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Mode of Slope Failure of Moderately to Completely Weathered Metasedimentary Rock at Bukit Panji, Chendering, Kuala Terengganu

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Abstract

Geology of Bukit Panji, Chendering, Kuala Teregganu consists of interbeded metasedimentary rocks (slate, phyllite and schists with minor quartzite) which have experience regional metamorphism. The age of this rock is Carboniferous. A development project which under construction in Bukit Panji, Kuala Terengganu has enabled a landslide assessment to observe the modes of failure in moderately to completely weathered metasedimentary rock. Development on hillsides caused many slope had to be cut to provide space for the infrastructure construction. From assessment analysis, a total of 21 cases of landslide failure occurred involving 17 cut slopes, and 4 cut-fill slopes. The most common type of failures is gully failures, with 9 cases represent 43% of all the observed slope failure. This was followed by 6 wedge failures, two planar and rock fall failures and one shallow sliding and toppling respectively. Cut slope failure involving moderate weathered rock mass (grade III) to the residual soil (grade VI). Relict structure was identified as the main factors controlling the failure, as well as water, natural slope-forming materials and the use of appropriate slope stabilization.

1. Introduction

Slope failure is a phenomenon that is very complex and can cause deadly to human. Currently slope failure tragidy is increase and it's associated with population growth and infrastructure development such as highway, dam and new settelement area is rapidly increasing and spread to hilly terrain (Tajul Anuar Jamaluddin et. al., 2003). From 1993 to 2006, there were 20 events of large scale slope failure that affect the country (Bujang et. al., 2008). Slope failure contributed to the loss of the country in terms of financially. From 1961-2007, the losses suffered by the state due to the slope failure is RM 2.996 billion (Public Work Department, 2009). The assessment has been conducted on metasedimentary cut slope at Bukit Panji, Chendering, Kuala Terengganu. The objective of the study is to quantify the type of slope failure and its contributing factor.

2. Study Area

The study area is located approximately 8 miles south of Kuala Terengganu. This area is bounded by the South China Sea to the east, the City of Kuala Terengganu and Marang is located in the north in the south. In terms of topography, the site is a hillside area at northern side of study area. Figure 1 shows the study area on the map.

3. General Geology

The metaclastics of the Bukit Panji, Chendering comprise a well foliated and heavily tectonised rocks. The rocks are interbedded and/or interfoliated slate, quartzite, phyllite and schist. The 8th edition of the Geological Map of Peninsula

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Malaysia (Geological Survey Department of Malaysia, 1985), shows that the rocks to be Carboniferous in age. In an earlier publicaton, MacDonald (1967) grouped the rocks into the so called "Arenaceous Sediments" of Kelantan and Terengganu.

At least two phases of tectonic deformation were deduced by previous researcher from detailed studies of the geological structures in this area. The younger deformation, folded the rocks around NNW-axes, tilted to almost vertical positions earlier formed NE-striking folds, created NW-lineations as crenulations, caused reverse faulting towards northeast and strike-slip faulting along existing and newly-formed faults in directions compatible with the compression directions in the sectors N310°-325°E and N46°-72°E. The older deformation is shown by overturned folds and NE-trending foliations reverse faulting towards northwest and presently reoriented to east-striking foliations and thrust faults. The two tectonic events were probably correlatable with Permian to Early Triassic diastrophism (indicated by East Coast Granite ages) and Late Triassic to Early Jurassic orogenesis that affected almost the entire Malay Peninsula (Tjia, 1978; Ismail Abu Bakar, 1976).

