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Relict Structures and Cut Slope Failures in Highly to Completely Weathered Rocks Along Jalan Tg. Siang, Kota Tinggi, Johor

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Abstract

A new road to Tg. Siang was completed in late 1998 as a by-pass to Tg. Balau and Tg. Siang from the main Kota Tinggi road. The by-pass transverses a gently undulating terrain of metasedimentary rocks of the Mersing Group (Permo-Carboniferous), consist of interbedded phyllite, slate and quartzite with minor intercalation of metavolcanics. The regional structural strike is in the NW-NNW direction and is dominated by dextral transpresional shear zones, intervened by zones of multiply deformed, tight to isoclinal folds. A slope failure survey conducted in September 1999, followed by geological mapping in April 2000, found that the number of slope failures increased from 10 to 18 cases. All the failures involve slopes cut in zones of highly-completely weathered rocks (grade IV-V) and residual soils (grade VI). The presence of relict structures has been identified as the main geological factor in controlling the failures, in addition to water and slope materials. Most of the slope cut failures in highly weathered rock (engineering soils) took place in the form of undercutting-induced failures. Instabilities of the slopes were initiated by ravelling of the loose materials, rill and gully erosions, which was subsequently followed by earth falls, shallow slips, earth wedges and/or slumping. The failure planes are largely controlled and defined by relict structures (e.g. relict joints, foliations, bedding and/or shear zones). Results of this study highlight the importance of geological input, especially on the nature and orientation of relict structures in slope engineering. Cut slopes in highly-completely weathered rocks should not be oversimplified and treated as homogeneous soil slopes. Instead, they should be treated as discontinuity-controlled soil or weak rock mass in order to successfully implement safe and economic design. It is always a good practice for the slopes to be mapped by engineering geologists with sound structural background or vice-versa, structural geologists with some knowledge of engineering geology. The structural mapping should be carried out during the site investigation stage to choose the most suitable alignment, and during construction to check the results and interpretation made in the earlier pre-construction stage.

Struktur Relikta dan Kegagalan Cerun Potongan pada Batuan Terluluhawa Tinggi Hingga Tanah Baki di Sepanjang Jalan Tg. Siang, Kota Tinggi, Johor

Abstrak

Jalan Tg. Siang siap di bina pada tahun 1998 sebagai jalan pintas ke Tg. Balau dan Tg. Siang dari Jalan Kota Tinggi. Jalan ini merentasi topografi beralun landai dalam terain metasedimen Kumpulan Mersing (berusia Perm-Karbon), terdiri daripada selang lapis filit, sabak dan kuarzit serta sedikit batuan metavolkanik. Jurus struktur rantau berorientasi sekitar baratlaut – utara baratlaut, yang didominasi oleh zon-zon ricih transpressi dekstral berselang seli dengan zon-zon lipatan ketat hingga isoklin yang telah tercangga berulang kali. Survei kegagalan cerun yang dilakukan pada September 1999, diikuti dengan pemetaan geologi pada April 2000, mendapati kes kegagalan cerun di sepanjang jalan ini telah meningkat daripada 10 kepada 18 kes. Kesemua kes kegagalan yang dicerap ini melibatkan cerun yang dipotong dalam zon batuan metasedimen terluluhawa tinggi (gred IV-V) hingga tanah baki (gred VI). Kehadiran struktur relikta dikenalpasti sebagai faktor utama yang mengawal kegagalan, di samping air dan tabii bahan pembentuk cerun. Kebanyakan kegagalan cerun potongan pada batuan terluluhawa tinggi ini (atau "tanah kejuruteraan") mengambil tempat dalam bentuk kegagalan yang dicetus oleh pencuraman kaki cerun. Ketakstabilan cerun lazimnya bermula dengan perleraian bahan-bahan longgar, hakisan galur, yang seterusnya diikuti oleh jatuhan, gelinciran, baji dan/atau lingkaran tanah. Satah-satah kegagalan lazimnya terbentuk mengikuti satah-satah ketakselanjaran relikta (e.g. kekar, foliasi, perlapisan, sesar atau zon-zon ricih relikta). Hasil kajian ini menekankan kepentingan input geologi, terutamanya mengenai tabii dan orientasi struktur relikta dalam kejuruteran cerun. Cerun potongan pada batuan terluluhawa tinggi-sepenuhnya tidak seharusnya di anggap mudah sebagai cerun tanah homogen. Sebaliknya cerun-cerun sebegini perlu dianggap sebagai jasad tanah atau batuan lemah yang dikawal oleh ketakselanjaran, untuk menghasilkan rekabentuk cerun yang selamat dan ekonomi. Menjadi suatu amalan yang baik sekiranya cerun-cerun tersebut dipetakan oleh ahli geologi kejuruteraan yang mahir dalam bidang struktur, atau sebaliknya ahli geologi struktur yang mahir dalam bidang geologi kejuruteraan. Pemetaan struktur tersebut seharusnya dijalankan di peringkat penyiasatan tapak lagi untuk memilih laluan yang paling sesuai, dan semasa pembinaan untuk menilai semula hasil dan tafsiran-tafsiran yang dibuat di peringkat awal.

