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The Stability of Metasedimentary Rock in Ranau, Sabah, Malaysia

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Abstract - The aim of this paper is to determine the stability of slopes and to propose preliminary rock cut slope protection and stabilization measures for Paleocene to Middle Eocene Trusmadi Formation along Marakau-Kigiok in Ranau, Sabah, Malaysia. The rock of Trusmadi Formation is slightly metamorphosed and dominated by interbeds of sandstone with quartz vein (metagreywacke), metamudstone, shale, slate, sheared sandstone, and mudstone. The rock unit can be divided into four geotechnical units namely arenaceous unit, argillaceous unit, interbedded unit, and sheared unit. Twelve slopes were selected for this study. Geological mapping, discontinuity survey, kinematic analysis, and prescriptive measure were used in this study. Results of this study conclude that the potential modes of failures are planar and wedge. Terrace, surface drainage, weep holes, horizontal drain, vegetation cover, wire mesh, slope reprofiling, and retaining structure were proposed protection and stabilization measures for the slopes in the studied area.

Keywords: Trusmadi Formation, Ranau, metasedimentary rock, slope stability, mode of failure

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Introduction

The studied area is located in the southeast of Ranau Town which covers Marakau-Kinapulidan-Kigiok road alignment (Figure 1). Generally, the topography of the studied area can be divided into hilly and lowland areas with the elevation of above 500 m and below 500 m, respectively. The hilly topography is situated at the western, eastern, and southern parts of the studied area. The topography also represents the northeastern-southwestern ranges in Ranau area. The highest elevation is about 900 - 1,000 m. The lowland area is situated at the middle part of the studied area and mainly controlled by Liwagu River. This river provides alluvial plain during flooding event and concentrated at the western part of the studied area. This lowland area is usually used for agriculture activity such as paddy cultivation.

The studied area is underlain by the Trusmadi Formation and Quaternary alluvial deposit (Figure 1). The age of the Trusmadi Formation is Palaeocene to Middle Eocene (Jacobson, 1970; Sanudin and Baba, 2007). This formation consists of interbedded mudstone and sandstone units of sedimentary rock with various thicknesses from thin to very thick. The mudstone is more dominant than the sandstone.

The Trusmadi Formation also experienced a low grade metamorphism into green schist facies. The metamorphism caused the Trusmadi Formation has altered into metasedimentary and/

