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Engineering geology of slopes for the preparation of EIA reports – A case study from the proposed site for a national secondary school at Ringlet, Pahang Darul Makmur

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Abstract: The site for the proposed National Secondary School at Ringlet, Cameron Highland is situated in a rugged hilly terrain underlain by granite and schist. The proposed school buildings is sited in a V-shaped valley because of the difficulty in getting flat or low-lying ground in the tropical highland areas such as Ringlet. Thus, existing slopes have to be cut to create room for the school building. The engineering geological study for slopes presented in this paper forms part of the geological input required for the preparation of an environmental impact assessment (EIA) report prior to approval by the local authority. To assess the stability of the existing and future cut slopes, structural geological mapping has been carried out by collecting data of relict structures in the intensely weathered and restricted outcrops. The study area has been arbitrarily divided into 3 structural domains, i.e Domain A, B and C. In the kinematic slope stability analysis, it is assumed that slopes in each structural domain contain similar structural style and orientation. Results of the anaysis indicates that most of the slopes in the study area have variable potential to undergo wedge and/or planer failures. This is evident in the field by some occurrences of wedge/planar failures, although they are of relatively small-scale. The risk of slope failures can be reduced if the proposed slopes are cut in the orientations and gradients recommended in this study.

Abstrak: Tapak Cadangan Sekolah Menengah Kebangsaan Ringlet, Cameron Highland terletak di dalam terain granit dan syis yang berbukit bukau yang kasar lagi sukar. Tapak sekolah yang dicadangkan itu terletak di dalam lembah berbentuk V kerana kesukaran medapatkan kawasan yang landai atau rata di kawasan tanah tinggi tropika yang kasar seperti di Ringlet. Oleh itu, cerun sedia ada terpaksa dipotong untuk mendapatkan ruang bagi pembinaan bangunan sekolah. Kajian geologi kejuruteraan cerun yang disajikan dalam kertas ini adalah sebahagian daripada input geologi yang diperlukan untuk penyediaan laporan EIA sebelum projek ini diluluskan oleh pihak berkuasa. Untuk menilai kestabilan cerun-cerun sedia ada dan yang bakal dibina, pemetaan geologi struktur terpaksa juga dilakukan dengan mengumpul data-data struktur relikta yang tersembunyi pada singkapan yang terhad dan terluluhawa teruk. Kawasan kajian telah dibahagikan secara arbitrari kepada 3 domain struktur, ia itu Domain A, B dan C. Analisis kinematik kestabilan cerun telah dilakukan dengan membuat andaian bahawa cerun-cerun di dalam setiap domain struktur yang sama akan mempunyai gaya dan orientasi struktur yang serupa. Hasil analisis mendapati bahawa kebanyakan cerun di kawasan kajian mempunyai berbagai potensi untuk gagal dalam bentuk baji dan/atau satah. Ini terbukti di lapangan kerana memang telah wujud beberapa kegagalan cerun dalam bentuk baji/satah yang berskala relatif kecil. Untuk mengurangkan risiko kegagalan, pemotongan cerun perlu dibuat mengikut orientasi dan sudut cerun yang disyorkan.

INTRODUCTION

Preparation of an Environmental Impact Assessment (EIA) report is mandatory prior to approval of the proposed development activities prescribed under the Environmental Quality Order 1987 (DOE, 1990). Currently, geological aspects are included as a small part in the EIA (DMG, 2000). Because the site for the proposed National Secondary School at Ringlet is situated in a rugged and rough hilly terrain, typical of the tropical highlands, emphasis has to be given to the engineering geology of both the existing slopes and slopes that will be cut in the future.

This paper presents examples of engineering geological studies carried out in a hilly terrain for the preparation of an EIA report. This study is by no means exhaustive and is limited to the engineering geological aspects of the slopes.

AREA OF STUDY

The study area, measures about 44500 m^2, is a site for a proposed National Secondary School at Ringlet (Figure 1). The site is located in a rugged hilly terrain with topographic height ranges between 1090 m to 1160 m above the mean sea level. In the central area, a stream flows eastwards into Tasik Habu (also known as Ringlet Lake), which is situated to the east of the main road to Cameron Highland. Rock outcrops are only exposed in the slope cuts along the access road to the project site. However, the rock exposures are highly to completely weathered.