INTRODUCTION

A new road was constructed along the existing track leading to Tg. Siang Estate from the Kota Tinggi Road at Kangkar Chemaran. The road, reffered to herein as Jalan Tg. Siang or Tg. Siang Road, was completed in late 1998.

Since the opening of Jalan Tg. Siang to the public, most of the cut slopes along the road have been been subject to extensive failures. A slope failure survey which was conducted in September 1999, less than 2 years after the opening of the road to the public, has recorded a total of 10 cases of failures. Follow-up geological mapping was carried out in April 2000, in which 18 cases of failure spots were recorded. Although the sizes of failures are mainly small- (<$10m^3$) to medium- ($10\text{-}30m^3$) scale, they create an eye-sore due to the alarming number of failures compared to the total length of the road, which is about 6.5 km long.

The main objective of this paper is to discuss the geological factors, with special reference to the influence of relict structures, and mode of slope failures in highly to completely weathered metasedimentary rocks along the newly built Jalan Tanjung Siang, in the district of Kota Tinggi Johor.

THE STUDY AREA

The location of Tg. Siang Road is shown in Figure 1. Construction of the 6.5 km long road commenced sometime in late 1997. The road alignment mainly follows the old track leading to Ladang Tanjung Siang, which links the existing Jalan Kota Tinggi at Kangkar Chemaran to the east, and Jalan Tg. Balau to the west. This road serve as a by-pass to Tg. Balau from Jalan Kota Tinggi, avoiding the need to go through Jalan Desaru and Bandar Penawar.

GEOLOGY

The entire route of Jalan Tg. Siang transverses gently undulating terrain of the Upper Palaeozoic (?Permo-Carboniferous) metasedimentary rocks of the Mersing Group (Suntharalingam, 1981). The metasediments consist of interbedded phyllite, slate and metaquartzite with minor intercalation of metavolcanics.

The rocks have been multiply deformed and at least three major phases of deformation can be distinguished (Mustaffa Kamal Shuib *et al.*, 1999; Tajul Anuar Jamaluddin and Mustaffa Kamal Shuib, 1999). The geometrical relationships and classical examples of structural superposition can be clearly seen in the outcrops along the nearby coast lines of Tanjung Balau, Tanjung Lompat and Tanjung Siang (Mustaffa Kamal Shuib & Tajul Anuar Jamaluddin, 1999).

In general, the rocks are tightly-multiply folded and highly sheared. The regional structural strike are oriented in NNW-NW directions and the bedding/foliation planes are steeply dipping to the E or W to subvertical. The well-developed first cleavage and foliation are generally aligned subparallel to the bedding. These planar structures, together with faults and shear zones, are very well preserved as prominent relict structures even though occuring in the highly to completely weathered rocks ("engineering soils").