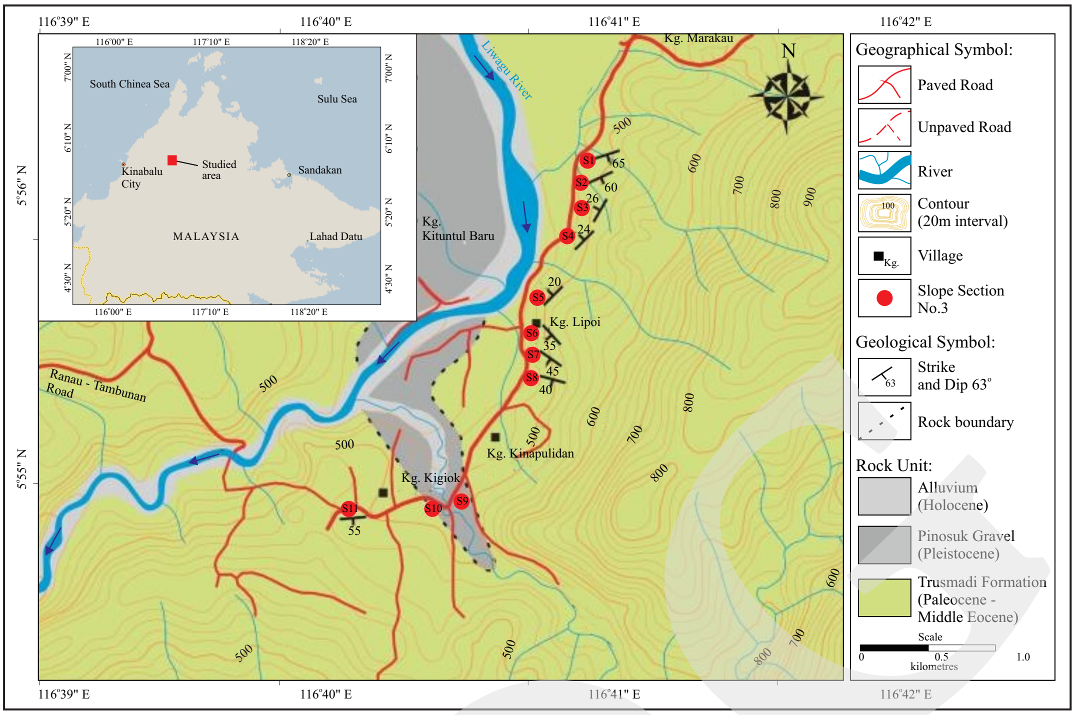

Figure 1. Geological map (from Yin, 1985) and sampling station of the studied area.

or metamorphic rock unit. The typical characteristic of Trusmadi Formation is the appearances of foliation (slaty cleavage) and quartz veins.

The fieldwork observation shows that the outcrops of metasedimentary rocks consist of mudstone, metamudstone, shale, and metasandstone with quartz vein. The metamudstone of the rock is represented by slate. The Trusmadi Formation was faulted and folded by moderate to high degree of deformations. These moderate and high degree of deformations are responsible for the formation of metasedimentary and metamorphic rock units, respectively. The high degree of deformation in the soft rock unit also contributed to the formation of fault zone and shear zones.

Quaternary deposits of Pleistocene and Holocene ages are distributed in the lowlandarea along the main rivers and flood plain in the studied areas. The field observation shows that the Pleistocene alluvial deposit is characterized by unconsolidated and poorly sorted sediment. The material comprises eroded and transported materials such as clays, sands, organics, pebbles, gravels, boulders, etc. The maximum thickness of this alluvial deposit is approximately 50 m (Hutchison, 2005).

Slope failure is the main factor in causing traffic interference, maintance coast to increase, property damage as well as lost of lives, especially in a weak and deformed rock formation such as metasedimentary Trusmadi Formation. Therefore, the main objectives of this study are to assess the stability and to propose protection and stabilization measures of rock cut slope along the road in the studied area.

Methods

Geological mapping, discontinuity survey, and a stereographic analysis have been used in this study. Geological mapping includes lithological and structural identification, measurement, and interpretation. A discontinuity survey has been conducted using a random method.

In a stereographic analysis, Dips V5.013 computer programme (Rocscience, 2003) of lower hemisphere spherical projection was used to perform the pole plot of discontinuity. The results obtained were used for the clustering of the discontinuity and identification of the discontinuity set or the average orientations of the discontinuity set.

To assess the relative stability and potential for future rock failures in the studied area, a graphical stereonet kinematic analysis by Markland (1972) has been carried out. The Markland test allows the orientation of joints, bedding planes, and fractures to be analyzed at numerous stations to discriminate which discontinuities are likely to provide failure surfaces for future rock failures. This method compares the orientation of the slope with orientations of rock discontinuities and internal friction angle (frictional component of shear strength) of the rock mass to see which fractures, joints, or bedding planes render the rock mass theoretically unstable.

Slope orientation, discontinuity set orientation, and friction angle of the Trusmadi Formation are the main parameters required in performing the Markland test. Data of the strike and dip values of slope have been obtained from the discontinuity survey and discontinuity sets from a pole plot. The slope face is shown as a great circle and friction angle is represented by an interior circle. A representative value of 30 degrees was selected for the internal friction angle along discontinuities in the meta- sedimentary Trusmadi Formation following Hoek and Bray (1981). Selections of slope protection and stabilization measures were conducted by using prescriptive measures (Yu *et al*., 2005) as well as the kinematic analysis result.

