

Engineering geology in Malaysia – some case studies

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Abstract: Engineering geology deals with the application of geology to civil engineering and construction works. The fundamental input in engineering geology would involve, among other things, studies on the lithologies, geologic structures and weathering grades of the rock masses since together they determine the characteristics and behaviours of the rock masses. In addition, project-specific requirements and problems need to be addressed. This paper presents several case studies on Engineering Geology in Malaysia such as: Foundations in Limestone Bedrock, Limestone Cliff Stability, Rock Slope Stability, Dams, Tunnels, Riverbank Instability, Slope Failure due to Rapid Draw-down, Urban Geology & Hillside Development, and Airports. The various case studies presented here are based mainly on the author's ~35 years of past practice and experiences.

Keywords: Engineering geology, case studies, rock slopes, limestone, tunnels

INTRODUCTION

Engineering geology is an applied science dealing with the application of geology and geological methods in civil engineering and construction works. The importance of geology as applied to the development of cities and general civil engineering works has been emphasised repeatedly by Legget (1973), Legget & Karrow (1983), Tan (1991, 2007, 2016), and many others. Numerous case studies can be found in the literature on the application of engineering geology in various engineering projects; perhaps the handbook by Legget & Karrow (1983) would be a good starting point for those interested in reading more about the use of geology in civil engineering works worldwide.

In Malaysia, the engagement of engineering geologists in various civil engineering works has been on the rise in the past three decades or so, in particular during the “construction boom” periods. Mega-projects such as the North-South Expressway, the Light Rail Transit, the Kuala Lumpur City Centre (KLCC) Petronas Twin Towers, the Bakun Dam, the Storm Management and Road Tunnel (SMART) project, the Pahang-Selangor Interstate Water Transfer Tunnel, the Kuala Lumpur International Airport 2 (KLIA2), the Klang Valley Mass Rapid Transit (KVMRT) project, etc. plus numerous other construction projects had witnessed some significant input by engineering geologists; or at the very least where the geological factors came into play and had to be contended with by the project engineers. Undoubtedly, this role of the geologist in civil engineering construction works will be a permanent feature for all future projects.

This paper discusses the roles or applications of engineering geology in civil engineering works. Fundamentals of engineering geology are first discussed, followed by various applications in civil engineering works, using some local case studies as illustrations. The topics on engineering geology and its applications to various civil engineering works, have been discussed at various times by the author previously. Hence, materials in this paper are based mainly on numerous previous publications by the

author, notably: Tan (1982, 1991, 1999a, 2004a, 2004b, 2004c, 2005a and 2005b), among others.

Two recent key references used in the preparation of this paper are: Tan (2007 and 2016).

FUNDAMENTALS OF ENGINEERING GEOLOGY

Engineering geology encompasses three fundamental studies or issues, namely: the lithology or rock type, geological structures, and weathering grades. These three fundamental issues are **ALWAYS** incorporated in any engineering geologic studies, Tan (1998a, 2007 and 2016). Together, they determine the mass characteristics and engineering behaviour of the rock formations encountered at a project site.

Lithology

Lithology means rock type. However, since superficial soils are also important in construction works, lithology here would include rock and soil types, or material types. Lithology is the first consideration since different rock types (and similarly soil types) would have different properties and behaviours. For example, granitic rocks differ from shales or schists. Limestone is yet another type of rock with its unique properties. Owing to the different nature and origin of the rock types mentioned above, the inherent geological structures associated with each rock type are also different. Granitic rocks are often intersected by three or more sets of joints as major structures; shales are dominated by bedding planes; schists are foliated; while limestones are characterised by their unique solution or karstic features. As such, for example, a rock slope cut into these different rocks would have to contend with different geological features or problems.

In addition, the residual soils derived from the weathering of the different rock types mentioned above would differ widely in soil properties. For example, granitic soils are usually sandy, while shales produce silty to clayey soils. Insoluble residues accumulated after the solution of the limestone form unique residual red clays called *terra rossa*.

Structures

Geological structures include a host of features such as joints, faults, bedding planes, foliations, dykes, folds, etc. In general, the major fracture planes such as faults and major joints are the more critical structures since they represent breaks or weaknesses in the rock mass. Rock slope stability, for example, is controlled by the fracture planes. The engineering of rock slopes is based on detailed measurements and analysis of discontinuities using the stereonet, Figure 1, Hoek & Bray (1974), Tan (1999b). Dykes and sills are yet other geological structures that can be important in engineering works. In a major highway cut-slope failure, for example, the occurrence of an aplite dyke played a major role in the failure, Ting & Nithiaraj (1998).

Similarly, the fracture systems in the underlying rock mass would determine seepage losses in dam foundations, bearing capacity, and settlement of buildings. The fracture system, weathering grade, also determine the rock mass quality, *Q*, intersected by a tunnel, for purpose of determining tunnel stability and support measures as well as seepage control, Barton *et al.* (1974), Kveldsvik & Karlsrud (1995).

Weathering

Weathering is particularly important in humid, tropical regions like Malaysia, since intense chemical weathering

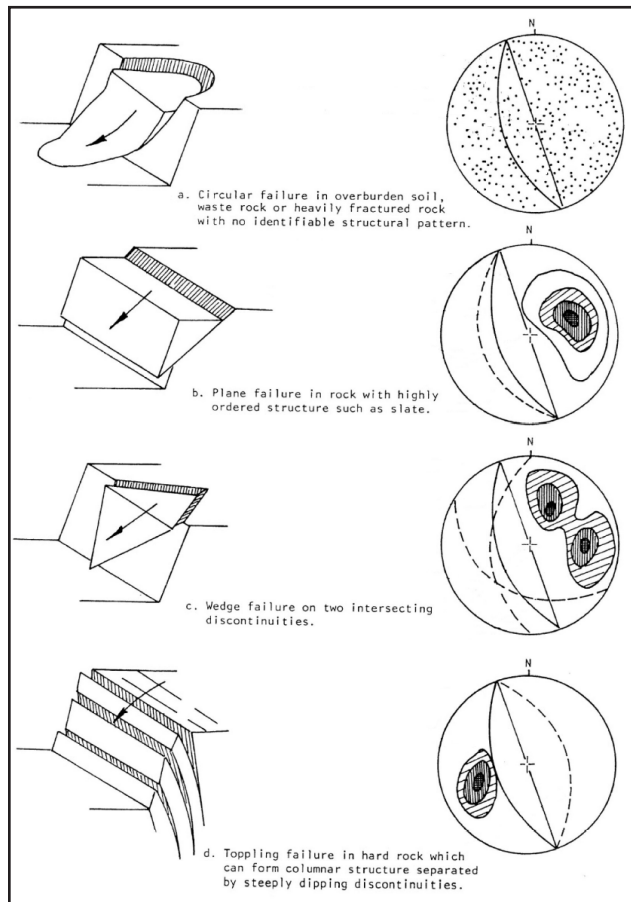


Figure 1: Stereonet plots of main types of rock slope failures, Hoek & Bray (1974).