Transpressive dextral shear zones (e.g. Mustaffa Kamal Shuib & Tajul Anuar Jamaluddin, 1999) are common. The occurrence of shear zones in the slope cuts is commonly characterised by abrupt changes in colour from reddish brown to darker (dark grey to black) zones of intense foliation, sheared and shattered rock texture. The materials exposed within the shear zones are characteristically less durable and tend to weather rapidly. As a result, these materials tend to be very weak, friable and prone to erosions; even ravelling down on their own weight due to gravity. The shear zones vary from a few cm to up to 0.25 m wide, striking NNW with subvertical to steep dips.

ENGINEERING GEOLOGY

Weathering

Jalan Tg. Siang is built across gently undulating terrain, ranging between 0.5 to 50 m above the sea level, and runs approximately in the E-W direction. In general, the slope cuts are relatively shallow (10-20m), only exposing highly to completely weathered rocks (Grade IV-V) and residual soils (Grade VI) (IAEG, 1981). Less weathered bedrock is expected to occur deeper in the ground.

The thickness of the residual soil ranges between 1 to 3 m, and the lower slope sections are cut within Grade IV-V rock mass (engineering soils). Grade VI materials consist predominantly of fine sandy CLAY, whereas Grade V comprises silty and fine sandy CLAY. Relict structures are conspicuously well preserved in Grade IV and V rock mass. The structures are still identifiable as cleavage, foliation, bedding, joints, shear zones and faults (Fig. 2).

Slope Failures

The location of failures are shown in Figure 1. Details of the geology, slope geometry, mode of failure and the likely causative factors are summarised in Table 1. Failures of cut slopes in the study area usually take place in the form of "soil" ravelling, erosion and undercutting-induced failures. Ravelling and erosional failures usually develop preferentially within shear zones, where the materials are relatively loose, friable, very weak, less durable and characteristically unfavourable for growth of vegetation (Figure 2).

While ravelling and erosion are considered as slope failures, both these mass wasting processes can lead to even more serious instability problems due to the creation of soil mass overhangs above them. Depending on the nature of the materials and relict structures, the failure of the overhanging mass may vary from earth toppling, earth fall, wedge failure, planar slide, to shallow slip and earth slump. Thus, the resulting failed slopes usually show up as having undergone composite failure – i.e. a combination of

NUMBER	*LOCATION (km)	SLOPE	GEOMETRY (APPROX.)	SLOPE FAILURE (REF. NO.)	MODE/TYPE OF FAILURE	FAILURE GEOMETRY	LITHOLOGY	DOMINANT STRUCTURES	WEATHERING GRADE	SLOPE PROTECTION	NOTES
1	0.25	TS1	W: 130m H: 10m A: 45°	TS1-A	Ravelling	W: 1-2m H: 2-3m D: 0.1-0.2m	Intensely sheared phyllite and slates within a shear zone	Shear zone, Foliation: 140/60W	V – VI	Moderately turfed	Plate 1
2	1.4	TS2	W: 100m H: 10m A: 42°	TS2-A	Earth falls	W: 15m H: 10m D: 0.1-1.0m	Phyllite, quartzite and slate interbedded	Foliation: 110/40 Joints: 200/80, 340/80/110/40	V-VI	Poorly turfed	
3	1.41			TS2-B	Planar failure & Earth falls	W: 10m H:10m D:0.5m	- Ditto -	- Ditto -	IV-VI	Porly turfed	Plate 2
4	1.43			TS2-C	Planar failure & Earth falls	W:30m H:10m D: 0.5-1.0m	- Ditto -	- Ditto -	V- VI	Poorly turfed	
5.	2.2	TS3	W: 110m H: 20m A: 42°	TS3	Slump, Earth falls	W:100m H:10-15m D:1.5-2.0m	Quartzite and slate interbedded	Foliation: 100/50 Joints: 210/40, 170/90	V-VI	Poorly turfed; Cut off drain (unlined) & Gabion wall.	
6.	2.5	TS4	W: 200m H: 15-20m A: 50°	TS4-A	Ravelling & Rill erosions, Shallow slip;	W: 20m H: 2-5m D: 1.0-1.5m	- Ditto -	Shear zone, Foliation: 150/45 Joints: 244/80, 094/80	V-VI	Poorly turfed	
7.	2.55			TS4-B	Shallow slip	W: 5m H: 10m D: 1-1.5m	- Ditto -	- Ditto -	V-VI	Poorly turfed	
8.	2.6			TS4-C	Ravelling & Earth falls	W: 50m H: 10-15m D: 0.2-0.5m	Phylite and quartzite interbedded.	- Ditto -	IV-VI	Poorly turfed	
9.	2.65			TS4-D	Shallow slip & Earth falls	W: 10m H: 10-12m D: 2m	Phyllite and quartzite interbedded	- Ditto -	V-VI	Poorly turfed	
10.	2.9	TS5	W: 200m H: 25m A: 43^0	TS5-A	Composite	W: 15m H: 20m D: 2-3m	Intensely sheared phyllite, slate, quartzite and metavolcanics within a shear zone.	Shear zone, Foliation: 160/60 Joints: 320/80, 135/40	V-VI	Poorly turfed	