Slope Stability Assessments

The slope stability assessment was conducted on twelve slopes along the road (Figure 2). In this

Figure 2. Slope sections. (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; (k) slope 11 left; (l) slope 11 right.

slope stability assessment, the rock units (Trusmadi Formation and alluvial deposit) are also divided into five geotechnical units, *i.e.* arenaceous unit, argillaceous unit, interbedded unit, sheared unit, and alluvial unit (Figure 3). The first four units are collected from the Trusmadi Formation. The arenaceous unit consists of sandstone with quartz vein (metagreywacke) (Figures 4a and 4b), argillaceous unit of metamudstone and shale (Figures 4c and 4d), interbedded unit of metagreywacke and slate (Figure 4e), sheared unit of sheared sandstone and mudstone (Figures 4f, 4g, and 4h), and alluvial unit of alluvial deposit (Figure 4i). Some slopes are labeled as ‘a’ and ‘b’ due to the occurrence of thick argillaceous unit in a slope such as S2a and S2b (thick argillaceous unit). However, for overall slope, the units were represented by numbers.

<u>Slope geometry and geotechnical unit</u>

The summary of slope geometry and geotechnical unit are shown in Table 1. Slope S2 (55.6 m) and slope S11 left (3 m) are the highest and the lowest cut slopes in the studied area, respectively. The thickest arenaceous unit, argillaceous unit, interbedded unit, sheared unit, and alluvial unit were found in slopes S1 (70 m), S4 (55.8 m), S4 (111.6 m), S3 (81.3 m), and S9 (20 m), respectively.

<u>Kinematic analysis</u>

Discontinuities sets and mode of failures for the slopes are shown in Table 2 and Figure 5. The slopes consist of three to six sets of discontinuities, but undetermined for sheared unit (S3 and S5), argillaceous unit (S11 right), and alluvial unit (S9 and S10).

