACT

Slope stability assessment using modified D-Slope method is been conducted on five (5) rock slopes from Sandakan, Sabah. D-slope method comprises of G-Rating determination and Potential Instability. G-Rating includes 17 parameters of field observation and laboratory analysis to assess the slope condition. Kinematic analysis is used for Potential Instability analysis to determine the type of failures for each slope. This later is to determine the level of slope's risk: No Risk, Low Risk, Moderate Risk or High Risk. Based on the results of G-Rating, only slope C1 and C2 have value more than 0.4 while other slopes have less than 0.4 which indicates stable slopes. Based on kinematic analysis, slope C1 and C3 experienced wedge failures, slope C4 with toppling failure, slope C5 with wedge/planar failures and no failure shown for slope C2. D-slope analysis indicates that slope C1 is considered as Low Risk with mitigation suggestions of stream system inspection and vegetation on exposed area of the slopes, while other slopes (C2, C3, C4 and C5) have no suggestion for mitigation as been assessed as No Risk.

KEYWORDS

Modified D-Slope, Sandakan Formation, G-Rating, Potential Instability

1. INTRODUCTION

Weathering process is one of the factors contributed to the slope failure due to the existence of discontinuities on slope materials. Slope materials such as rocks or soils received average temperature of 21°C to 34°C daily with more than 2500 mm of yearly average rainfall distribution to experience extensive weathering process which able to differ the slope's strength thus may influence to its failure. Slope failures are considered as common disaster which is frequently occurred; when the slope is steeper than its gravity which holds the load to stay put (Rodeano, 2004). It is controlled by discontinuities which reduce the shear strength of the slope such as the appearance of faults, folds and fractures. Sheared shale in fault zone also acted as a medium for slope failure process (Turner and Schuster, 1996; Tating, 2003).

Modified D-Slope system is introduced based on original D-Slope method to assess the rock slope stability (Erfen and Malik, 2008; Husaini, 2002). The modified system is consists of suitable method from field studies and laboratory analysis by taking geological, geotechnical and hydrogeology data into consideration to determine the risk hazard value (G-Rating). The system also used kinematic analysis and discontinuities survey for Potential Instability (PI) which then combined with G-Rating value, to classify the slope as No Risk, Medium Risk, Medium Risk and High Risk (Bujang et al., 2008). The modified system is based on 13 parameters from field data with four (4) additional parameters from laboratory analysis (porosity, rock's strength, micro-petrography and micro-fractures index) to be included to study the potential of slope's instability. Microfractures will increase throughout the weathering grade which accelerates the formation of porosity with smaller distance of fractures and decrease the rock's strength (Kamoo and Akhir, 1990).

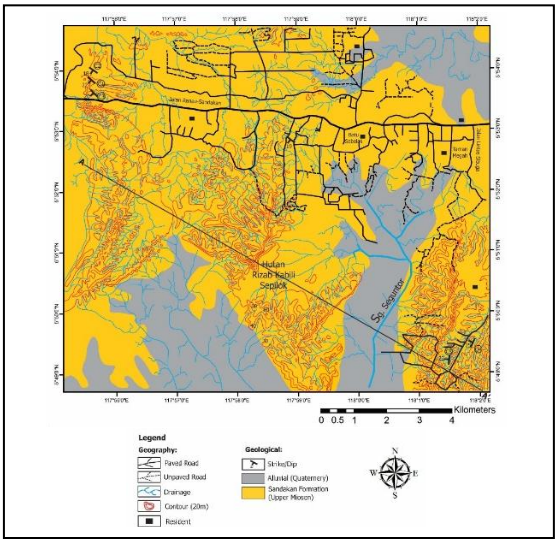

Figure 1: Geological map of the study area

The study area is located at western part of Sandakan, Sabah which is bounded by 5° 49'N – 5° 54'N and 117° 56'E – 118° 2'E (Figure 1). The study area includes Gum-Gum and Ulu Sibuga area which consists of Sandakan Formation and Quaternary- aged alluvium deposition. Sandakan Formation is formed during Early Miocene which is younger and overlying

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Cite the Article: Hennie Fitria Wulandary Soehady Erfen, Amirul Adlie bin Mohd Rosli (2020). Slope Stability Assessment Using Modified D-Slope Method Of Western Part Of Sandakan, Sabah. *Geological Behavior, 4(1): 13-17.*

unconformably on Garinono Formation (Haile and Wong, 1965). Sandakan Formation consists of several units, namely thick sandstones unit, thick mudstones unit and interbedded of sandstones and mudstones unit with little appearance of carbon and conglomerate (Collenette and Goh, 1967). This confirmed the sedimentation interpretation which stated that Sandakan Formation is shallow water and deltaic deposition environment based on fine-grained sandstones found in the study area (Chung, 1968).