Table 1: Cut slope failures along Jalan Tg. Siang as recorded up to April 2000. *Measured westward from the roundabout at the eastern end of Jalan Tg. Tiang.

NUMBER	*LOCATION (km)	SLOPE	GEOMETRY (APPROX.)	SLOPE FAILURE (REF. NO.)	MODE/TYPE OF FAILURE	FAILURE GEOMETRY	LITHOLOGY	DOMINANT STRUCTURES	WEATHERING GRADE	SLOPE PROTECTION	NOTES
11.	2.9	TS5	W: 200m H: 25m A: 43^0	TS5-B	Preferential erosions & ravelling, Wedge & Earth falls.	W: 15m H: 10-15m D: 0.5-1m	Interbedded phyllite and quartzite.	Shear Zone	IV-VI	Moderately turfed	
12.	3			TS5-C	Ravelling, Gully erosions & Earth falls	W: 10m H: 15m D: 0.3-2m	Interbedded phyllite, quartzite and slate	Shear Zone	IV-VI	Moderately turfed	Plate 3
13.	3.8	TS6	W: 230m H: 20m A: 45^0	TS6-A	Earth falls	W: 15m H: 1-1.5m D: 0.5-1m	Interbedded slate and quartzite.	Foliation: 140/40 Joints: 080/80, 240/80	IV-VI	Poorly turfed	
14.	3.85			TS6-B	Ravelling & Earth falls	W: 5-7m H: 7-10m D: 0.5-1m	Phyllite	Shear zone	V-VI	Moderately turfed and earth drain.	
15.	4	TS7	W: 120m H: 15m A: 45^0	TS7-A	Ravelling & Erosions, • Earth topples	W: 24m H: 15m D: 1-1.5m	Interbedded phyllite, slate and quartzite.	Shear zone, Foliation: 010/12 Joints: 310/80, 060/80	V-VI	Poorly turfed and Cut off drain (unlined)	
16.	4.03			TS7-B	Ravelling & Rill erosions	W: 30m H: 5-7m D: 0.2-0.5m	- Ditto -	- Ditto -	IV-VI	- Ditto -	
17.	4.05			TS7-C	Earth falls & Gully erosions	W: 10m H: 7m D: 2m	Interbedded slate and quartzite.	- Ditto -	V-VI	- Ditto _	
18.	5	TS8	W: 120m H: !0m A: 40^0	TS8-A	Gully erosions & Earth falls	W: 5m H: 7m D: 1-1.5m	Interbedded slate and quartzite	Foliation: 120/40	V-VI	Moderately turfed	

Table 1(continued): Cut slope failures along Jalan Tg. Siang as recorded up to April 2000. *Measured westward from the roundabout at the eastern end of Jalan Tg. Tiang.