The slope gradients are generally steep (40-60°), notably in the upper northern, northwestern, western and southern parts of the area. Most of the area is covered by dense tropical forest except in the abandoned vegetable fields on the northwestern and western hill slopes. Adjacent to the south of the study area, earthworks for a proposed primary school are in progress.

METHOD OF STUDY

The geological mapping was carried out in May 2000, to assess the existing geology and site conditions. All pertinent geological features were mapped on 1:100 scale topographic map. Structural discontinuity data was collected from all available outcrops for the purpose of slope stability assessment.

In order to assess the stability of the existing slopes and to recommend the safest, economical and environmental friendly slope design, the key geological factors to be considered and comprehended are the slope materials and structures. Due to the limited number and the highly weathered nature of the outcrops, structural mapping has to rely heavily upon relict structures. In order to trace the nature (or type) and orientation of the "commonly hidden" relict structures in the highly to completely weathered outcrops. Frequent use of the geologist's pick is necessary to get fresh cut surfaces. Based on the authors experience, relict structures are often best displayed in newly cut surfaces (Tajul Anuar Jamaluddin, 1999; Tajul Anuar Jamaluddin and Mohd Fauzi Deraman, 2000), notably in fine-grained rocks.

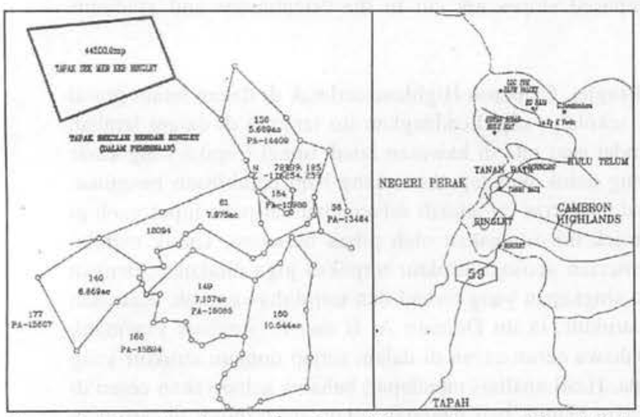

Figure 1. Map showing the location of the study area (Tapak Sek. Men. Keb. Ringlet).

GEOLOGY

On a regional scale, the Cameron Highland (including the study area) is situated in the Main Range of Peninsular Malaysia (*Banjaran Titiwangsa*) (GSD, 1985). The mountain range is made up predominantly of granite The granite batholith, also widely know as the Main Range Granite (Bignell and Snelling, 1977; Gobbett and Hutchison, 1973) trends NNW-SSE, and intruded into the older sedimentary rocks, which resulted in the occurrences of metasedimentary and metamorphic rock roof pendants above the granite bodies. The age of the granite ranges from Lower to Upper Triassic, while the older metasedimentary rocks are believed to be Upper Palaeozoic.

The general geology of the site is shown in Figure 2. The bedrock of the project site comprises metamorphic and igneous rocks. The metamorphic rocks consist predominantly of schist. The exposed schists are highly to completely weathered, light brownish grey to greyish brown in colour, fine to medium grained and very well foliated. In hand specimens, the schist composed essentially of quartz and mica, with smooth and shiny foliation surfaces. In places, traces of original bedding are still visible, which is almost parallel to the foliation, suggesting that the schist was originally a sedimentary rock. Schist forms about two-thirds of the project site, notably in the central and eastern portions of the area.