2. Materials and Methodology

Previous research is been conducted in the early study to understand the study area and related methodology to be used for this study. Base map and geological maps are produced before fieldworks started. Base map contains geographical information such as stream, topography and transportation system while the geological map shows the distribution and boundary of rock units in the study area. Fieldwork is crucial in this study to obtain detailed information on the study area including slope observation. Five (5) rock slopes are selected from Sandakan Formation to be observed on field based on modified D-Slope assessment system. Rock samples from each slope also are collected for laboratory analysis purposes.

There are two parts in D-Slope system which is the G-Rating value determination and Potential Instability (PI) analysis (Hussaini, 2002). Thirteen (13) parameters are set to be observed on field based on the type of rocks, weathering grade, existence of faults and joints, number of major sets, number of orientations, aperture, persistence, spacing of discontinuities, slope height, instability history, rainfall distribution and hydraulic condition. Additional parameters from laboratory analysis comprise of four (4) characteristics which are porosity, strength, micro-petrography and micro-fractures of slope materials which influenced to its instability is added to observe the internal condition of the slope.

The porosity and strength analysis are carried out based in International Standard of Rock Mechanics (ISRM) [11] where porosity analysis is to determine the percentage of pores through calculation of voids over total volume of rocks (ISRM, 1985). Meanwhile strength analysis is conducted using point load test where the samples are been cut into cubic size and place in between two vertical cones before the stress is applied. Microfabric analysis is also conducted in this study to determine the micro-petrography and micro-fractures index of rocks by using thin section and scanning electron microscope (SEM). Micro-petrography index is determined by the ratio of primary mineral to secondary minerals, while micro-fractures index is to determine the number of microfractures presence along 1 mm in the rock's thin section. The presence of secondary minerals and the higher number of microfractures show the low strength of rocks which affects the slope stability.

Therefore, there are 17 parameters of slope characteristics to be observed internally and externally to assess the slope stability. Each parameter consists of rating value from 0 (minimum) to 2 (maximum) (Table 1). All values obtained then been added before divide it with the maximum value of all parameters (Formula 1).

G-Rating = $\Sigma R_i / \Sigma R_{max}$ (Formula 1)

Where:

ΣR_i = Total of each parameter's rating value

ΣR_{max} = Total of maximum rating value of all parameters

Table 1: Modified parameter used for G-rating determination

Parameters	Remarks	Rating Value
1. Geology	Igneous Rocks	0
	Metamorphic Rocks	1
	Sedimentary Rocks	2
2. Weathering Grade	1 – 2	0
	3 – 4	1
	5 – 6	2
3. Faults	None	0
	Minor	1
	Major	2
4. Joints	Minor	0
	Major	1
	Too Many	2
	< 2	0
	3 – 4	1
5. Number of Major Sets	> 4	2
6. Number of Orientation	< 2	0
	3 – 4	1
	> 4	2
7. Apertures (mm)	< 2	0
	2 – 4	1
	> 5	2
8. Persistence (m)	< 4	0
	4 – 10	1
	> 10	2
9. Spacing (mm)	< 200	0
	201 – 2000	1
	> 2000	2
10. Slope Height	< 5	0
	5 – 15	1
	> 15	2
11. Instability History	No proof	0
	Fragments of smaller rocks on the side of the slope	1
	Rock falls (Major/Minor) ~50m^3	2
12. Rainfall (mm/month)	< 100	0
	101 – 300	1
	>300	2
13. Hydraulic Condition	Dry	0
	Damp	1
	Dripping – flowing	2
14. Micro-petrography Index, I_{mp}	>12	0
	2 – 12	1
	<0.5 – 2	2
15. Micro-fractures Index, I_{fr}	<0.5 – 2	0
	2 – 10	1
	>10	2
16. Porosity (%)	< 15	0
	15 – 30	1
	>30	2
17. Strength (MPa)	>100	0
	12.5 – 100	1
	<12.5	2

Meanwhile Potential Instability analysis is based on the survey of discontinuities to determine failure type that occurred on slope (kinematic analysis). This analysis refers to slope's potential to fail with the existence of wedge, planar and/or toppling failure. If there is no failure detected, thus there is no instability potential (Table 2).