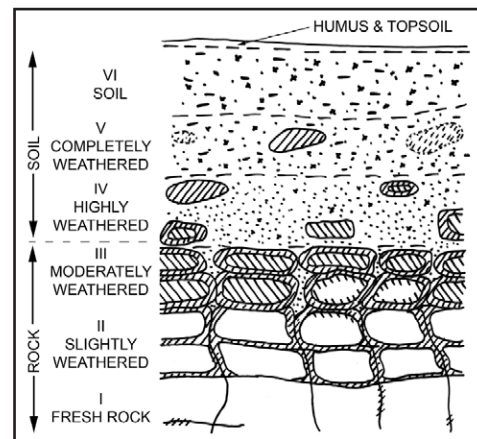


Figure 2: Weathering profile, Little (1969).

reduces rocks to soil-like materials, resulting in thick soil mantles over bedrock formations. Again, the details and thickness of soil cover over rock in weathering profiles differ from rock to rock. In granitic rocks, for example, the thickness of the soil zone is generally around 30 m, reaching up to 50 m in some extreme cases. In sedimentary (eg. sandstone, shale) and metasedimentary (eg. quartzite, phyllite, schist) rocks, the soil zone is thinner, say around 10 m only. For engineering purposes, the standard six-grade weathering classification as proposed by Little (1969), ISRM (1977), is most useful and has been used frequently by many workers, Figure 2. Some local experiences on weathering of rocks in relation to engineering have been summarised by the author, Tan (1995a).

Superimposed on the lithology and structures, the weathering effects can be predominant in controlling the behaviour of the resultant rock or soil materials. For example, in a granitic weathering profile, the grades IV to VI zones behave as soil, while the grades I to III zones behave as rock (rock mechanics applies). This weathering effect is most pronounced and clearly illustrated in the treatment of cut slopes in hilly terrain - in analysis, design, excavation, stabilization, etc. of the cut slopes; utilising either soil engineering or rock mechanics methods depending on the grades of weathering.

Similarly for a construction site, the nature or consistencies of the sub-surface soil strata would depend on the weathering profiles. In residual soils, for example, the soil strata would generally show increasing stiffness with depth, as evidenced by increasing Standard Penetration Test values with depth. Hence the deeper the soil stratum, the higher the bearing capacity and shear strength.

ENGINEERING GEOLOGY APPLICATIONS AND CASE STUDIES

Foundations in limestone

Limestone is rather unique since it is soluble in even slightly acidic waters to produce a host of solution or karstic features, with its associated engineering problems, now well known to many civil and geotechnical engineers. Many papers dealing with foundations in limestone are contained in two major publications by IEM, namely the Proceedings

of the 8th and 12th S.E.Asian Geotechnical Conference held in Kuala Lumpur in 1985 and 1996 respectively. In addition, a more recent Proceedings of the IEM-GSM Forum on “Karst: Geology & Engineering” (1999), also focus on the geology and engineering of limestone.

In the site investigation of limestone bedrock for foundation purposes, the adequacy of the number of boreholes drilled to sufficient depths to define the intricate nature of the limestone bedrock, solution channels, cavities, slumped zones, etc. cannot be over-emphasised. The number of boreholes for a high-rise building site underlain

by limestone bedrock now generally reaches over 100, with the KLCC Petronas Twin Towers project in Kuala Lumpur setting the record at ~ 400!, Tarique Azam (1996). Incidentally, the shifting of the Twin Towers by about 50m from their original proposed positions was partly related to the geologic setting at the site (limestone versus Kenny Hill Formation, etc.). Figures 3a-3b show some limestone bedrock profiles for several high-rise building sites in Kuala Lumpur. Besides pinnacled bedrock profiles, sinkholes, overhangs, etc., the contact zones between the limestone and other rock formations such as granite and the Kenny Hill Formation are of great interest to engineers and geologists alike. The contact zones often exhibit deep solution erosion/solution along the limestone side of the contact zone.

In addition to the irregular or highly pinnacled bedrock profile and solution cavities, the occurrence of very weak slumped materials immediately above the limestone bedrock is yet another geological feature of great concern to the foundation engineers. These weak slumped materials are characterised by their very low Standard Penetration Test (S.P.T.), N values of ~ 0, Figure 4. Their origin or formation plus additional characteristics have been discussed previously (Tan, 1988, 1990a, 2004b), Tan & Ch'ng (1986), Ting (1985). The slumped zone has been encountered in numerous high-rise building sites in Kuala Lumpur, including the KLCC or Petronas Twin Towers site, Hamdan & Tarique (1995). Typically for the Kuala Lumpur area, the slumped zone comprises collapsed materials of the Kenny Hill Formation that overlies the Kuala Lumpur Limestone. The thickness of this slumped zone can vary from several meters to tens of meters. The slumped zone can also occur at great depths, say ~100 m from the ground surface. Note that overlying the slumped zone, materials representing the original, undisturbed residual soils of the Kenny Hill Formation can have high S.P.T. N values of, say 30-50, or even >50, i.e. stiff to hard materials. The slumped zone thus represents a hidden danger or soft “bottom” that can pose problems if undetected earlier during site investigation.

Figures 5a-5b show examples of the highly pinnacled limestone bedrock exposed in a previous tin mine/ex-quarry