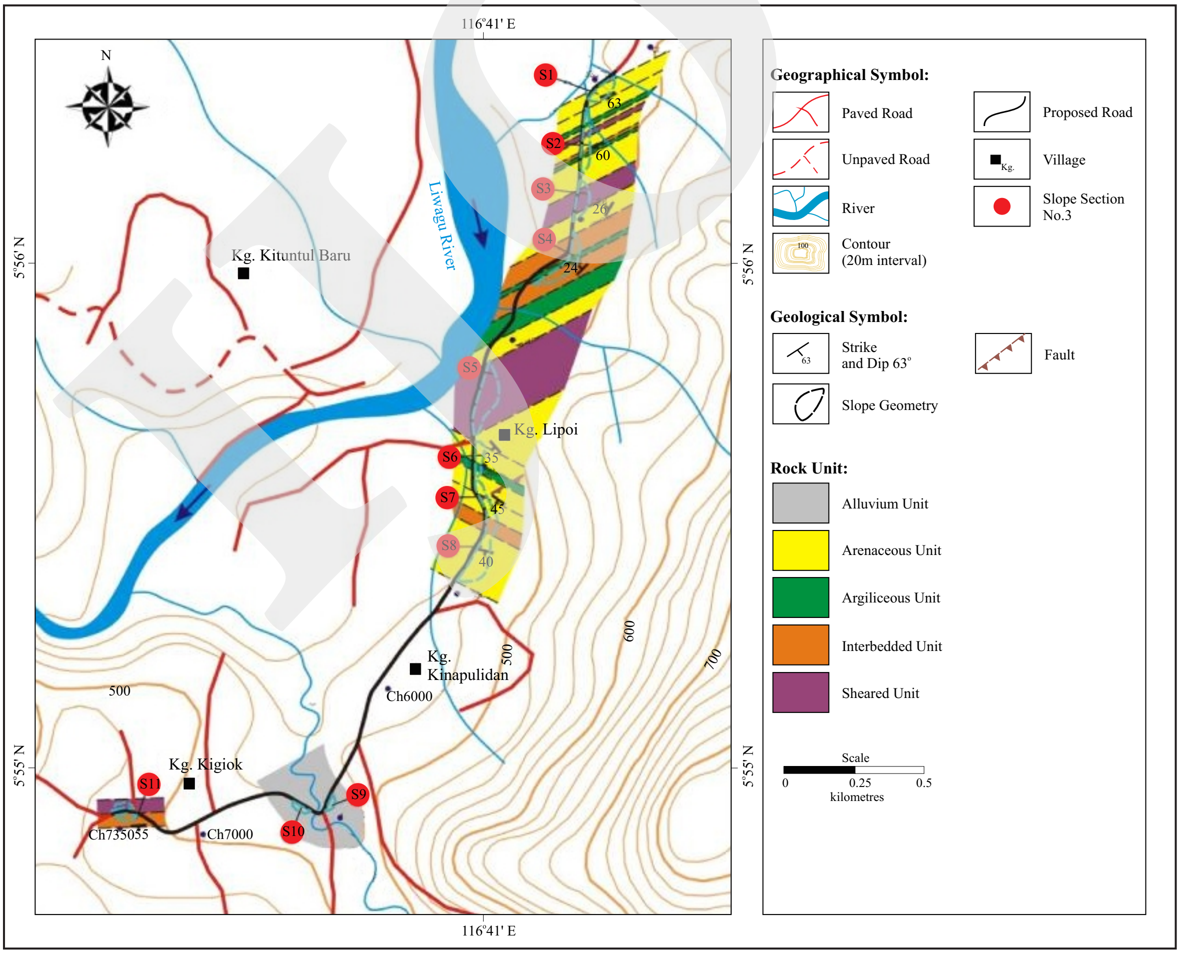

Figure 3. Geotechnical rock units along the road alignment.

Figure 4. Geotechnical units. (a and b) arenaceous unit; (c and d) argillaceous unit; (e) interbedded unit; (f, g, and h) sheared unit; (i) alluvial unit.

Table 1. Slope Geometry, Geotechnical Units, and Thicknesses

	Slope			Geotechnical Unit	
	Strike (º)	**Dip (º)**	**Height (m)**	**Type**	**Thick (m)**
S1	221	35	23.4	1	70
S2	185	41	55.6	1; 2; 1; 4; 1; 3; 2; 1	99.3; 19; 15.4; 22.4; 43.3; 13; 4.6
S3	186	58	29.8	4	89.3
S4	215	45	24.5	3; 2; 3	111.6; 55.8; 70.9
S5	185	48	11.9	4	155.8
S6	198	37	14.4	1; 2; 1	59; 34
S7	173	40	21.1	1	54.2
S8	206	40	34	3; 1	50.3; 94
S9	208	53	3	5	20
S10	295	50	4	5	1
S9	208	53	3	5	20
S10	295	50	4	5	1
S11	Left	301	35	10.8	3
S11	Right	121	35	3	4

Note: Type 1 - arenaceous unit; 2 - argillaceous unit; 3 - interbedded unit; 4 - sheared unit; 5 - alluvium unit

It is found that there are potential wedge failures in slope S2a, S4a, and S6a; but none for S1, S7, S8, and S11 left. Circular failures were found to occur in slope S3, S5, S9, S10, and S11 right.

Table 2. Discontinuities and Mode of Failures

Slope	Discontinuities			Mode of failure
	Set	Strike/Dip (o)	Unfavourable	
S1	J1; J2; J3; J4	76/50; 244/78; 280/78; 174/69	Nil	Nil
S2a	J1; J2; J3; J4; J5; J6	60/61; 132/70; 156/44; 227/67; 273/69; 330/72	J3J5	Wedge
S2b	Nil	Nil	Nil	Circular
S3	Nil	Nil	Nil	Circular
S4a	J1; J2; J3; J4; J5; J6	226/20; 297/75; 342/66; 53/70; 141/52; 160/40	J1J6	Wedge
S4b	Nil	Nil	Nil	Circular
S5	Nil	Nil	Nil	Circular
S6a	J1; J2; J3; J4; J5; J6	170/16; 244/50; 272/79; 15/35; 79/83;308/79	J2J3	Wedge
S6b	Nil	Nil	Nil	Circular
S7	J1; J2; J3; J4; J5; J6	78/64; 283/39; 145/28; 217/42; 199/73; 237/82	Nil	Nil
S8	J1; J2; J3; J4	142/41; 264/58; 290/53; 61/84	Nil	Nil
S9	Nil	Nil	Nil	Circular
S10	Nil	Nil	Nil	Circular
S11 L	J1; J2; J3	234/50; 83/46; 339/78	Nil	Nil