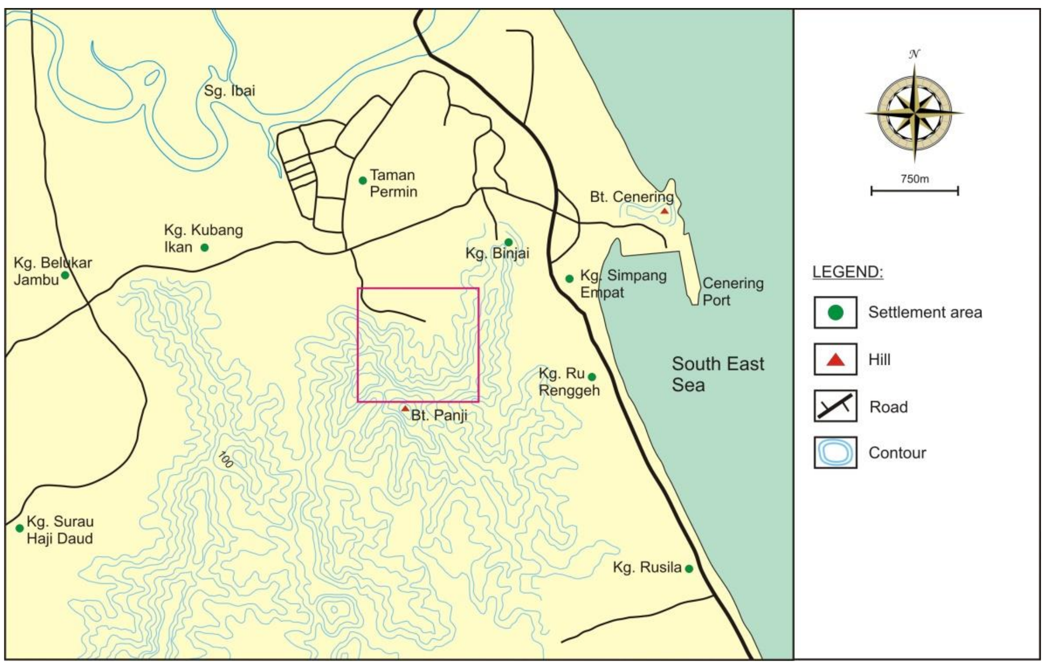

Figure 1: Location of study area

4. Materials and Methods

Several classifications can be used to describe slope failures assessment method. A very complete classification system for general use has been proposed by Varnes (1978), Crozier (1986), Hutchison (1988) and Dikau et al. (1996). For this study, the classification of slope failure is based on the classification system by Ibrahim Komoo (1985) and Tajul Anuar Jamaluddin (2007). Assessment of slope failures is carried out on all man-made slopes. This assessment was done using assessment data sheets of slope failure (Tajul Anuar Jamaluddin, 1990) to assist the collection of field data information. Parameters recorded from each slope failure include discontinuity, lithological type, size of slope failure, weathering grade, seepage and the factors that cause to slope failure. Size of failure was determined base on classification by Tajul Anuar Jamaluddin (1990) as shown in Table 1. Geometry of slope failure and the type of stabilization and slope protection used on the slope was also recorded.

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Table 1: Classification of slope failure size

Scale of slope failure	Volume of failure (m^3)
Small	< 100
Medium	100 – 1000
Large	1000 – 5000
Very large	> 5000

Source: Tajul Anuar Jamaluddin (1990)

5. Engineering Geology

5.1. Slope Geology

Geology of the site is essentially consisting of metamorphosed sedimentary rocks, which can be classified as interbedded metaquartzite, phyllite with minor intercalation of slate (Figure 2). The rocks are well foliated and are heaviliy jointed and in places, sheared. The metaquartzite is generally fine to medium-grained, and is generally light coloured compared to phyllite and slate. Phyllite is generally fine-grained and the weathered surface is generally light yellowish to reddish brown, but light grey on freshly cut surface. Slate is very fine grained, very finely laminated and is commonly black to dark grey.

Figure 2: Metamorphosed sedimentary rocks, which can be classified as interbedded metaquartzite, phyllite with minor intercalation of slate.

In the lower part of the slope, the rocks are moderately weathered. As moving up higher to the upper slope, the rocks gradually changed into highly weathered rocks. The rocks are well foliated and very heavily jointed. The joint spacing varies from a few cm to up to tens of cm. This is evident from the loose individual rock blocks within the failure debris, which are highly variables from as small as a few cm to up to 0.5m across (Figure 3).

Figure 3: The slope rock mass forming a high density of plane discontinuities due to tectonic action. The rock mass is prone to disintegrate into varies size to the average size of 20cm resulting slope prone to failure.

5.2. Weathering

Classification of weathering profile is based on the concept of weathering grade, the grade I (fresh rock) to grade VI (ground balance). For this study, the classification by IAEG (1981) was used. The weathering grade of rock mass is ranges from Grade III (moderately weathered) to Grade VI (residual soil). However, Grade IV (highly weathered) to Grade V (completely weathered) rocks dominated the rock mass of study area. Grade VI or residual soils formed the topmost overburden soil cover and in the range of 1.5-2.0m thick. The moderately weathered (Grade III) is generally light to pale grey in color. Grade III of rock material normally behave as medium strong to weak rocks. While Grade IV (highly weathered) and Grade V (completely weathered) vary in color from light yellowish brown to light reddish brown and in places are red due to cauterization and high iron oxide contents. Grade IV are generally very weak to extremely weak rocks, while Grade V totally behaves as soft soils (clayey silt and/or silty clay). In both Grade IV and V, the original rock fabrics and structures (e.g. foliation, bedding planes, joints) are still recognizable and their geomechanical behaviours are largely governed by the nature and orientation of the relict structures.