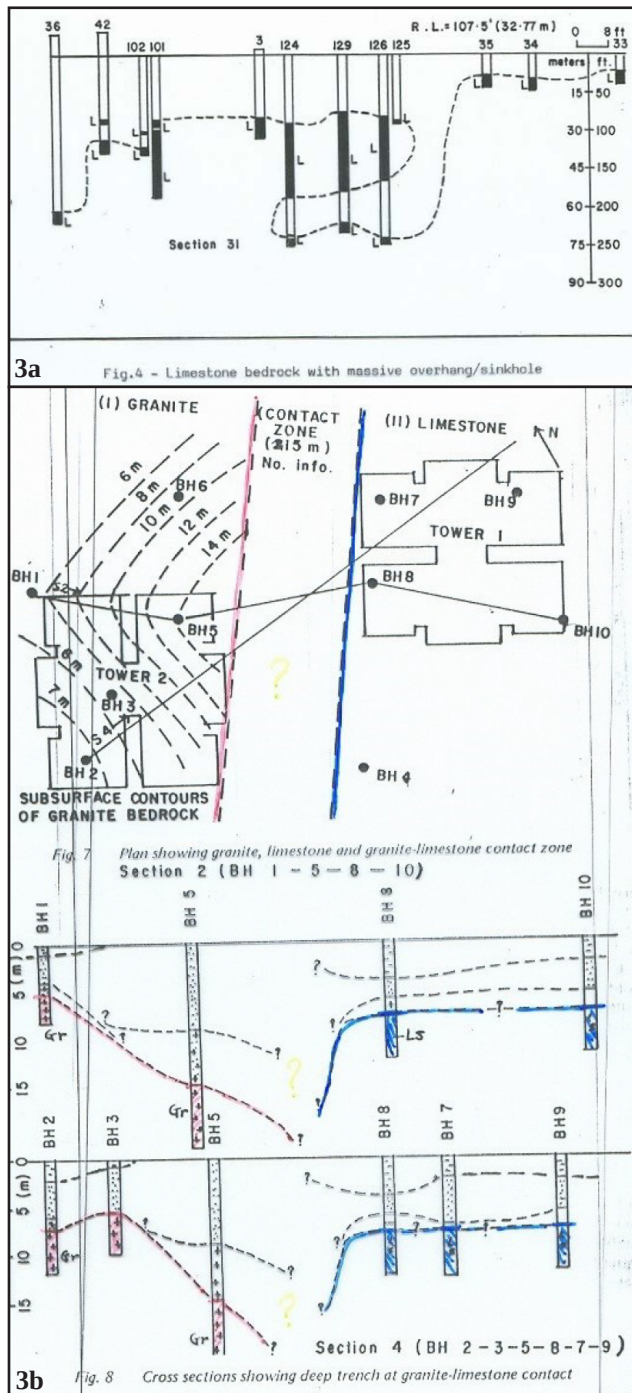


Figure 3a, 3b: Limestone bedrock profiles, Kuala Lumpur.

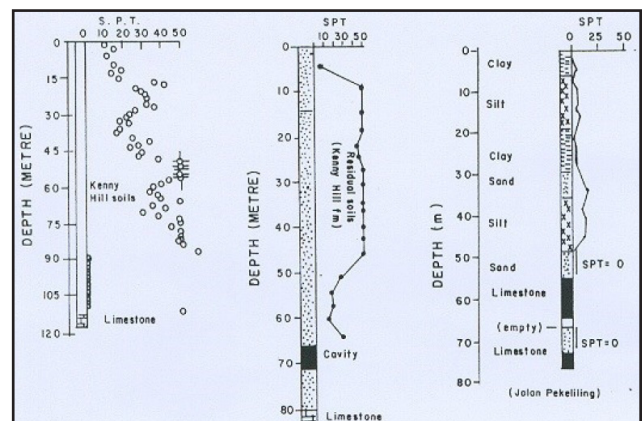


Figure 4: Slumped zone, S.P.T., N=0.

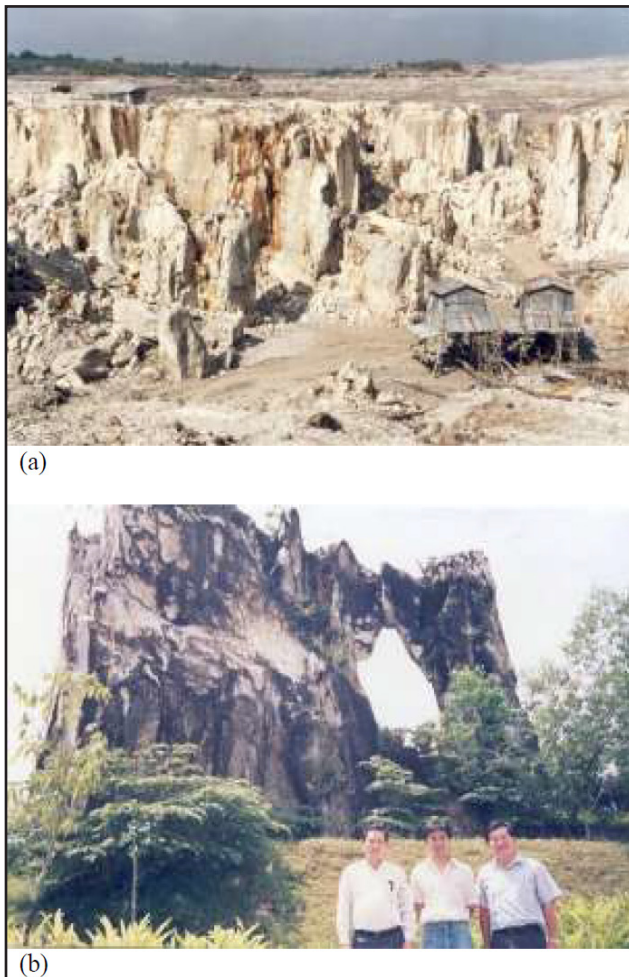


Figure 5a, 5b: Pinnacled limestone bedrock, Sunway.

in the Sungai Way area (now Bandar Sunway), Subang Jaya, a suburb of Kuala Lumpur. Similar exposures of karstic limestone bedrock are retained in the Sunway Lagoon area as they enhance the aesthetics of this recreational site.

Limestone cliff stability

The stability of limestone cliffs is one of the major concerns for development projects near or adjacent to limestone hills, such as around the Batu Caves area in Kuala Lumpur, and the Ipoh and vicinity areas in the Kinta Valley where numerous limestone hills are encountered.

Rockfalls represent one of the major geohazards associated with limestone cliffs, and their past occurrences have been documented from time to time, for example, Shu & Lai (1980), Shu *et al.* (1981), Chow & Abdul Majid (1999), etc.

A major rockfall in 1973 at Gunung Cheroh, Ipoh, which inflicted 40 human fatalities and numerous cows as well, was documented by Shu & Lai (1980). This rockfall involved the collapse of the entire cliff face as a single slab measuring some 33m in length and weighing 23,000 tonnes and was one of the major rockfall disasters associated with limestone hill in the country. The corpses entombed have never been recovered due to the enormous size of the rock slab involved.