Table 2: Relation between slope failures with instability potential

Type of Failure	Instability Potential
None	No
Rotational Failure	Yes
Planar Failure	Yes
Wedge Failure	Yes
Toppling Failure	Yes

By combining both G-Rating value and PI analysis, the risk or stability of the slope can be assess and estimated. Level of risk is divided into four which are: Low Risk, Less Risk, Medium Risk and High Risk (Table 3).

Table 3: Classification of risk for rock slopes (Bujang et al., 2008)

Classification	G-Rating	Instability Potential	Risk Level
I	<0.4	Yes	No Risk
II		No	No Risk
III	0.4 – 0.5	Yes	Low Risk
IV		No	No Risk
V	0.5 -0.7	Yes	Medium Risk
VI		No	No Risk
VII	>0.7	Yes	High Risk
VIII		No	No Risk

After the stability has been assessed, suggestions to improve the stability are needed to prevent any slope failures. Based on D-Slope system, every risk level has certain suggestions and steps to take (Table 4). Each suggestion is a basic preparation to overcome slope failures in the future.

Table 4: Mitigation suggestions based on risk level of rock slopes (Hussaini, 2002)

Risk Level	Mitigation Suggestions
No Risk	• No suggestion
Low Risk	• Inspection of stream system • To plant cover plant on the exposed slopes • No immediate steps taken
Moderate Risk	• Inspection of stream system • To plant cover plant on the exposed slopes • Rock anchor • Soil nailing or stone pitching • Further inspection proceed
High Risk	• Immediate actions taken and further inspection conducted • Maintenance works started • Inspection of stream system • To plant cover plant on the exposed slopes • To build retaining walls

3. RESULTS AND DISCUSSIONS

3.1 Field Observation

Five (5) slopes are chosen along Gum-Gum and Ulu Sibuga area which comprise of Sandakan Formation (Figure 2). Field observation is conducted for observation of 13 parameters on field (discontinuities survey using scanline) where the appearance of discontinuities such as faults, joints, beddings and fractures are seen; besides the characteristics of the slope itself to assess the stability potential (Table 5). All slopes consist of interbedding of sandstones and shales with different thickness. Table 4 below shows the field observation of all slopes where the weathering grade is between III to IV with major fault structure can been seen at slope C1 and C2. Number of joints and orientation set are small while the aperture and persistence of joints show less than 2 mm and up to 10 meters respectively. All slopes received similar rainfall amount of 101 to 300 mm/month where slope C3 and C5 show instability history with the existence of small fragmented rocks on the foot of the slope. All slopes show the appearance of seepage either as in damp condition or water flow.

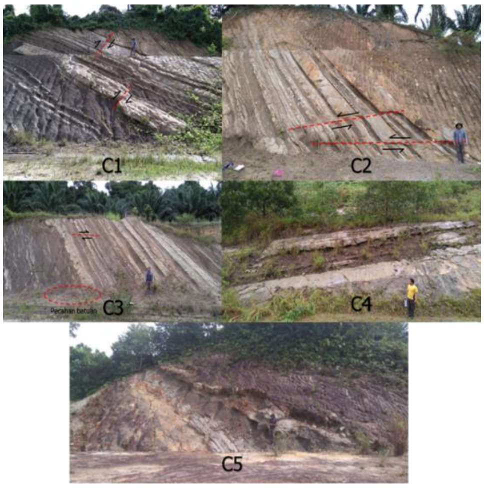


Figure 2: Slopes for research purpose (C1- C5: interbedded sandstones and mudstones of Sandakan Formation)

Table 5: Field observation of rock slopes in the study area

	C1	C2	C3	C4	C5
Geology	Sedimentary	Sedimentary	Sedimentary	Sedimentary	Sedimentary
Weathering Grade	3 – 4	3 – 4	3 – 4	3 – 4	3 – 4
Faults	Major	Major	Minor	None	None
Joints	Minor	Minor	Minor	Major	Major
No. of Major Sets	3 – 4	< 2	< 2	3 – 4	< 2
No. of Orientation	3 – 4	3 – 4	3 – 4	< 2	3 – 4
Apertures (mm)	< 2	< 2	< 2	< 2	< 2
Persistence (m	4 - 10	4 - 10	< 4	4 - 10	< 4
Spacing (mm)	< 200	< 200	< 200	< 200	< 200
Height (m)	5 - 15	5 - 15	5 - 15	5 - 15	5 - 15
Instability History	None	None	Fragments on side	None	Fragments on side
Rainfall (mm/month)	101 - 300	101 - 300	101 - 300	101 - 300	101 - 300
Hydraulic	Damp	Damp	Damp	Flow	Flow