5.3. Structure and Discontinuity

The pertinent geological structures in the granitic rock masses are limited to the structural discontinuities. Discontinuities include all types of mechanical breaks or planes of weakness in the rock

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mass (e.g. joints, bedding planes, faults, shear zones, fractures, foliation), that caused the tensile strength of the rock is zero or much lower than the strength of the rock material (ISRM, 2007).

The rock mass is well jointed and in places is dissected by fault, joint and shear zone. In the studied slopes, discontinuities in the rock mass are mainly found in the form of joints and some localized faults and shear zones. The discontinuity planes exert profound control on the geomechanical properties of the rock mass. The discontinuity can be found both in fresh rock and highly to completely weathered rocks. Relict discontinuities in the highly weathered rocks can found in almost all slopes.

6. Results and Discussion

From assessment conducted on 19 slopes, there were 21 cases of slope failure were identified in the study area as shown in Table 2. A total of 17 failures occurred on cut slopes while 4 failures in embankments slope. A total of 9 failures represent 43% of slope failure is gully erosion (Figure 4). This type of failure is dominant because the slope forming material was highly to completely weathered to form 20m thick of top soil. This soil is loose and friable and easily eroded by surface water run-off, especially during heavy rain. Two major factors that control the gully erosion are erosion agent and geological factors as well as the slope angle and length of the slope face. The higher quantity and velocity of water will increase the process of erosion.

Figure 4: Gully erosion is observed because of surface water run-off. This failure becomes worse because no temparory erosion control measure was installed during construction stage.

For the shallow failure, a case of failure was occurred and its size is categorized as medium (Figure 5). This failure is causes by inappropriate earthwork management where earth material is dumping along slope face without proper method. Dumping earthworks waste on the shoulder slope is an unhealthy practice of construction as this will produce a layer of loose soil on the shoulder slope. These wastes can swipe down the slope, especially if there is heavy rainfall in a long period and this may contribute to the occurrence of larger slope failure (Tajul Anuar Jamaluddin, 2010a). For the wedge failure, six slope failure cases are observed and most of failures are causes by slope geometry and discontinuities orientation. Wedge failures can occur when there is an intersection between the two sets of discontinuities and the line of intersection of discontinuity planes is plunged towards the slope face (Hoek & Bray, 1981). The angle of slope face gradient, reaching 60° indirectly increase the probability of failure wedge.

Figure 5: Shallow failure occurred after heavy raining and its involved loose earth material that had dump along slope shoulder.

Planar failures can occur when a discontinuity plane tilted towards the face of the slope at an angle lower than the angle of inclination of the slope face (Hoek & Bray, 1981). Two cases of planar failure have been recorded at slope A and F. The volume of the failure can be classified as small. Planar failure mainly occurs because the influenced of foliation plane.

Two cases of rock falls have been recorded from this study and it's controlled by discontinuity structure on a cut slope. Rock materials involved are usually grade IV of weathered rocks. Rock fall failure usually occurred in wedge failure form, based on

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intersection of two or more plane discontinuities at the scars of failure (Figure 6). Based on the assessment, there was only one case of toppling failure, which occurred on E. Size of failure can be classified medium scale.