The engineering geology of limestone, covering both limestone hills and bedrock, with their associated problems such as rockfalls and sinkholes, cavities, slumped zone, etc. has been reviewed by the author in a previous paper, Tan (1999c). Further details can be referred to in the IEM-GSM forum proceedings on karst/limestone mentioned above. Of particular interest and reproduced here is the case study on the survey of limestone cliffs for urban development purposes in the Tambun (Ipoh) area. The limestone cliffs were surveyed for geological structures (fractures) and solution features, and were then assessed for their stability based on the combination of these features. Hazard maps were then produced to indicate various segments of the cliff faces with differing stability or degree of hazards. Figure 6 shows an example of the hazard map produced for some segments of the limestone cliffs. The results of the survey indicate that the stability of the various limestone cliffs was controlled by-and-large by the north-south trending bedding planes, e.g. Figure 7. More details on this case study are contained in Tan (1998b, 1998c).

Figure 8 shows a case study on the assessment of limestone cliff stability adjacent to a water tank site in Batu Caves, Kuala Lumpur, Tan (2005a). The stability of the limestone cliff is of great concern, and again, assessment is based on the combination of geologic structures and solution features present at the limestone cliff in question.

Limestone hills form picturesque backdrops which attract many housing/condominium development projects. Two case studies, both located adjacent to the Batu Caves limestone hill in the Kuala Lumpur area are presented here, Tan (2016). It is interesting to state at the outset that, in both cases, quite a bit of planning works, etc., including physical models of the condominium, have already been carried out, before the developer decided to call in the geologist to check on the stability of the limestone cliff adjacent to the planned condominium!

As it turned out, the limestone cliff in condominium “A” showed a major overhanging cliff, with evidence of previous rockfalls (rockfall debris) at the base of the cliff.

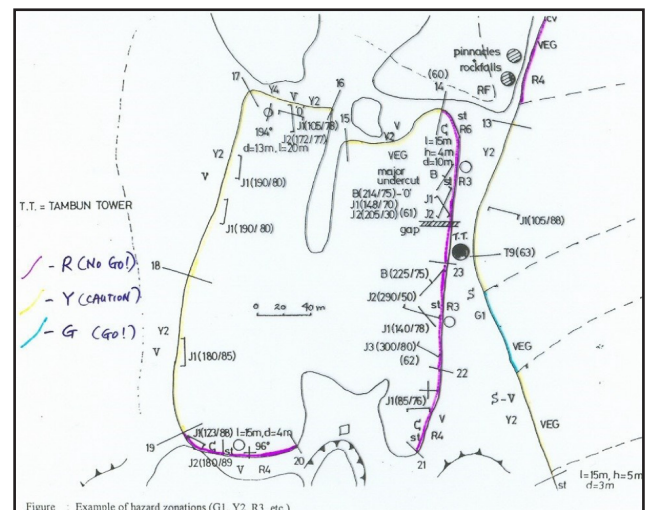


Figure 6: Rockfall hazard map, Tambun, Ipoh.



Figure 7: Sub-vertical bedding planes giving rise to rockfall, Tambun, Ipoh.



Figure 8: Water tank at Batu Caves limestone cliff, Kuala Lumpur.

It was deemed unsuitable for development. In the case of condominium “B”, the adjacent limestone “cliff” was in fact an ex-quarry face, cut back to $< 90^\circ$. In addition, the original limestone beds which were initially overhanging, had also been cut back to $< 90^\circ$. Nearby limestone beds were also

dipping at $\sim 70^\circ$ and appear stable. Hence, condominium “B” was deemed suitable for development.

While condominium “A” was eventually rejected by the local authorities for development (a decision which the author concurs with), condominium “B” was also rejected by the JMG (Jabatan Mineral dan Geosains/Dept. of Minerals and Geoscience) – a decision which the author does not concur with. The decision by JMG is based simply on the rule-of-thumb that no development is allowed adjacent to the limestone cliff within the buffer zone of 2x the height of the cliff. This rule-of-thumb on the buffer zone is archaic, to say the least. It is a rough guide only when no investigations have been carried out on the limestone cliff, and serves as a preliminary screening tool. When detailed investigations have been conducted on the limestone cliff concerned, such as in the case of condominium “B”, then this rule-of-thumb should not apply, see Tan (1998b, 1998c). Besides, if one looks at the aerial photo of Batu Caves limestone hill, one can see numerous housing projects surrounding the limestone hill, many of which are well within the 2x height buffer zone!

Figures 9 and 10 show the limestone cliffs concerned.



Figure 9: Overhanging limestone cliff adjacent to proposed condominium “A”, Batu Caves, Kuala Lumpur. Lower half of cliff has fallen previously, producing rockfall debris at the base of the cliff.



Figure 10: Limestone cliff adjacent to proposed Condominium “B”, Batu Caves, Kuala Lumpur. The cliff face is an ex-quarry face which has been blasted to $< 90^\circ$. Bedding planes can be seen on the lower right corner of the quarry face.

Rock slope stability

Highways and roadways require significant engineering geological input. Besides mapping the highway route geology so that the rock and soil types traversed by the highway can be known in advance, geological inputs during the construction stage are also very necessary. Excavation and treatment of cut slopes, sourcing for construction materials such as rock quarries, earth borrow pits, etc. require engineering geological input. The various works involved in the geological and hydrogeological investigations for highways and roadways have been summarised in Tan (1994a). Example case studies on the engineering geology of highways and roadways are presented in Tan (1987, 1992, 1994b, 2013a, 2016) which include the Karak Highway, parts of the North-South Expressway, a rural road in Sarawak and the new access road to Murum Dam, Sarawak.

Detailed mapping of cut slopes along an existing highway has become a routine work for the engineering geologist involved in the assessment of cut slope stability and in post-failure investigations for remedial works. Figure 11 shows a sample field survey sheet for cut slopes for such purposes. Note that the three fundamental items in engineering geology, namely lithology, structures and weathering form the gist of the survey sheet. Assessment of slope stability can then be carried out using the stereonet method of Hoek & Bray (1974). The data and sketches on weathering profiles can also help in slope treatment

or remedial works, such as proportioning rock and soil slopes for different treatment works. Hydroseeding, for example, is only suitable for soil slopes, i.e. grades IV to VI materials only. Blindly spraying the entire cut slope without due regard to the weathering grades/profiles is wasteful, to say the least.

Figures 12a-12b provide examples of graphitic schist soil slope failures along the Senawang - Air Keroh Highway. Route geology along the Senawang - Air Keroh Highway shows the predominance of graphitic schist towards the Air Keroh end of the highway. The survey results show that the majority of cut slope failures occurred in the graphitic schist material, indicating geological or material control in the failures. Figure 12c shows secondary minerals formed from the oxidation and hydrolysis of pyrite contained in the graphitic schist – these chemical reactions involving the pyrite cause weakening of the graphitic schist soils.