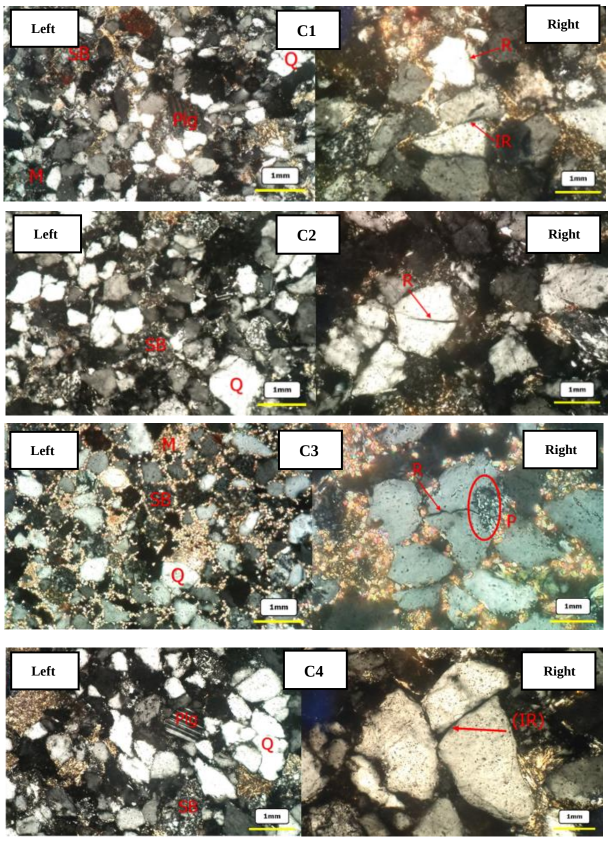
3.2 Microfabric Observation

Microfabric analysis is conducted to study the internal of rock's materials which influenced the physical properties of rocks. Micro-petrography and micro-fractures index were included in modified D-Slope system based on [12] which to see the ratio of primary minerals and secondary minerals in rocks; and the appearance of inter-fractures (between particles) and intra-fractures (within particles) (Table 6) (Fookes et al., 1971). Exposed rocks on weathering processes might altered the microfabric such as decrement of primary minerals, the formation of secondary minerals, existence of porosity and microfractures to develop failure planes (Erfen, 2017).

Table 6: Value of micro-petrography and micro-fractures index of rock samples

Slopes	Micro-petrography Index (I_{mp})	Micro-fractures Index (I_{fr})
C1	6.5	6.0
C2	9.7	8.0
C3	5.1	4.0
C4	8.6	9.6
C5	4.8	6.0

Rock samples were collected from weathering grade III to IV with fine particles size between 0.125 – 0.063 mm. The samples are dominated by quartz as primary minerals with 58% to 78% and the existence of 7% to 12% of secondary minerals. The microphotographs showed fragmented poly-crystalline quartz which surrounded with matrixes and clay minerals as pore filling (Figure 3- left). The abundance of quartz minerals indicates the resistance of rocks towards weathering process; however still show great presence of intra- and inter-fractures (Figure 3 – right). Therefore, the micro-petrography index for rocks from Sandakan Formation ranges from 4.8 to 9.7, while the micro-fractures index ranges from 4 to 9.



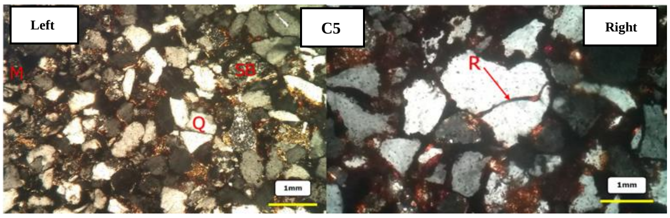


Figure 3: Photomicrographs of sandstones from Sandakan Formation (left) show interlocking of particles produce less microfractures with domination of quartz as primary minerals, while abundance of microfractures can be seen clearly on the grains (right). (Legends: Q = quartz, M = matrix, SB = rock fragments, Plg = plagioclase, R = intrafractures, IR = interfractures).