Note: (J1) discontinuity 1; (J2) discontinuity 2; (J3) discontinuity 3; (J4) discontinuity 4; (J5) discontinuity 5; (J6) discontinuity 6; (J3J5) intersection of discontinuity 3 and discontinuity 6.

Slope stability

The stability of cut slopes in the studied area is summarized in Table 3. Based on this study, eight out of twelve slopes are determined as stable slopes.

Slope protection and stabilization measures

The proposed slope protection and stabilization measures are summarized in Table 4. Most of terraces and surface drainage are suggested for high slopes.

The slopes that are dominated by arenaceous unit and alluvial unit are suitable for vegetation cover. Weep hole is proposed to argillaceous, sheared, and alluvial units. However, it should be added with horizontal drain for higher slopes. Wire mesh is suggested to be installed in fail slopes. Finally, soil nail is suggested for fail and high slopes. The entire fail slopes must be cut according to the proposed optimum slope angle, but the maintenance for those stable slopes should be carried out.

Results and Discussion

Based on the result from the field study and data analysis, it was found that most of the slopes along the road alignment are potential for the wedge failure and circular failure, except for slope S1, S7, S8, and S11 left. Generally, the slopes are considered stable except three slopes that have the potential for wedge failures. The expected circular failure slopes of argillaceous and sheared units are high but localized in nature, low in height, and small in volume.

Therefore, they will not much affect the infrastructures. The stability of the slopes in the road alignment is influenced by the types of geotechnical rock units, geological structures, weathering, erosion, groundwater, and slope geometry.

The Trusmadi Formation composed of sandstone interbeds with quartz vein (metagreywacke), meta-mudstone, shale, slate, sheared sandstone, and mudstone can be divided into four geotechnical units, *i.e.* arenaceous unit, argil-