The igneous rock consists of hypidiomorphic-granular, coarse-grained biotite granite. The granite comprises essentially of quartz, feldspars and some black spots of biotite and/or tourmaline. An unconformable, discordant contact between the granite intrusion and schist is exposed in the cut slope on the north side of the access track to the

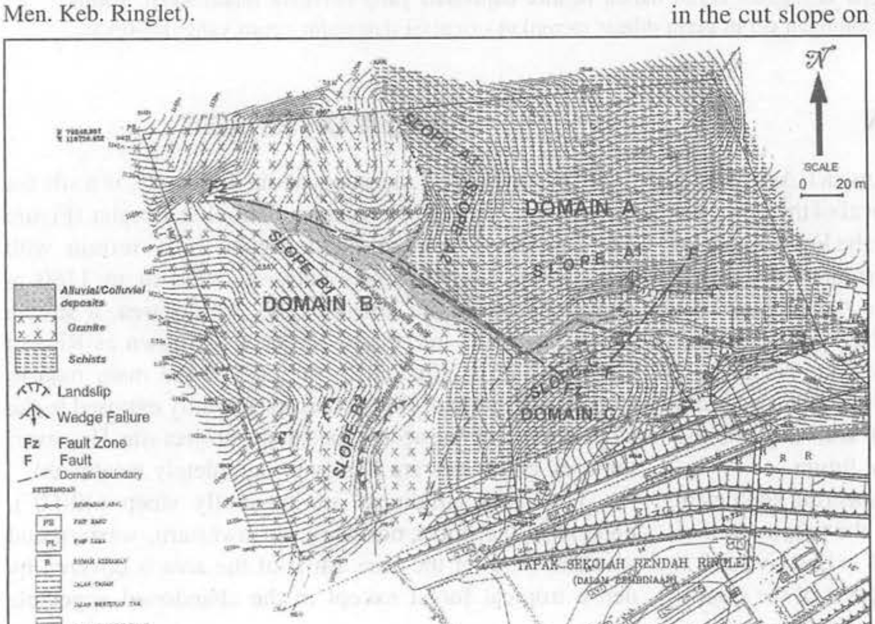

Figure 2. General geological map of the study area.

site. Both of the lithologies, however, are highly weathered. Unconsolidated colluvial deposits are locally encountered at the foot of a slope along the river to the NW part of the area. The deposit is characteristically a mixture of boulder, pebbles, sands and mud derived from the upper slopes.

The rocks are tectonically deformed. At least 4 major sets of discontinuity (predominantly joints) are recognised in the schist and granite. The schist is also well foliated and has been folded with fold axis approximately in NW-SE direction. A NW-SE striking shear zone is encountered along the stream in the central part of the area. Along the access road cut behind the quarters, another shear zone striking 034°/60°SE, is characterised by intense fracturing and shearing of the schists.

ENGINEERING GEOLOGY

Weathering

The rocks have undergone severe chemical weathering, producing a thick residual soil of various consistencies. The overburden soil above the bedrock comprises of materials ranging from Grades VI, V and IV. The bedrock comprises of grade III material or fresher. The top section of the soil profile above granite comprises predominantly of medium dense silty and clayey SAND with some gravels. More dense silty SAND is expected to be encountered before reaching the bedrock. The residual soils derived from granite are generally light yellowish brown, dense sandy and silty CLAY with some gravels. Whereas the residual soils derived from schist gives reddish brown, stiff silty CLAY and clayey SILT.

The thickness of the residual soil (Grade VI to IV) may varies from 1.5 m to 20 m. Thicker soil cover is generally encountered in granite compared to schists, and on hills (higher ground) than the valleys. The presence of core boulders is not very pronounced in the granitic soil profile. Weathered core-stone boulders of several cm to 0.5 m diameter were encountered in the field. This probably indicates core boulders might present in the granite soil profile in small quantities.

Discontinuities

Discontinuities in the rock mass occur as joints, foliation, bedding, faults and shear zones. Mapping of the structural discontinuities was carried out on all available cut slopes on site due to lack of rock exposures. Orientation data (strike and dip) are plotted onto the lower hemisphere stereographic projections to identify the discontinuity sets and their average orientation. For the purpose of slope stability assessment, the study area was arbitrarily divided into 3 structural domains, i.e. Domain A, Domain B and Domain C as shown in Figure 2. Results of the discontinuity mapping are discussed in the following sections.