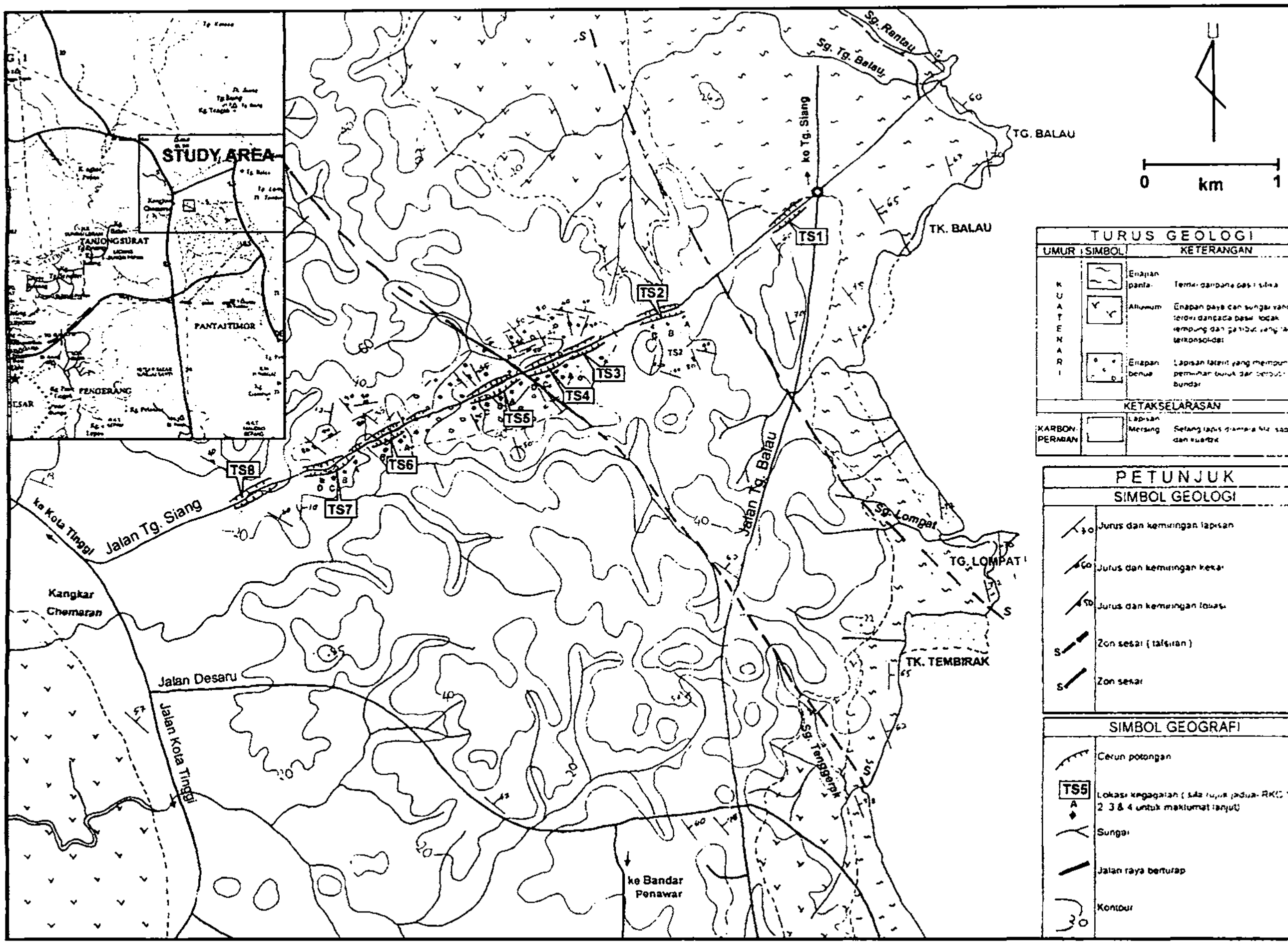

Figure1: Simplified geological map of Jalan Tg. Siang, showing the locations of cut slope failures (largely after Muhammad Fauzi Deraman, in prep.)