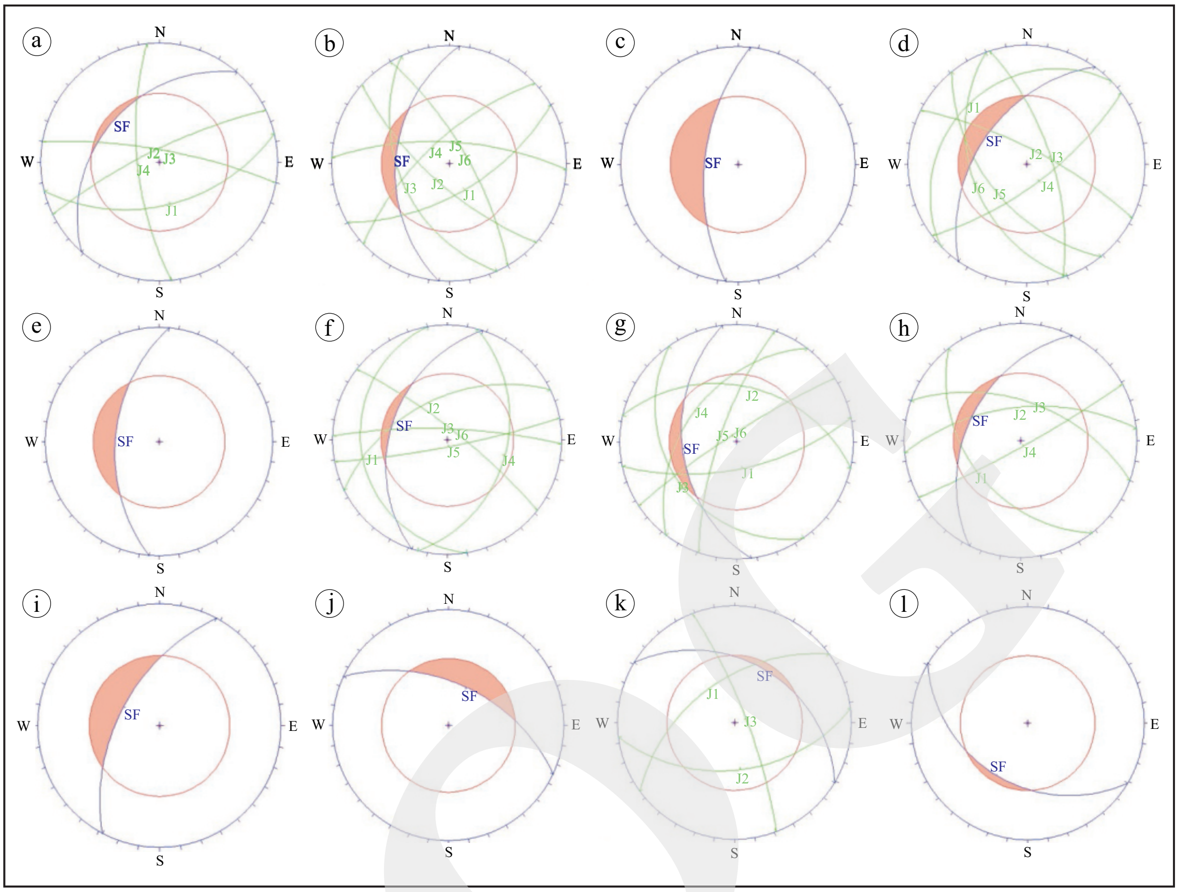

Figure 5. Result of the Markland test. Note: (a) slope S1; (b) slope S2; (c) slope S3; (d) slope S4; (e) slope S5; (f) slope S6; (g) slope S7; (h) slope S8; (i) slope S9; (j) slope S10; (k) slope S11L; (l) slope S11R; (J1) discontinuity 1; (J2) Discontinuity 2; (J3) discontinuity 3; (J4) discontinuity 4; (J5) discontinuity 5; (J6) discontinuity 6; (SF) slope face; mottled area- critical zone.

Table 3. Slope Stability

Slope	**Stability**
1	Stable due to underlying arenaceous unit, favourable discontinuity and absent of water seepage
2	Unstable due to potential wedge failure, occurrence of thick sheared rock mass unit and water seepage
2b	Stable because expected circular failure is localized
3	Unstable due to occurrence of water seepage and thick sheared unit which potential for circular failure
4	Unstable due to the occurrence of potentially wedge failure, water seepage and thick argillaceous unit
4b	Stable because expected circular failure is localized
5	Stable because of low slope although expected for circular failure but the material (debris) volume is small
6	Unstable due to potential wedge failure and thick argillaceous unit
6b	Stable because expected circular failure is localized
7	Stable because no potential failure
8	Stable because no potential failure
9	Stable because of low slope although expected for circular failure but the material (debris) volume is small
10	Stable because of low slope although expected for circular failure but the material (debris) volume is small
11R	Stable because no potential failure and the slope is low although expected for circular failure but the material (debris) volume is too small
11L	Stable because no potential failure and the slope is low

Table 4. Protection And Stabilization Measures

Slope	Protection and stabilization measures						
	Terrace and Surface Drainage	Vegetation Cover	Weep Holes	Horizontal Drain	Wire Mesh	Rock Bolt	Optimum Slope Angle
1	√	√	-	-	-	-	35º
2	√	-	√	√	√	√	35º
3	√	-	√	√	√	-	45º
4	√	-	√	√	√	√	45º
5	-	-	√	√	-	-	45º
6	√	-	√	-	√	√	37º
7	√	√	-	-	-	-	40º
8	√	√	-	-	-	-	40º
9	-	√	√	-	-	-	45º
10	-	√	√	-	-	-	45º
11R	-	-	√	-	√	-	35º
11L	-	√	√	-	-	-	35º

laceous unit, interbedded unit, and sheared unit, but alluvial deposit as an alluvial unit.