Domain A

Domain A comprises the hill slopes to the north of the main valley. Structural data were collected from the highly to completely weathered cut slopes in schist along the access road. Stereographic plot of the discontinuity data (Figure 3a) indicates that the rock mass in Domain A contains at least 4 sets of discontinuities (Table 1).

Domain B

Domain B comprises the hill slopes in granite at the northwest and west of the project site. Structural data was mainly collected from the relict structures preserved in the completely weathered cuts in the lower hill slopes in the abandoned vegetables fields. Stereographic plots of the discontinuity data (Figure 3b) indicates that the rock mass is affected by at least 5 sets of joints. Some of the joints are however randomly oriented and could not be easily grouped into any one of the five sets identified (Table 1).

Domain C

Domain C comprises the hill slopes in the southern part of the project site, with similar lithology as Domain A. Structural data was collected from the available cut slopes along the access road and along the earth ditch. The exposed rock is highly to completely weathered schist. Stereographic plot (Figure 3c) indicates that the structural discontinuity in Domain C is almost similar to those in Domain A (Table 1).

SLOPE STABILITY ASSESSMENTS

The slope stability assessment carried out in this study is for a preliminary assessment, i.e. to highlight the potential danger and possible modes of failure that might occur along the existing slopes. Therefore the graphical method

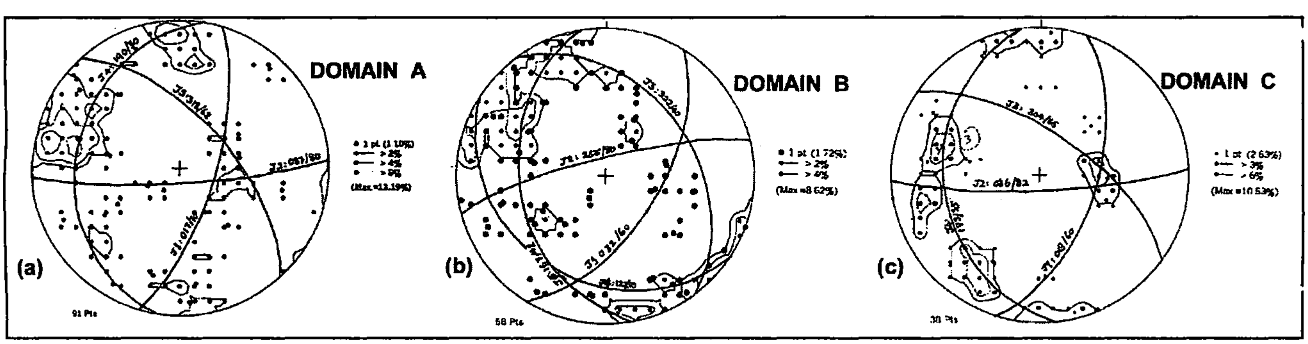

Figure 3. Lower hemisphere stereographic projections of pole to discontinuities in a) Domain A; b) Domain B and c) Domain C.

or kinematic slope stability assessment (Hoek and Bray, 1981) is most suitable. In this stability analyses, the friction angle (q) along the discontinuities for weathered granite is estimated to be 33°, whereas for weathered schist q is about 30°. The presence of soft infilling material such as wet clay in the discontinuity planes may reduce the friction angle to as low as 25°.

In general, for weathered rocks such as those in the study area, the potential modes of failure can either be one or a combinations of the following (Hoek and Bray, 1981):

Circular failure - this type of failure generally occurs within a very heavily fractured rock mass where no identifiable pattern of structures is present.

Planar failure - failure that take place along a dominant discontinuity plane or highly ordered structures, which is parallel or nearly parallel to the slope face.

Wedge failure - commonly occurs at two or more intersecting discontinuity planes.

Toppling or rock fall - failure in hard rock, which can form columnar or block structures separated by steeply dipping discontinuities.

These are schematically illustrated in Figure 4, together with typical examples of the respective stereoplots. Most of the modes of failure described above may occur even in highly to completely weathered rocks (Tajul Anuar Jamaluddin, 1999; Tajul Anuar Jamaluddin and Muhammad Fauzi Deraman, 2000) such as those encountered in the study area.