Another major cut-slope failure involving graphitic schist soils at the Lojing Highway is shown in Figures 13a-13b. Slope failure occurred at the same spot here at least three times, twice after re-grading of the slope, indicating again the weak nature of the graphitic schist soils. These repeated failures of the same slope are reminiscent of similar failures involving graphitic schist along the Senawang-Air

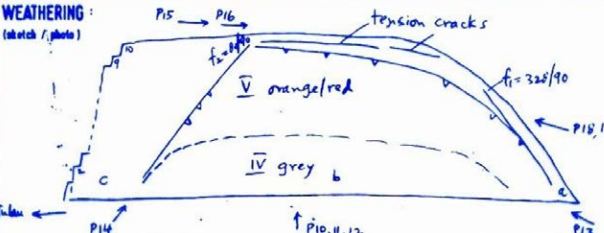
KJD Road, Sarawak		DATE :
LOC : KM. 9300 L	A	N/B M S/D
LITHOLOGY : Shale. Red/orange on grey. Laminations mm-cm.		
STRUCTURES : a) 106/60, 120/70 (I = joints, F = faults, etc.) b) 121/5-10, 120/5-20 (undulating-disturbed?) c) 124/60, 145/40; Fo = foliation D = bedding		
WEATHERING : (sketch / photo) 		
SLOPE GEOMETRY : i) strike = 290° ii) height = 20 m iii) length = 100 m iv) angle = 45°		
NOTES ON STABILITY / FAILURES : (erosion, seepage, stabilization, etc.) Major failure of entire slope face. Foliations of grey shale ~ subhorizontal along base (disturbed?) Tension cracks at crest (~2 m depth) Toppling along foliations at right (P18, 19)		
PHOTO NO : 10 to 16, 19, 19	SAMPLE NO : (R = rock, S = soil)	

Figure 11: Field survey sheet for cut slope.



Figure 12a, 12b: Graphitic schist soil slope failures, Senawang-Ayer Keroh Highway.



Figure 12c: Secondary minerals on graphitic schist, Senawang-Ayer Keroh Highway.

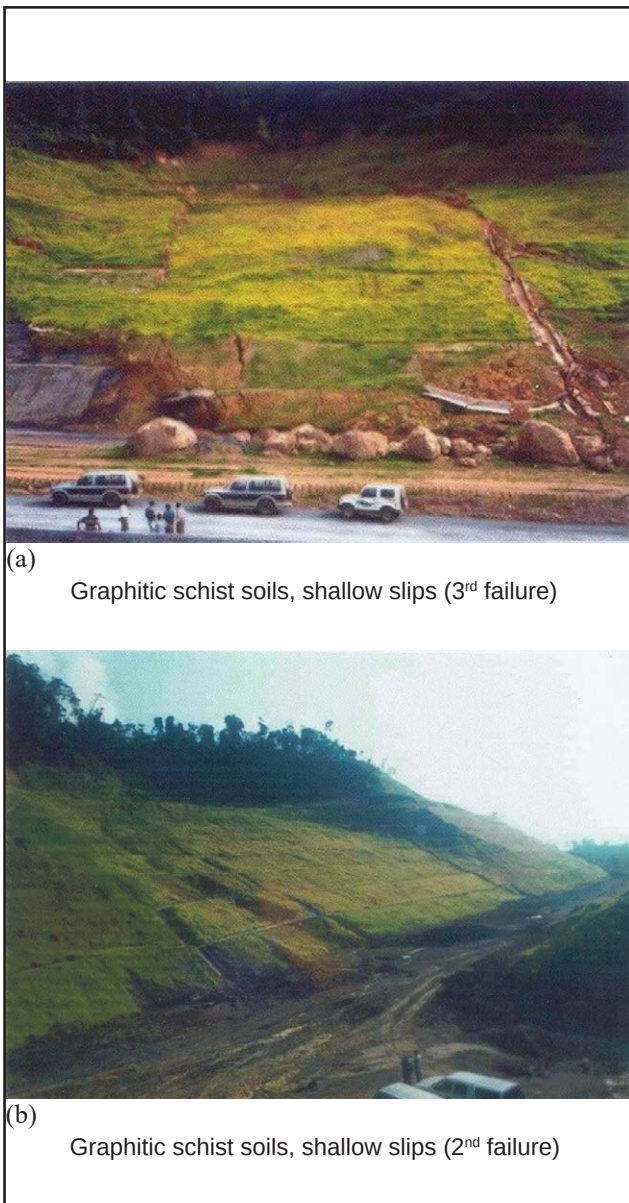


Figure 13a, 13b: Failures in graphitic schist cut slopes, Lojing Highway.

Keroh Highway, and again clearly illustrates the very weak nature of the graphitic schist soils.

Yet another major slope failure involving the graphitic schist soils occurred along the North-South Highway near Rawang - again, slope failure occurred repeatedly even after re-grading. The slope has since been practically “flattened”, Figure 14.

Slope failures in graphitic schist soils deserve special mention. This topic has been dealt with in the previous paper, Tan (2007). An updated paper on this topic is presented in Tan (2011, 2013b). The slope failures in graphitic schist soils (residual soils) involve soil mineralogy (pyrite, etc.) and soil chemistry (acid sulphate soils, acid mine drainage or acid rock drainage). Further details of these related topics can also be found in the following publications, ICE Manual of Geotechnical Engineering (2012).

In the case of a rural road in Sarawak, shale slopes are the problematic slopes compared to the sandstone slopes; in addition, structures such as bedding planes/foliations and faults, produce the major slope failures, Figures 15a-15b.

Figures 16a-16b show classic, textbook examples of planar and wedge failures in granite rock slope for the SILK highway in Kajang. Detailed mapping of the various major joint sets in the granite rock mass along the highway is necessary for rock slope stability analysis and implementation of remedial measures such as rock bolting, etc.

Rock slopes still form a major undertaking by Engineering Geologists. This is not surprising since rock slopes can involve more geological input and complex geology – matters which the majority of civil/geotechnical engineers are not very comfortable with, to say the least. Also, the traditional trainings by geotechnical engineers deal more with Soil Mechanics, hence soil slopes, rather than Rock Mechanics/rock slopes.

A recent, interesting case study on rock slopes deals with sedimentary rocks of the Belaga Formation in Sarawak. A new access road to the Murum Dam in the interior Kapit Division of Sarawak traverses interbedded sandstone and shale of the Belaga Formation. These rock strata are folded



Figure 14: “Flattened” cut slope in graphitic schist, N-S Highway near Rawang.