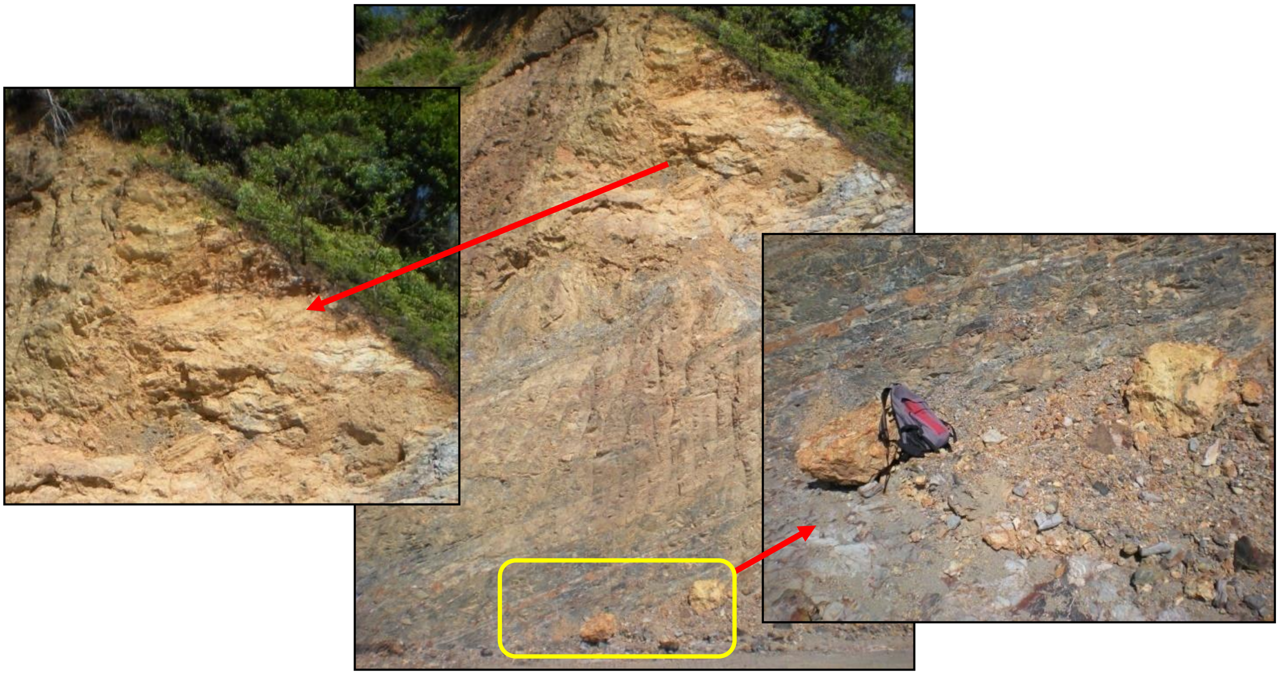

Figure 6: Rock fall in the form of wedge failure occurred at slope G. Size of blocks that fell is measured 1m x 1m x 0.5m.

7. Suggestion for Slope Stabilization and Protection Measures

Rock mass of cut slope at study area consists of highly to completely weathered metasedimentry rocks require specific and unique slope stabilization and protection method. Slope failure will still occurred if inappropriate slope stabilization methods used after several years of its completed installation. This structure failure can occur because of unsuitability design due to lack of understanding of the geomechanics behavior of the rock mass, geological processes acting on slopes and geological factors affecting slope stability.

Most of the weathered rock slope in Malaysia is protected and stabilized with soil nails and shotcrete besides steel mesh. Such slope protection methods are often preferred by owners and engineer because it is relatively easy and quick to be built, although not necessarily cheap. However, studies show that the structure of the slope protection failed, only a few years after installation (Tajul Anuar Jamaluddin, 2010b).

The key to stabilize the highly weathered metasedimentary rock slope is to prevent rock material from disintegrated and fell to the foot of cut slope. Cut slope of highly weathered metasdimentary rock require slope protection structures which have special features. One of them is its can trap disintegrated materials from slope due to the continuous decomposition of slope mass. Use a flexible structure such as steel wire mesh supported by ground spike is the most appropriate and effective methods. Installation of drainage system also needs to overcome the problem of surface water and groundwater, which has been identified as a major trigger for slope failure. Planting trees / vegetation can protect slopes while beautifying the views of the slopes.

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Table 2: Inventory of slope failure observed at Bukit Panji, Kuala Terengganu.

No	Slope	Slope Geometry	Mode of failure	Litology/Slope material	Size of failure	Causes of failure	Weathering Grade	Type of slope stabilization/protection
1	Slope A	H= 8m W= 15m G= 60°	Wedge failure	Interbeded of quarzite and phyllite	W= 2m, H= 3m D= 1m ($6m^3$ / small)	a.Discontinuity b.Weathering	IV-V	Slope protection & stabilization is not installed
2			Planar failure		W= 2m, H= 3m, D= 0.5m ($3m^3$ / small)	a. Discontinuity		
3			Gully erosion	Dumping area of earthwork soil	W= 10m,H= 6m, D= 1m ($60m^3$ / small)	a. Surface water run-off		
4	Slope B	H= 20m W= 50m G= 60°	Composite wedge failure	Interbeded of schicts, quarzit and phyllite	W= 40m, H= 25m D= 5m (5000m3 / very huge)	a. Discontinuity b.Overstapping/slope geometry c.Seepage d.Unsuitable slope protection method	III-IV	Proper vegitation
5			Gully erosion		W= 40m, H= 25m D=0.5m ($500m^3$ / medium)	a. Discontinuity b.Slope geometry c. Weathering		Slope protection & stabilization is not installed
6	Slope C	H= 40m W= 50m G= 60°	Gully erosion	Interbeded of schicts, quartzit, phyllite and slate	W= 25m, H= 15m D= 1.5m ($562.5m^3$ / medium)	a. Surface water run-off b. Weathering	III-VI	Slope protection & stabilization is not installed
7			Wedge failure		W= 15m, H= 15m D= 2m ($150m^3$ / medium)	a. Weathering b. Discontinuity c. Surface water run-off		
8			Shallow slide	Dumping area of earthwork soil	W= 30m, H= 20m D= 0.5m ($300m^3$ / medium)	a. Surface water run-off b. Loose tip-fill material		
9	Slope D	H= 30m W= 30m G= 60°	Gully erosion	Interbeded of schicts, quartzit, phyllite and slate	W= 5m, H= 6m D= 0.5m ($15m^3$ / small)	a. Surface water run-off	V-VI	Slope protection & stabilization is not installed
10	Slope E	H= 40m W= 100m G= 75°	Wedge failure	Interbeded of schicts, quartzit, phyllite and slate	W= 3m, H= 8m D= 1m ($24m^3$ / small)	a. Discontinuity b. Weathering	III-VI	Slope protection & stabilization is not installed
11			Toppling failure		W= 10m, H= 10m D= 2m ($200m^3$ / medium)	a. Discontinuity b. Weathering		
12			Gully erosion		W= 10m, H= 7m D= 1m ($70m^3$ / small)	a. Discontinuity b. Weathering		