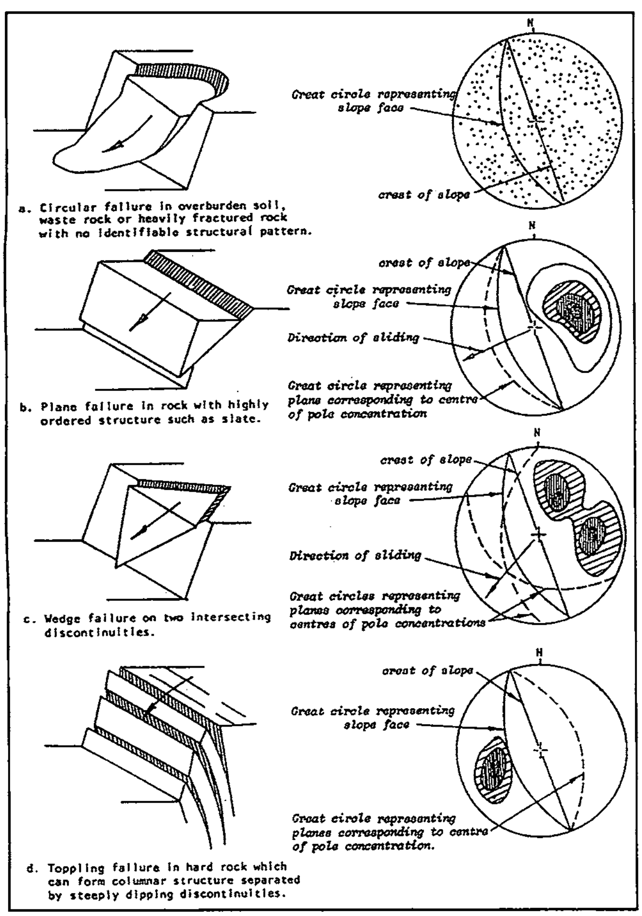

Figure 4. Main types of slope failure and stereoplots of structural conditions likely to give rise to these failures (Hoek and Bray, 1981).

Domain A Slopes

Domain A is further divided into 3 sections, namely Slope A1, Slope A2 and Slope A3, based on their average orientation. Their locations are indicated in Figure 2. General orientation (strike/dip) of Slope A1, Slope A2 and Slope A3 is 082°/45°S, 195°/45°W and 128°/40°SW, respectively.

a) Slope A1

Results of kinematic stability analysis suggest that the existing Slope A1 is not likely to fail. However, if the slope is cut steeper than 45°, it will have a potential to fail in wedge failure due to the intersection of J1 and J2 (Figure 5a). This is evident in the field, where the existing cut slope with 65° angle has undergone wedge failures. This problem can be minimised by making the cut slope angle gentler than 55° with strike maintained at 100°.

b) Slope A2

Slope A2 also has a potential to undergo wedge failure due to the intersection of J2 and J4 (Figure 5b). Because some of the joints in set J4 are daylighting towards the slope face, they may also cause planar or sliding failure. To minimise such risks, it is recommended that any future cut slope in Slope A2 should be cut gentler than 40° with the slope faces striking in 120° direction.

c) Slope A3

Slope A3 also has the potential to undergo wedge failure due to the intersection of J2 and J4 (Figure 5c). This problem can be reduced by making the slope angle gentler than 40° and the slope is cut in 115°-120° direction.