Figure 15a, 15b: Slope failures controlled by bedding planes and faults, Sarawak rural road.

and faulted, and depending on the orientations (dip direction/dip) of the bedding planes with respect to the orientation of the cut slope at each and every location/chainage, the resulting cut slope can be stable or subject to various instability problems. The stereonet method, Hoek & Bray (1974), is the common method adopted in the assessment of the stability of each individual cut slope. In this particular case study, the bedding planes of the sandstone and shale are the key, major structures controlling the stability of the rock slopes. In addition, minor joint sets within the thick or massive sandstone beds can also result in some instabilities and give rise to planar slides or rock falls. The black, carbonaceous shale beds, due to the nature of the weak materials, can also give rise to ravelling and erosion problems, ultimately causing the shale beds to fail.

Figure 17 shows some major plane failures involving the sandstone beds of the Belaga Formation. Figure 18 shows ravelling and erosion of the carbonaceous shale which resulted in the slope failure. Further details can be referred to in the report by Tan (2013a).

Another case study of rock slope stability involves also the same Belaga Formation at the nearby Bakun Dam in Sarawak. Slightly downstream from the Bakun Dam, a major high rock slope suffers from a series of toppling failures due to a major set of sub-vertical joints that strike sub-parallel to the rock slope. The same set of joints can be traced from the base of the slope to the top of the slope, and as the joints open up, they form a series of potential toppling failures.

Figures 19a and 19b show some examples of these toppling failures.

Yet another case study on rock slope, albeit a minor case study, involves the Kenny Hill formation in the Kuala Lumpur area. What is interesting in this case study is that

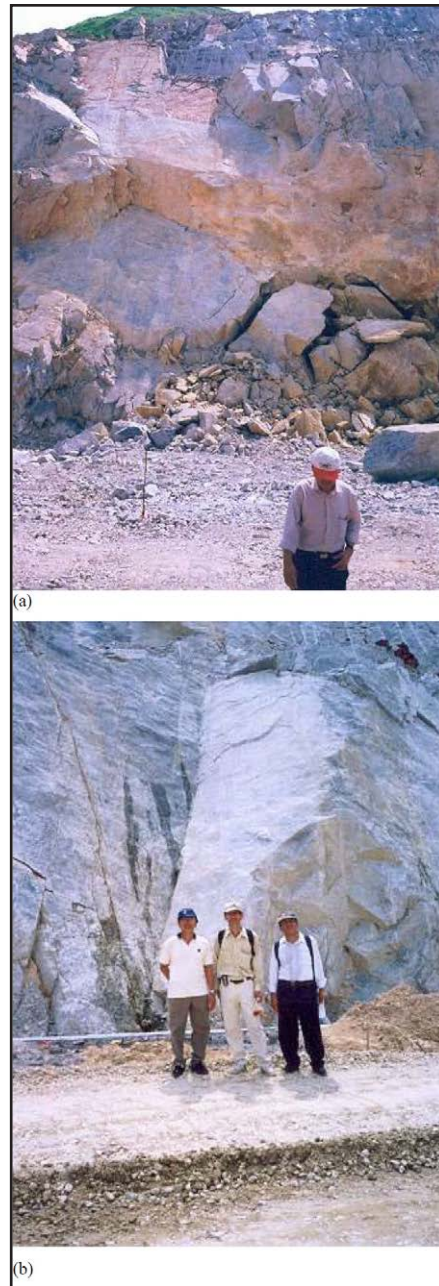


Figure 16a, 16b: Classic examples of planar and wedge failures in granite cut slope, SILK highway, Kajang.



Figure 17: Major plane failures along bedding planes in sandstone of the Belaga Formation, Sarawak.



Figure 18: Failure in black carbonaceous shale due to ravelling and erosion, Belaga Formation, Sarawak.

the instability and potential rock falls involving the quartzite rock slope is caused by roots of large trees penetrating the joints in the quartzite rock, and wedging out the blocks or wedges of rock. This is a classic case of root wedging and destabilizing the rock slope, in contrast to plants/plant roots being used as reinforcing elements for stabilizing soil slopes. As remedial measures, the roots were dug out/killed off, and the large trees growing on top of the rock slope were all chopped down (much to the chagrin of the landscape guys), among other things.

Figure 20 shows the example of root wedging and destabilizing of the rock slope.

Dams and damsite investigations

Of all the engineering works, dams are perhaps the most interesting and challenging for the engineering geologist. Damsite investigations not only cover the main damsite foundations; they also include other possible saddle dams, diversion tunnels, spillways, dam abutments, and the entire reservoir and catchment areas. Other investigations would include material survey for rock quarries, earth/clay borrow pits, sources for construction sands, etc. The site and regional geologic settings, including seismic risk, reservoir induced seismicity (in the larger dams), potential major fault movements/reactivation, etc. have to be dealt with. Faults are particularly relevant since dams are built across rivers, and often rivers flow along fracture traces or fault lines. Thus, possible problems from reactivation of fault movement, seepage losses, need for grouting of dam foundation, permeability tests, etc. are matters of great concern in the investigation of damsites. The type of dam selected can also be dictated by the availability of materials: for example, rockfill versus earth dam depending on the availability of suitable rock or soil at close proximity to the damsite.

A review of some local experiences in damsite investigations and related issues can be referred to in Tan (1995c). Details of individual case studies on dams are contained in Tan & Wong (1982), Au Yong & Tan (1984), Tan (1983a, 1994c, 1994d). In the case of the Tawau dam



Figure 19a: Opening of sub-vertical joints in sandstone due to toppling failure, Bakun Dam, Sarawak.



Figure 19b: Toppling failure due to sub-vertical joints in sandstone, Bakun Dam, Sarawak.



Figure 20: Root wedging along joints in quartzite of the Kenny Hill Formation, Kuala Lumpur.

in Sabah, the volcanics in the area (andesite and basalt) were mostly weathered to thick layers of dark brown silty soils, with only minor, isolated occurrences of fresh basalt (with its typical polygonal, columnar jointing) at some

distance upstream from the damsite. Though three small hills representing stocks of an intrusive, igneous rock (diorite) occur near the damsite, due to environmental and other landuse considerations, the rock has to be procured from the hill located furthest away from the damsite, hence increasing the cost of the project. In a detailed (1999) investigation of a proposed damsite in Sarawak, the dam type selected is likely to be changed from the originally proposed rockfill dam to an earth dam due to the lack of suitable rock source not too distant from the damsite. Incidentally, the use of a helicopter to fly over the damsite and reservoir area can be very fruitful and cost-effective, since ground survey can be hampered by poor accessibility of forested areas associated with dam projects.