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13	Slope F	H= 30m W= 35m G= 65°	Planar failure	Interbeded of schicts, quartzit, phyllite and slate	W= 3m, H= 4m D= 0.1m (1.2m^3 / small)	a. Discontinuity	III-V	Slope protection & stabilization is not installed
14			Wedge failure		W= 2m, H= 1m D= 0.3m (0.6m^3 / small)	a. Discontinuity		
15	Slope G	H= 150m W= 15m G= 60°	Rock fall (wedge failure)	Interbeded of schicts, quartzit, phyllite and slate	W= 3m, H= 8m D= 1m (24m^3 / small)	a. Discontinuity b. Weathering	III-VI	Some part of slope is stabilized using vegetation, horizontal pipe, drainage
16			Wedge failure		W= 5m, H= 7m D= 1.5m (small)	a. Discontinuity b. Weathering		
17			Gully erosion		W= 6m, H= 3m D= 0.5m (9m^3 / small)	a. Weathering		
18	Slope H	H= 150m W= 80m G= 40°	Gully erosion	Interbeded of schicts, quartzit, phyllite and slate	W= 1m, H= 6m D= 0.3m (1.8m^3 / small)	a. Surface water run-off b. Discontinuity		Vegitation, horizontal pipe, drainage system
19	Slope I	H= 12m W= 20m G= 50°	Gully erosion	Dumping area of earthwork soil	W= 15m, H= 6m D= 1.5m (135m^3 / small)	a. Surface water run-off b. Loose tip-fill material	III-IV	Intallation of soil nail is in progress during this study
20	Slope AR-1	H= 7m W= 40m G= 60°	Rock fall (wedge failure)	Interbeded of schicts, quartzit, phyllite and slate	W= 2m, H= 3m D=1m (6m^3 / small)	a.Discontinuity b. Weathering	III-VI	Slope protection &stabilization is not installed
21	Slope KR-N	H= 20m W= 30m G= 60°	Ravelling	Dumping area of earthwork soil	W= 20m, H= 7m D= 0.3m (42m^3 / small)	a. Surface water run-off b. Loose tip-fill material	IV-VI	Slope protection & stabilization is not installed

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8. Conclusion

Slope failure is a common phenomenon, especially in the hilly areas disturbed by human activities. The studies done at 19 slopes shown 21 events of slope slope failures recorded. These failures are included cut and embarkment slope. A large scale slope failure was recorded while five failures can categorized in medium scale failures (100m3-1000m3). Another 15 failures are included in small (less than 100m3).

A total of 9 cases of gully erosion had been recorded, representing 43% of total slope failure occurred. This was followed by six wedge failure and two planar and rock fall failures respectively. Only one case of shallow slip failure and toppling ware recorded. Slope failures usually occur in moderately to highly weathered rock mass.

Slope failures in the study area ware influenced by factors five factors which are the presence of discontinuities, presence of water, the slope geometry, weathering and inappropriate slope stabilization and protection methods. Each failure is influenced by more than one factor. The main factors causing the slope failure is discontinuity because all types of failures that occurred clearly influenced by the presence of structural discontinuities and its orientation.

To build a safe, stable and economic slope, all the main factors (e.g; discontinuities, hidrology and hydrogeology, weathering, slope geometry) should be considered. Cut slope not only be design based on strength of rock material only or type of slope forming material either rock or soil but requires other complete and comprehensive geological information. Involvement of expert engineering geologist is required in all stages of the slope construction either pre-construction, during construction and after construction.

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