Domain B Slopes

Domain B is further divided into 2 sections, namely Slope B1 and Slope B2 based on the their average

Domain	Discontinuity Sets	Average Orientation (Strike/Dip)	Notes
A (n= 91)	J1	017/70E	Joints
	J2	087/80S	Joints and foliations
	J3	318/62N	Joints with minor faults and shear zones
	J4	190/30W	Predominantly foliations
B (n=58)	J1	032/60E	Joints
	J2	255/80N	Joints
	J3	322/40NE	Joints
	J4	122/30SW	Joints
	J5	167/42W	Joints (minor)
C (n=38)	J1	018 / 60E	Joints
	J2	086 / 82 S	Joints and foliations
	J3	304 / 65 E	Joints with minor faults and shear zones
	J4	173 / 35 W	Predominantly foliations

Table 1. Summary of discontinuities data in Domain A, B and C. (n = number of readings)

orientation. Their locations are indicated in Figure 2. The average orientation (strike/dip) of Slope B1 and Slope B2 are 320°/40°E and 021°/42°E, respectively.

a) Slope B1

Slope B1 has the potential to undergo wedge failure due to intersections of J1, J2 and J3 (Figure 5d). Joint set J3 is considered critical as it is daylighting towards the slope face, and thus has a potential to cause planar or sliding failure as well. The potential of failures is greatly increased if the slope is cut steeper than 45°. Elements of instability may be greatly reduced if the slope is cut in the north-south direction and the slope angle is less than 40°.

b) Slope B2

Under existing conditions (angle £ 42°), Slope B2 shows no signs of major instability. However, if the cut slope made steeper than 50°, the slope has the potential to undergo wedge failure due to intersections of J1, J2 and J3 (Figure 5e). Elements of instability can be reduced if the slope is cut in 010° direction and the slope angle is less than 45°.

Domain C Slopes

Domain C slopes are relatively small and their heights are generally less than 30 m. By assuming the average slope orientation of 240°/40°N (Slope C), results of the kinematic stability analysis (Figure 5f) indicates that the slope has the potential to experience wedge failure due to intersections of J3 and J4. Elements of instability can be reduced if the slope is cut in 270° direction and the slope angle is less than or equal to 45°.

POTENTIAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH SLOPES ENGINEERING

The development of the hilly terrain (the creation of cut slopes) inevitably will involve extensive deforestation or removal of trees. These, in combination with earthworks during development, will inevitably cause direct impacts on the soil and geology of the project site and the adjacent areas. The environmental impacts that are of prime concern due to the creation of slopes are erosion and landslides.

Erosion

In a new development such as this project, two major controlling factors that cause erosions are the removal of vegetation and steepness of slopes. Once the vegetation is cleared, interception of rainfall and transpiration (the return of rainfall to the atmosphere by biological processes) will be greatly reduced. This will result in a drastic increase in runoff volume and velocity. Increased runoff on the hilly terrain will certainly cause substantial soil erosion.

Erosion by surface runoff may take place in the form of rill or gully erosion, notably in a sandy granitic soil or reworked residual soils. Excessive erosion may cause toe undercutting and subsequently induce slope failures.

When soil erosion by water occurs, damage will often not only restricted to the terrestrial environment. Soil removed will affect the nearby watercourses, such as increased siltation and sedimentation, and consequently flash flood in downstream and the surrounding low-lying areas. In this case, the existings quarters and main road located at the downstream area to the east will be at risk of flash floods and mudflows. The Ringlet Lake, which is situated on the east of the main road will also be substantially affected by sedimentation and siltation. The water quality in the reservoir, and subsequently in Sungai Bertam the main river, will be degraded by the silt and runoff from the project site. Although this is an unavoidable impact, particularly during the construction phase, it can be reduced by adapting appropriate mitigation measures.

Landslides

Landslide is one of the hazardous impacts commonly associated with development in hilly terrains. The three principal triggering factors for landslides are excessive rainfall, human activities and earthquakes, although many other factors can contribute towards the slope instability. The main controlling factors are the geology (nature of the underlying bedrock and soil), hydrogeology of the slope and slope configuration. Thus, the key to understanding the stability of rock or residual soil slopes lies in recognizing the geology of the area which includes the geomorphology and hydrogeology of the area, the orientation and properties of the geological structures (discontinuities), the weathering profiles and the mechanical properties of the materials. Thus, each geological domain will have distinctive slope stability problems.