Tunnels

Construction of tunnels and tunnelling are rather specialised engineering projects that require advanced technology and know-how. Investigations for tunnels are targeted towards the determination and classification of the quality of the rock masses along the tunnel alignment, for the purpose of assigning the type of tunnel support or support systems along the various segments of the tunnel. The method of tunnelling adopted, for example drill-and-blast (New Austrian Tunnelling Method, NATM) versus tunnel boring machine (TBM), would also depend on the type and quality of the rock masses. Tunnel investigations involve drilling along the tunnel alignment prior to construction, and then detailed mapping of geology and fractures/discontinuities during tunnelling. Various classification systems in relation to tunnel support and rock quality have been proposed, the Norwegian system being the most widely used and accepted worldwide. Details of the Norwegian Q-system are contained in the Proceedings of Seminar on Tunnelling in Weak Rocks, June 1999, Kuala Lumpur and also in Barton *et al.* (1974), Kveltsvik & Karlsrud (1995), and Barton (2006).

In addition to the tunnel proper, the tunnel portal areas are subject to slope instability problems due partly to the greater degree of weathering of the rocks at the portal areas. These areas are thus often supported by heavy steel sets in the tunnel besides other slope stabilisation measures (guniting, rock bolts, etc.) at the portal slopes.

Figures 21a-21b show highly fractured granite and heavy steel sets support for the highly fractured and sheared granite in the diversion tunnel of the Sungai Selangor dam at Kuala Kubu Baru.

Tunnelling activities in Malaysia have been summarised by Ting *et al.* (1995, 2006), Tan *et al.* (2012). While the conventional Drill-and-Blast method of tunnelling was and continues to be widely adopted. In recent years there has been a significant increase in the use of Tunnel Boring Machines (TBM's) for major tunnelling projects, e.g. the SMART project, and the KVMRT tunnels in Kuala Lumpur. Some earlier case studies can also be found in Tan (1983b). In the diversion tunnel of the Upper Muar dam, numerous vertical faults were not detected during the site investigation stage which utilised only a limited number of boreholes, all



(a)



Figure 21a, 21b: Highly fractured granite and steel sets support, diversion tunnel, Sg. Selangor dam.

vertical (no inclined boreholes). During the excavation of the tunnel by the drill-and-blast method, frequent collapses and excessive over-breaks occurred when the tunnel intersected the vertical faults with their crushed and weathered materials. The excessive over-breaks led to extra concreting for the tunnel linings, hence claims for additional works and some disputes. This simple example illustrates the need for adequate and suitably conducted boreholes (number plus inclined boreholes if faults are vertical).

Geological input in tunnelling, needless to say, is a necessary pre-requisite to ensure the “smooth” running and successful completion of the project, hopefully without too many “unforeseen” surprises and problems.

Tunnelling projects completed or on-going in the Kuala Lumpur area include: the SMART tunnel/project, the KVMRT tunnels, etc. Various forms of tunnel boring machine (TBM) were employed in these projects. The geology of the Kuala Lumpur area, i.e. karstic limestone, the Kenny Hill Formation, the granite and allied rocks (granitic dykes, quartz veins and dykes), faults, etc. feature strongly in the construction of these tunnels. In addition, the weak alluvial deposits and mine tailings/slime which are often found filling the deep troughs within the limestone pinnacle zone further exacerbate the problems.

The karstic limestone with its myriad of problems such as the highly irregular bedrock profile or pinnacle zone, cavities/solution channels, slumped zone with S.P.T. = 0, etc. has contributed to the formation of sinkholes and subsidence during tunnelling. The quartzite rock of the Kenny Hill Formation, with unconfined compressive strength, UCS = 300 MPa, has also caused problems to TBM cutters and caused delay in the tunnelling. Highly abrasive quartz dykes would cause high wear and tear of the TBM cutters, and slow down the progress of the TBM. In addition, serious water ingress into the tunnel from major fault zones, quartz dykes, limestone cavities/solution channels would interfere with the progress of the TBM.

Figures 22a and 22b show some karstic limestone in the Kuala Lumpur area, exposed by previous tin mining and limestone quarrying works. It is not difficult to envision the difficulties associated with tunnelling in such ground conditions. The highly variable ground conditions within short distances (tunnel face varying from full face rock, mixed face rock-soft soil, to full face soft soil) would be the key, major factors affecting the TBM works.

The Pahang-Selangor Interstate Water Transfer Tunnel was completed recently (but unfortunately still no water

flowing in the tunnel yet to-date!). This tunnel traverses mostly granitic terrain, and intersects a number of major faults in the granite. It cuts through the Main Range granite from Pahang to Selangor, and reaches a maximum depth of 1-1.2 km (deep tunnel). As such, there were high ground stresses at some sections of the tunnel, inducing spalling and rock burst problems. *In-situ* measurements of ground stresses were also carried out. Major water ingress problems and collapses were also encountered during the construction of the tunnel, which employed tunnel boring machine (TBM) – see Pittard (2013) and Matsumoto (2013) for further details on Engineering Geology, and Tunnelling Methods/TBM/Drill and Blast in this project.

Riverbank instability

Collapse of river bank is a natural phenomenon, part and parcel of the geological processes in the widening of rivers. Riverbank instability becomes a major concern for riverine townships or settlements built along major rivers, such as along the Batang Rajang (Rajang River) in Sarawak. Numerous major riverbank collapses affecting infrastructures in some of these riverine townships have been documented, Tan (2001). Figure 23 shows an example. The weak nature of the alluvial deposits constituting the riverbank slopes and rapid fluctuations (especially lowering) of water levels are some of the major causes for the slope failures.

Slope failure due to rapid draw-down

Rapid draw-down triggering slope failure is a well known phenomenon. A classic example is shown in Figure 24. The pumping of water in an ex-mining pond has triggered the drastic failure of the slope adjacent to the pond, destroying newly completed houses built on top of the slope.

Urban geology and hillside development

Urban geology and hillside developments are major topics for the engineering geologist. As the name implies, urban geology is the application of geology to urban development, as amply illustrated in the book by Leggett (1973). The case of the collapse of the Highland Tower in 1993 also brought to centre stage the problems associated

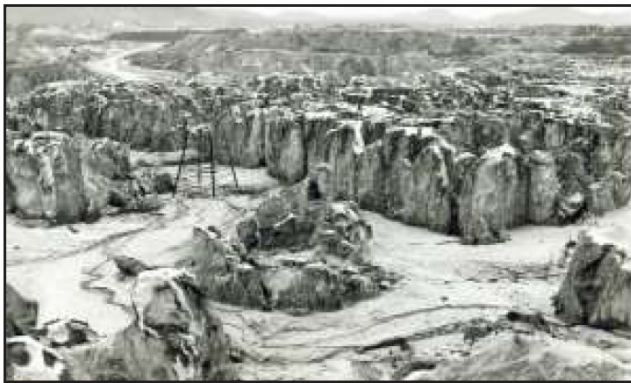


Figure 22a: Limestone pinnacles/bedrock exposed by previous alluvial tin mining, Sungai Way (now Bandar Sunway), Kuala Lumpur.