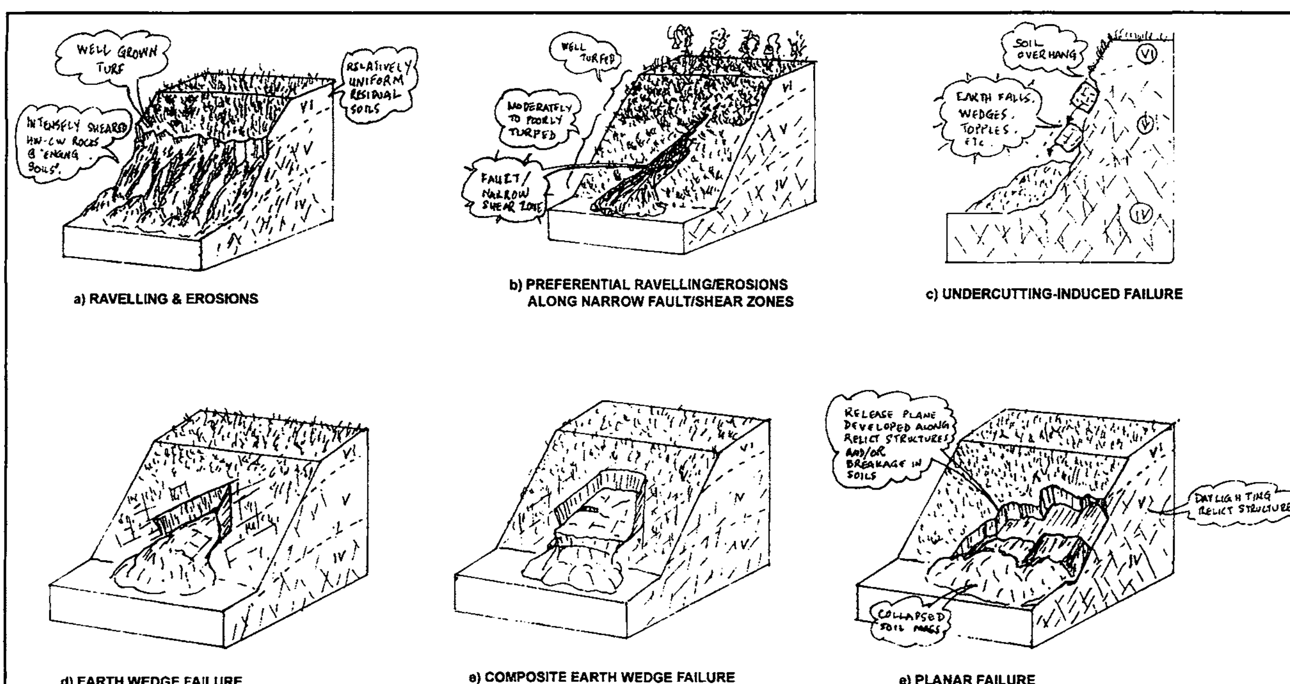

Figure 2: Some common modes of cut slope failures along Jalan Tg. Siang.

two or more types of failures described above.

The following sections discuss some of the outstanding modes of slope failures encountered along Jalan Tg. Siang.

Ravelling

Most of the slope failures in the study area occur in the form of ravelling of the highly – completely weathered materials encountered in the shear zones (Plate 1, 2 and 3). Shear zones are usually developed in the carbonaceous metapelites (graphitic pyllite and schist). The highly sheared meatapelites are often dark grey to black purplish (possibly rich in manganese). The derivative weathered soils are often loose, very weak and friable, rapidly weather and readily disintegrate and move downslope under gravitational force. The nature of the soils, with low pH conditions inhibit vegetation growth, leading to failure in turfing efforts.