In the proposed site where the cutting of slopes is inevitable to create room for the proposed infrastructures, risks of landslides or slope failures exist. In the hilly terrain such as the study area, landslides can occur in the following general types:

a) Shallow slides in the upper residual soils. These are shallow slides in which the upper zones of the residual soil slide on the underlying weathered rock. This commonly results from the increase in pore water pressure that builds up beneath the residual soil during period of intense rainfall.

b) Block, planar or wedge slide along relict discontinuities. These slides involve movement of a block or a wedge of soil and/or weathered rock along major planes of weakness within the zone of weathered rocks or even within the unweathered zone. These have been addressed in detail in the earlier sections.

RECOMMENDED MITIGATION MEASURES

Mitigation is aim to avoid or minimise the impacts (Morris and Therivel, 1995). The following general mitigation measures are recommended to mitigate impacts associated with the construction of cut slopes in the study

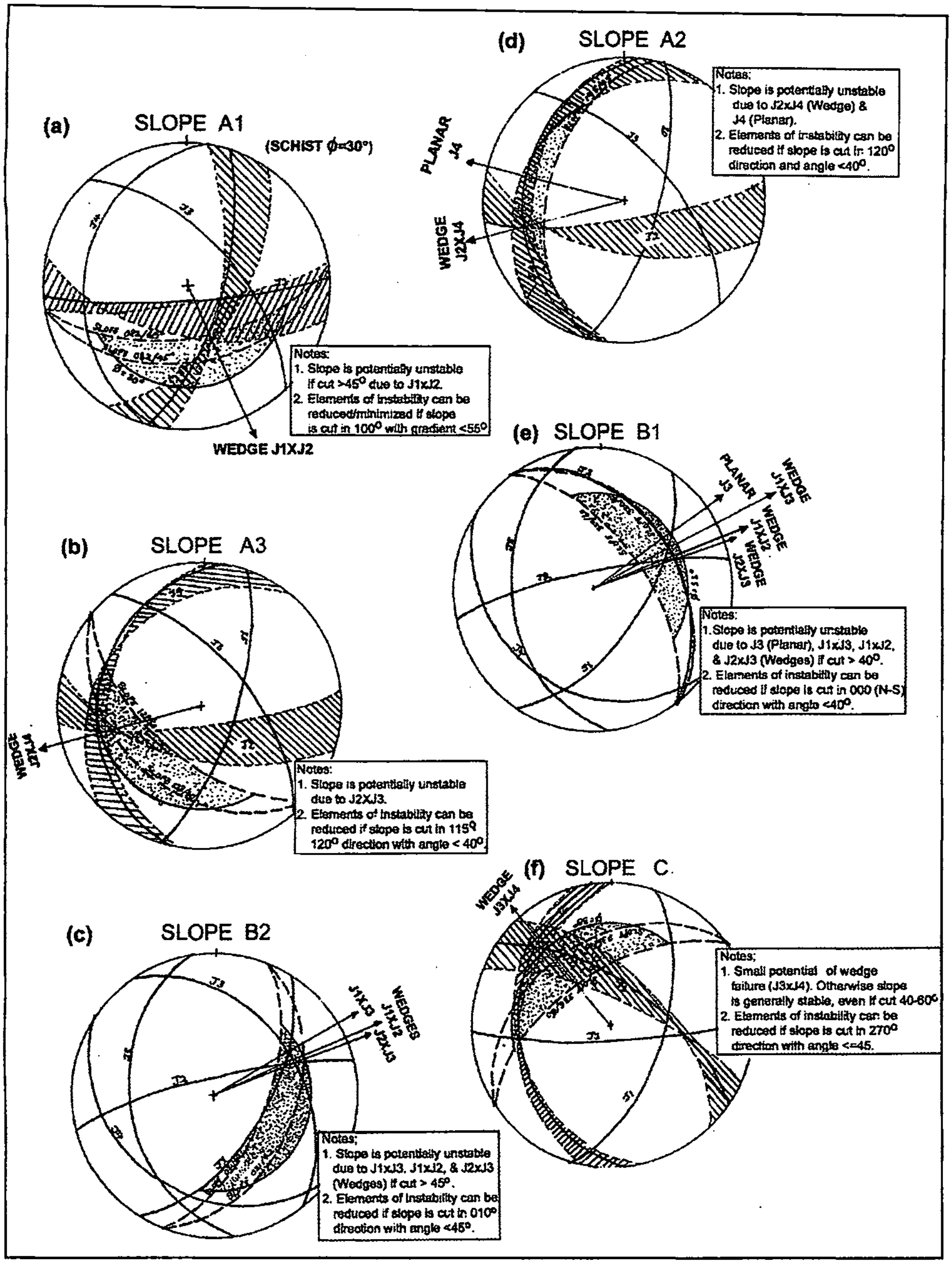

Figure 5. Kinematic stability analyses of the existing slopes in the study area.

area.

i. Where possible, create gentle gradients and avoid steep slopes. Refer to the recommendations given for each domains described in the earlier sections. The recommended cut slopes layout for the study area is shown in Figure 6.
ii. Avoid excessive cutting of natural slopes, excessive earthworks and excavation, unless necessary. Where possible create landscape according to the existing contour (contoured landscape), with appropriate siting of structures, roads and buildings.
iii. Install suitable drainage systems to direct water away from the slopes. Divert run-off originating from upgrade with ditches or proper drainage systems to prevent water flowing over work areas and adjacent low grounds. The drains should be designed to accommodate the maximum rainfall. These drains should be maintained regularly to prevent clogging and overflow over the slopes.