Rock samples of Sandakan Formation consist of kaolinite and illite (Figure 4) which formed during the weathering process or hydrothermal action of deposition of sediments (Azlan et al., 2017). The force between clay minerals can determine the strength of rocks where domination of clay minerals enables the particles to collide and fails. Existence of expanded clay even in small percentage may increase the plasticity of the material (Vacondios et al., 2007). Illite (mostly feldspar) is dominant in weathered argillaceous rocks with higher capability of water absorption than kaolinite. Kaolinite is inactive but stable clay mineral; is easily to disintegrate when in contact with weathering agents which can cause the slope failure (Roslee et al., 2010). The weathering process on feldspar to kaolinite allows some of main element Si in sandy materials to be replaced with Al, which reduce the bond between minerals and enable to form pores between particles (Rodeano et al., 2010).

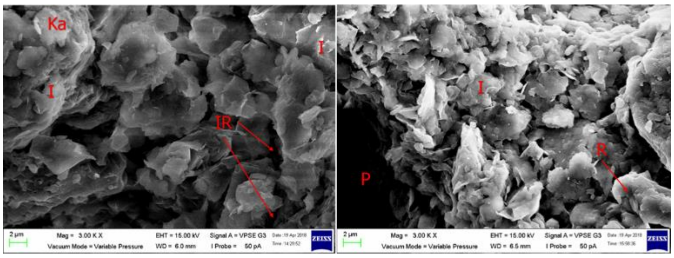


Figure 4: Scanning electron micrographs show the appearance of clay minerals kaolinite (K) and illite (I) with the existence of microfractures (IR/R) and pore spaces (P) (Magnification 3000X).

3.3 Laboratory Analysis

Laboratory analysis for this research purpose includes porosity and strength analysis. These two parameters are additional parameters from modified D-Slope method where the properties of the material are also included to assess the slope failure potential. Based on Table 7 below, all slopes showed porosity value of 21.66 % to 24.47%, except slope C3 which possess less than 20% of porosity (17.56%) and all these were classified as high porosity based on (Bell, 2007). This is due to the random arrangement of primary porosity in sedimentary rocks along with the formation of microfractures and dissolution of minerals during the weathering process.

Table 7: Porosity value of rock samples from slopes in the study area

Slopes	Porosity, n (%)
C1	21.66
C2	24.26
C3	17.56
C4	24.08
C5	24.47

For strength analysis, point load test is to test the rock's strength and is classified based on (Table 8) (ISRM, 1985; Bieniewski, 1975). Rock samples were collected on each slope to understand its strength to affect the slope stability. Based on Table 8, the rock samples show the classification from moderately strong to really strong with 41.85 MPa to 160.40 MPa value. Slope C3, C4 and C5 showed more than 100 MPa in strength due to the thick bedding of sandstones with no major faults seen on the slope compared to slope C1 and C2. The strength of rocks is influenced by the increment of pores which resulted to low density and allows the moisture to fill up the voids and acted as the lubricants for collision among particles.

Table 8: Strength value of rocks samples and its classification

Slopes	Uniaxial Strength Value (MPa)	Classification (ISRM, 1985)
C1	61.90	Strong
C2	41.85	Moderately Strong
C3	117.45	Really Strong
C4	158.93	Really Strong
C5	160.40	Really Strong

3.4 G-Rating Value Determination

G-rating value is determined based on data obtained from field and laboratory analysis which rated between 0 and 2. To obtain the G-rating value, individual parameters are added together before been divided to the total of maximum rating which is 34. Based on Table 9, slope C1 and C2 show G-rating value higher than 0.4, while other slopes C3, C4 and C5) have value less than 0.4. Small value of G-rating indicates more stable potential compared to higher value rating.

Table 9: Value of G-rating for rock slopes in the study area

Rock Slopes	Total of Individual Rating ($\sum$ Ri)	Total of Maximum Rating ($\sum$ Rmax)	G-Rating Value ($\frac{\sum Ri}{\sum Rmax}$)
C1	16	34	0.47
C2	15	34	0.44
C3	13	34	0.38
C4	12	34	0.35
C5	11	34	0.32

3.5 Potential Instability (Kinematic Analysis)

Potential Instability analysis was conducted after G-Rating is done by using kinematic analysis to determine the failure type occurred (Husaini, 2002). Based on the kinematic analysis of the study area, slope C1 and C3 showed wedge failures, C4 with toppling failure and C5 with both wedge and planar failure. No failure showed by slope C2 which indicated no potential instability (Table 10).