In humid tropical countries such as Malaysia, it is common to encounter slope cuts in highly-completely weathered zones, where sheared metapelites are left bare and unvegetated. Many examples of similar situations can be encountered along the East-West Highway between Gerik and Sri Banding (Abdul Ghani Rafek *et. al*, 1989; Tajul Anuar Jamaluddin, 1990) and the North-South PLUS Highway somewhere between Air Keroh – Tangkak (e.g. Tan, 1996) and between Tg. Malim and Slim River. Cut slopes in such materials tend to be easily eroded and ravelled.

The direct effect of ravelling processes may not be so critical, as the downslope movements of the disintegrated materials are relatively slow. However, in the long term, ravelling may cause substantial undercutting and result in the creation of overhanging soil mass. The failure of the overhangs is of prime concern because the undercutting-induced failures are usually of large scale.

Erosional Failures

Cut slopes in soils which are poorly turfed and/or lack adequate drainage controls will be subjected to erosion. Erosion usually begins in the form of a network of subparallel rills. If left unattended, rills will eventually develop into gullies.

Gullies may progressively grow bigger and deeper, undercutting the lower slope sections, reducing the slope angle and creating soil overhangs, which is subsequently followed by earth falls, earth toppling, planar slides, wedge failures, slumps and/or shallow landslips of the upper slope sections. The type of subsequent failure is largely controlled by the relict structures, water and slope materials.

Once developed, the resulting effects of gully erosions are often detrimental, unless immediate mitigation and protection measures are undertaken. The eroded surface should be backfilled and turfed. All surface water and runoff should be diverted away from the slope by installing suitable surface and subsurface drainage.

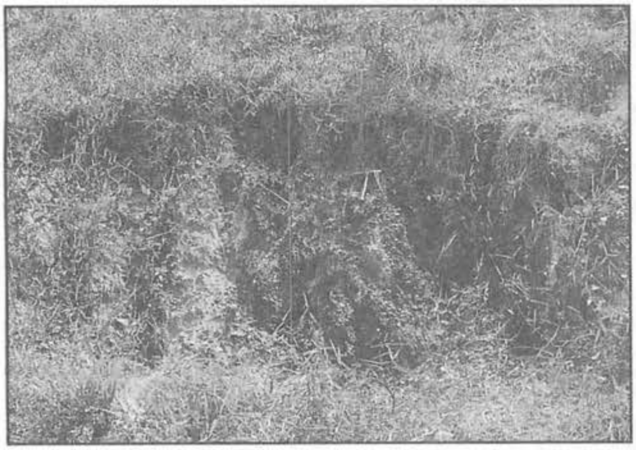

Plate 1: Slope TS1 - substantial undercutting due to ravelling and preferential erosion of the completely weathered shear zone.

Plate 2A: Planar earth slide along the outcropping relict foliations. (Slope TS2-B)

Plate 2B: Closer view of the above; showing the nature of the relict discontinuities, which control the failure.

Plate 3A: Slope TS5-C - Ravelling and erosional failures in the completely weathered shear zone, leading to earth falls in the upper slope section.

Plate 3B: Closer view of the above; showing the ravelling and erosion of the sheared graphitic phylitte which resulted in the development of soil overhang above it.

Planar Failure

Planar failure is not necessarily preceded by slope undercutting. Slopes cut parallel or sub-parallel to the strike, and steeper than the dip of the daylighting foliation planes, can lead to planar failure (Plate 2). The mechanism of the failure is virtually similar to those of planar failure in rock slope. In rock slope, planar sliding requires some orthogonal sets of joints as release planes for the rock slab to slide, but in soil slope, this condition may not be a requirement. This is mainly because the release plane for planar sliding to occur may develop within the soil material itself. The detachment or release planes can be readily developed when the down pull weight of the earth slabs exceeds the tensile strength of the soil material. This condition is favourably accomplished during or after heavy and prolonged rainfalls, when the soil is saturated. This is aggravated by increased pore water pressure along the foliations. In such condition, the shear strength is drastically reduced and rapid downslope movement result in the originally tabular-shaped failed mass collapsing and spreading over the footslope. The nature of the relict structures, along which the sliding plane developed, can be clearly seen in the failure scar (e.g. Plate 2A and B).