iv. The use of sediment or siltation traps and uncleared buffer strips along rivers can minimise siltation and sedimentation of rivers and the nearby lake.
v. Landslides and other types of slope failures (including erosion) can be minimised or prevented by the following steps:
   a) reduce slope angle, apply bench terraces,
   b) avoid creating slopes with daylighting discontinuities (e.g. faults, joints, relict joints, etc.),
   c) draining of sag ponds and water-filled depressions that occur above the slopes, from which water could seep into the slope body,
   d) install suitable drainage systems to direct runoff

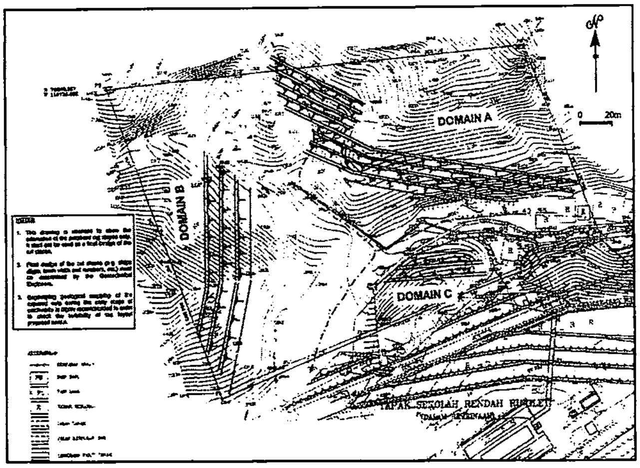

Figure 6. Map showing the proposed layout for future cut slopes in the project site.

away from the slopes and install subsurface drains to reduce pore water pressure and reduce the water table in the slopes,

e) establish vegetative covers on all soil slopes, preferably fast growing plants with sturdy root systems,

f) place additional supporting structures (e.g. soil nails/anchors, buttress wall, etc.) at the foot of potentially unstable slopes to prevent slide or flow at the base of the slopes,

g) reduce the load (weight, shearing stress) on the slope by removing some of the rock or soil high on the slope, and

h) exercise regular maintenance or periodical slope inspection to detect any sign of newly developed instability such as tension cracks, toe undermining, gully erosion.

CONCLUSIONS

Geological inputs required for the preparation of EIA reports may vary from one location to another, depending on the nature of the proposed project and the geology of the project site. The case study presented herein illustrates examples of geological studies conducted on a site located in a hilly terrain. In this example, emphasis has been given on the engineering geology of slopes and landform geomorphology, because the environmetal impacts will be closely related to slope stability and the associated predominant geomorphic processes. By identifying the likely geological and geomorphic processes, suitable mitigation and abatement measures can be adequately proposed.

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