Figure 22b: Limestone pinnacles/bedrock exposed by previous alluvial tin mining, Sungai Way (now Bandar Sunway), Kuala Lumpur.



Figure 23: Riverbank instability, Sarawak.



Figure 24: Rapid draw-down of mining pond triggering slope failure and destroying houses, Kuala Lumpur.

with hillside development, not only in Kuala Lumpur but also in other urban centres in Malaysia. Useful papers related to engineering geology and geotechnical engineering in hillside development are contained in the Proceedings of the Symposium on Hillside Development: Engineering Practice and Local By-Laws (1995) published by IEM. Geologic input and engineering geology in urban and hillside development have been discussed previously, Tan (1986a, 1986b, 1990a, 1990b, 1993, 1995b), Tan & Komoo (1990). In addition to the problem of limestone bedrock and limestone cliffs for the Kuala Lumpur and Ipoh areas, other urban and hillside development problems include landslides in its widest definition, involving both rock and soil materials, including man-made fill, mine tailings, colluvium, etc. The fundamentals of engineering geology, namely: lithology (material type), structure, and weathering are needed input in the various studies on urban and hillside development, even in the case of simple housing projects located near hill slopes. Figures 25a-25c provide some examples of slope failures for housing development projects located in hilly terrains in the Kuala Lumpur area. Survey of rock slopes and assessments of potential instability problems were made to aid in the planning and implementation of slope stabilization measures.

Hillside development is a rather “hot” topic, especially in the Klang Valley/Kuala Lumpur area where, due to the shortage of flat land within the Klang Valley, many development projects are now chasing up the hills. The numerous high-profile disasters involving major landslides and fatalities within the last two decades, starting with the Highland Tower collapse in 1993, continue to put this topic in the lime light – see Ooi & Ooi (2009) for further details on these major landslides and disasters. Some case studies on hillside developments are presented below:

Popularly known as the Damansara 21 project, this hillside development plans to build 21 units of high-end bungalows on a slope/sloping land. Preliminary works were carried out, including stabilization of the upper part of the slope with contiguous bored piles, etc. The site was located within the Kenny Hill Formation, with the rock strata mostly sub-horizontal in orientations, hence stable. A



(a)



(b)



(c)

Figure 25a-25c: Slope failures associated with housing projects in hilly terrains, Kuala Lumpur.

minor incidence involving some surficial fill materials/soils caused some adverse publicity, in addition to protests from residents at the base of the slope. The last straw came when the Bukit Antarabangsa landslide/disaster occurred in 2008, when the project was slapped with a stop-work order from the authorities. Today, the site is covered entirely by mature trees, with no sign of any future development on this site.

Figure 26 shows the project site during the early stage of construction.



Figure 26: Housing development on slope underlain by the Kenny Hill Formation, comprising interbedded quartzite and phyllite, Kuala Lumpur.

Airports

Two case studies on airports are presented below, to illustrate the contrasting geologies/soil strata, and hence the contrast in construction difficulties/cost, etc. Simply put, these two case studies should highlight the importance of “site selection” in avoiding problematic grounds/soils and associated construction and post-construction problems.

New LCCT/KLIA2. The new Low Cost Carrier Terminal/ Kuala Lumpur International Airport 2 is sited west of the original existing KLIA, nearer to the west coast of Peninsular Malaysia. It falls within the coastal deposits, with thick marine clay of > 30m, peat and organic soil deposits, loose sands, etc. Figure 27 shows the isopach map of the soft soil deposits. With such problematic materials, it is no wonder that

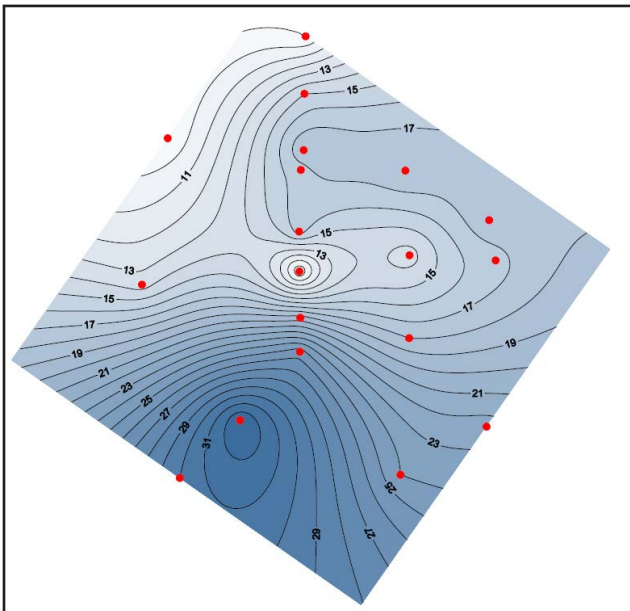


Figure 27: Isopach map of soft soil deposits (marine clay/peat/organic clay), KLIA2, Sepang. Maximum thickness of the soft soils exceeds 30m.



Figure 28: Ponding at KLIA2 – “Now everyone can swim” (from Malaysiakini, July 2015).

numerous construction problems and serious delays ensued, with some of the problems continuing post-construction (e.g. long term settlement of the underlying soft clays resulting in cracking of pavements, ponding/flooding after heavy rains, etc.). As the story goes, the initial site chosen for KLIA2 was north of the KLIA, where the underlying geology comprises residual soils and rocks of the Kenny Hill Formation, minus all that soft materials of the coastal deposits and all in all less problematic – so wither the “site selection”?

Figure 28, taken from a recent website posting, shows the continuous problem of serious ponding/flooding at KLIA2 – interesting enough, the heading for the photo was “Now everyone can swim”, a play on the slogan “Now everyone can fly” by a local, very successful airline.

Senai Airport. The new development and extension of the Senai (Johor Baru) airport was relatively non-problematic, partly due to the favourable underlying geology. The entire site is underlain by residual soils and bedrock of granite, with much of the construction materials (soil borrow pits, etc.) available on site. This is in stark contrast to the soft soil deposits of KLIA2.

CONCLUSIONS

Engineering geology is, needless to say, important in various engineering construction projects. Engineering Geology in relation to various civil engineering works are discussed in this paper. Fundamental input of engineering geology in many engineering projects would include studies on lithology, structure and weathering grade, as these factors control the behaviour of the rock mass.

Numerous local case studies are provided, and references are cited and listed below for the reader who may wish to seek further details on some of the case histories mentioned.

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