Table 10: Potential instability analysis for slopes in the study area

Slopes	Type of Failure	Potential Instability
C1	Wedge Failure	Yes
C2	None	No
C3	Wedge Failure	Yes
C4	Toppling Failure	Yes
C5	Wedge and Planar Failure	Yes

Planar failure occurs when rock mass is collided along fractured surface axis where the plane of failed discontinuities is parallel with slope face axis. The strike of failed axis must be in range of 20° from the strike of slope face. Toppling failures occurs when steeply dipping discontinuities rotates near the base of the slope followed by slippage between layers that dip away from the slope surface. Meanwhile, wedge failure occurs when there is any intersection between discontinuities. Rock mass will collide downwards along intersection planes and fall as wedge blocks. All slopes are only considered as failure potential when the discontinuities planes are within the critical zone (Figure 5).

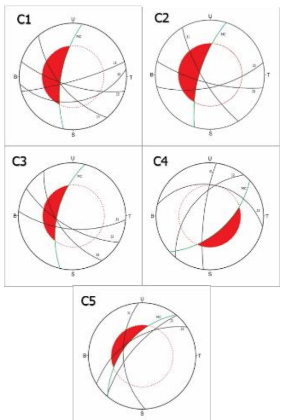


Figure 5: Type of failure on slope in the study area where slope S1, S2 and S3 show wedge failure while S4 and S5 show both wedge and planar failures.

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3.6 D-Slope Analysis

D-slope analysis is a technique to identify the risk level based on G-rating determination and Instability Potential. Table 11 shows the risk level where all slopes except C2 have potential to fail due to occurrences of wedge, toppling and planar failures. Only slope C1 shows low risk of failure while other slopes (C2, C3, C4 and C5) show no risk due to no failure and less than 0.4 value of G-rating value.

Table 11: Result of risk level of rock slopes in the study area

Slopes	G-Rating	Instability Potential	Type of Failures	Risk Level	Category
C1	0.47	Yes	Wedge Failure	Low Risk	III
C2	0.44	No	None	No Risk	IV
C3	0.38	Yes	Wedge Failure	No Risk	I
C4	0.35	Yes	Toppling Failure	No Risk	I
C5	0.32	Yes	Wedge and Planar Failure	No Risk	I

3.7 Mitigation Suggestions

Based on a study, there are suitable mitigation methods to prevent slope failure to occur (Table 3) (Hussaini, 2002). Each proposed mitigation methods are depending on the risk level achieved by the slopes. Slope C1 is classified as low risk which no immediate action but is suggested to make inspection on the stream system and vegetation on the exposed area to reduce the instability potential. As for other slopes, no suggestion is needed for there is no risk of slope failure to occur (Table 12).

Table 12: Mitigation suggestions proposed based on the risk level

Slopes	Risk Level	Category	Mitigation Suggestions
C1	Low Risk	III	• To inspect the stream system • To plant vegetation on the exposed area of the slope • No immediate action needed
C2	No Risk	IV	No suggestion
C3	No Risk	I	No suggestion
C4	No Risk	I	No suggestion
C5	No Risk	I	No suggestion

4. Conclusion

Modified D-Slope comprise of G-rating determination and Potential Instability using kinematic analysis, with additional of laboratory analysis (porosity and strength analysis) and microfabric observation (micro-petrographic and micro-fractures index) to assess the slope stability. G-rating determination show slope C1 and C2 have value more than 0.4 (0.47 and 0.44 respectively), while other slopes have value less than 0.4 which indicates no risk of failure. Slope C1 and C3 show wedge failures, C4 with toppling failure and C5 show both wedge and planar failures which indicate the potential instability of slopes except for slope C2 with no failure shown. Based on modified D-Slope analysis, slope C1 is classified as Low Risk (III) and other slopes as No Risk (IV and I). Mitigation suggestions are depends on the risk level of the slopes. Slope C1 (Low Risk) is suggested to inspect the stream system and plant vegetation on the exposed area of the slope as no immediate actions needed. Other slopes (C2, C3, C4 and C5) have no suggestion for mitigation as been assessed as No Risk.

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