Wedge Failure

Wedge failure develops when the intersection of two major sets of relict discontinuities outcrops in the slope face. Wedge failures in the study area are usually induced by ravelling and erosions of the lower slope sections. The size and geometry of the wedge is controlled by the orientation of the intersecting relict discontinuities with respect to the slope geometry.

Slope undercutting either by ravelling and/or erosions can cause wedge failure to occur in more competent soil layers even when the lines of intersection do not initially outcrop on the slope face. When the line of intersection is steeper than the slope face, the earth wedge has a greater tendency to move downward than outward. When the line of intersection is nearly vertical, as will be the case for a wedge formed by nearly vertical relict discontinuities, the wedge can fail only by downward movement. Such movement can occur only if the underlying rock is removed through the process of ravelling or erosions. The term "wedge falls" can be appropriately used to describe such combinations of wedge failures and earth falls.

CONCLUSIONS

Failures of the cut slope in highly to completely weathered rocks or "engineering soils" along the Tg. Siang Road, mainly take place in the form of ravelling, erosion and undercutting-induced failures. Elements of instability in the cut slope are often initiated either by erosion (rill and gullies) and/or ravelling of the loose, friable materials formed in the shear zones.

Materials formed in the shear zones are characteristically very weak, non-durable, weather rapidly and the derivative soils are often unfavourable for vegetative growth. Weathered shear zones serve as a preferred site for soil ravelling and rill and gully erosion and this progressively causes slope undercutting. Eventually, the soil overhangs can fail in the form of earth falls, earth topples, earth slumps, planar slides, wedge or compound failures; depending on the presence and orientation of the relict discontinuities.

Examples of slope failures presented in this study highlight the critical influence of relict structures (discontinuities) on the stability of cut slopes in highly-completely weathered rocks (or "engineering soils"). Shear zones in HW-CW rocks itself is a relict structure, which acts as an impetus for ravelling and preferential erosions. The resulting undercutting-induced failures are also largely controlled by relict structures (e.g. relict joints, faults, foliation, etc.).

Erosional and ravelling failures are often overlooked, because their actions are relatively slow and direct impacts are often non-hazarduos. However, as the toe undercutting grows larger and deeper, the consequent effect on the stability of the slopes are often detrimental. Once a larger scale failure occurs, slope remedial work is often very costly.

Examples of cut slope failures discussed in this study again highlight the important effects of relict discontinuities in controlling the mode, geometry and type of failures (Tajul Anuar Jamaluddin, 1999, 2000). It is often the case where failures of cut slope in "soils" are often oversimplified and simply described as landslides or circular slip. In engineering practice, it is commonly assumed that the failure occurred along a single circular slip plane or straight planar sliding plane (e.g. Bishop, 1955; Bishop & Morgenstern, 1960; Janbu, 1972). This assumption is not always valid and can lead to unrealistic methods of slope stability analysis (Hencher & McNicholl, 1995). Examples shown in this study, clearly indicate that most of the failures; their geometry and mode of failure are far more complex where the geometry of the failed masses are largely defined by the intersecting planes of relict discontinuities.

RECOMMENDATION

In order to sucessfully implement safer and economical design of slope cuts in highly to completely weathered rocks (or engineering soils), detailed structural mapping is identified as a vital tool. The mapping should be carried out in the pre-construction (site investigation) stage to help the slope designer to choose the most suitable slope orientation by avoiding unfavorable or outcropping relict discontinuities. The mapping should also be extended during the early stage of slope construction to check the results and/or interpretation made from the site investigation stage. It is highly recommended that slope mapping be carried out by competent and experienced geologists, preferably engineering geologist with sound structural background or vice-versa, structural geologist with some background in engineering geology.

The engineering behaviour of cut slopes in *in-situ* soils (highly to completely weathered rocks) should not be treated as a uniform soil mass. They should instead be treated as a discontinuous soil mass due to relict structural control.

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