Deformation has affected the formation of joints in the rock mass of Trusmadi Formation. The joints (discontinuities) that daylight on the slope face are potential to form planar, wedge or toppling failures. Arenaceous units with 4 - 6 discontinuity sets are potential to form wedge failures such as in slope S2a and S6a. These slopes must be designed by terrace, surface drainage, and vegetation cover, weep hole, and wire mesh, but horizontal drainage is vital if seepage activities occur such as in slope S2b.

The occurrence of water seepage on the slope shows the infiltration of water from the fractures (joint or fault) in the rock mass. The infiltration has potential to enlarge the fractures and shortening the saturation period. High density of fractures and occurrence of water will increase the pore pressure as well as unit weight. Therefore, it will reduce the stability of slope material, especially during the rainy season. Interbedded rock unit with3 - 6 discontinuity sets have potential to form wedge failure such as in slope section no. 4 (Table 3). The slopes for this geotechnical unit must be designed by considering the terrace, surface drainage, weep hole, vegetation cover, horizontal drainage, and wire mesh.

The deformation is also caused by the folded, jointed, and faulted Trusmadi Formation. The fault zone has changed into shear zone after multiple deformation acts, especially in argillaceous rock unit. In the shear zone, the rock unit is found broken and fractured which is naturally weak and unstable. Discontinuity sets can not be identified in sheared unit such as in slope S3, S5, and S11R. The rock material is loose, weak, and highly weathered. The characteristics have potential to be circular failure once they are highly saturated with groundwater. Terrace, surface drainage, wire mesh, vegetation cover, and horizontal drain are recommended for high slopes (S3) but without horizontal drain and wire mesh for low slopes (S5 and S11R).

An exposed argillaceous rock unit on the earth surface will break into small particles and produce thick weathered material or soil layer. The thickness of the soil and saprolite (weathered material) is approximately up to 20 m. The weathered argillaceous rock unit will produce clayey material which is characterized by low permeability and able to hold maximum water content hence rising the total weight. The occurrences of low permeability and heavy weight become a triggering factor for slope failure. The potential mode of the failure in this weathered material is circular failure.

In order to form circular failure, argillaceous unit must have more than 10 m thick. This has been found in slope S2b, S4b, and S6b (Table 3). Discontinuitiy sets can not be determined because of sheared and weathered natures of the rock mass. Terrace, surface drainage, weep hole, wire mesh, and horizontal drain are recommended mitigation measures for high slopes (S2b and S4b) but without horizontal drain and vegetation cover for low slopes (S6b).

Discontinuity sets can not be determined in alluvial unit due to the loose nature of the rock mass material such as in slope S9 and S10. This will contribute to small scale of circular failure. Rock netting or wire mesh, vegetation cover, and weep hole are recommended mitigation measures for these slopes.

Potential fail slopes also must be cut according to the optimum slope angle to ensure their stabilities. The proposed optimum slope angle ranges from 35^o to 40^o but most of the slopes are 45^o.

Conclusions

The detailed mapping and analysis along the road enabled the recognition and documentation of the slope instability in the studied area. Generally, the existing condition of the slopes are stable, but degradation of the rock cut slope forming material by weathering will affect their stability in the future. Moreover, the kinematic analysis shows that the slopes are potential for wedge failure and circular failure. These failures are influenced by the types of geotechnical rock units, geological structures, weathering, erosion, ground water, and slope geometry. Daylighting occurrence of at least two intersect discontinuities contributes to the formation of the wedge failure in a relatively strong arenaceous unit, a highly deformed zone, and high slopes, but the circular failure is potential in a relatively weak argillaceous unit, unconsolidated alluvial deposit, highly weathered, and low slopes.

Therefore, upgrading the slope protection and stabilization measures such as reducing slope angle up to the optimum angle, repairing the terrace and surface drainage, installation of proper horizontal drain and weep hole in weak and highly fractured zones, planting vegetation in very weak rock material, and installation of wire mesh on potentially localized wedge failure rock cut slope are proposed.

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