Urban geology of Kuala Lumpur and Ipoh, Malaysia

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Abstract: Kuala Lumpur and Ipoh are two major cities in Malaysia. They provide good examples of the application of geology to urban construction and development in Malaysia. The geologic settings of Kuala Lumpur and Ipoh are strikingly similar, with limestone bedrock, granitic hills, and mine wase deposits that are comparable. As a consequence, very similar engineering geologic problems have been encountered in both cities and their immediate vicinities, including subsidence and sinkholes, landslides and rockfalls, foundation problems in limestone bedrock, problems with ex-mining grounds (slime, tailings, mining ponds). This paper discusses the engineering geologic problems in these two cities, and provides case histories as illustrations. The fact that engineering construction problems are closely controlled by the local or site geological setting cannot be over-emphasised. Experience gained in one area can be usefully applied to tackle problems in another area with similar geology.

Resume: Kuala Lumpur et Ipoh sont deux villes principales en Malaisie. Ils fournissent de bons exemples de l'application de la géologie à la construction et au développement urbains en Malaisie. Les arrangements géologiques de Kuala Lumpur et d'Ipoh sont de façon saisissante semblables, avec la roche en place de pierre à chaux, les collines granitiques, et les dépôts de wase de mine qui sont comparables. Comme conséquence, des problèmes géologiques de technologie très semblable ont été produits dans les deux villes et leurs proximités immédiates, y compris l'affaissement et les effondrements, éboulements et rockfalls, les problèmes de base dans la roche en place de pierre à chaux, problèmes avec les raisons d'ex-extraction (boue, produits de queue, étangs d'extraction). Cet article discute les problèmes géologiques de technologie dans ces deux villes, et fournit des histoires de cas comme illustrations. Le fait que machinant des problèmes de construction soyez étroitement contrôlé par l'arrangement géologique de gens du pays ou d'emplacement ne peut pas être suraccentué. Une expérience acquise dans un secteur peut être utilement appliquée aux problèmes d'attirail dans un autre secteur avec la géologie semblable.

Keywords: geological hazards, geology of cities, land subsidence, limestone, urban geosciences

INTRODUCTION

Urban geology is the study or application of geology to urban centres, urban construction and planning. The importance of geology to the development of cities in general has been emphasised by Legget (1973), Legget and Karrow (1983) and Tan (1991). In which case studies from all over the world on the application of geology to urban construction and development have been well documented.

Kuala Lumpur and Ipoh are major urban centres in Malaysia which are undergoing continuous development and expansion. They provide good case studies on the application of geology to urban development. This paper reviews and compares some aspects of the urban geology of these two cities and is based mainly on the author's personal experience and case studies working in these two areas for the past 25 years, some of which have been documented previously, for example: Tan (1987a, 1987b), Tan (1988a), Tan (1990a, 1990b), Tan & Batchelor (1981), Tan and Komoo (1990).

GEOLOGIC SETTING

The geologic setting of Kuala Lumpur and Ipoh is strikingly similar. It is this similarity in geologic setting that has contributed to the common historical background and development of the two regions (Klang Valley where Kuala Lumpur is located, and Kinta Valley where Ipoh is located) which contain two major tin (cassiterite, SnO_2) fields of the country. The hey-days of the tin mining industry have contributed tremendously to the growth and development of Kuala Lumpur and Ipoh up to its present stature. Interestingly enough, it is precisely the same mining activities that have now left behind in the two areas, now that tin mining has passed into its twilight, problematic mine tailings and ponds for the geotechnical engineers to contend with in many construction projects.

Surface geology

The geology of the Kuala Lumpur and Ipoh areas is well documented by Yin (1976) and Ingham & Bradford (1960) respectively. Table 1 summarises the stratigraphy of the two areas, and compares the major rock formations in these two regions. Both areas are underlain by an extensive limestone bedrock formation, namely the Kuala Lumpur Limestone and the Kinta Limestone. The limestone bedrock in each area rises above the alluvial plains to form limestone hills with steep to vertical slopes (mogote or tower karst). Flanking the limestone on the eastern and western sides of the valleys are granitic uplands. This similarity in geologic setting has given rise to similar alluvial deposits rich in tin content – hence, the growth and development of the two areas as "mining towns" since the last century.

However, there are some significant differences in the rock formations present in each area. For example, the Kenny Hill formation comprising interbedded quartzite and phyllite is significant in Kuala Lumpur not only as a major geologic formation, but also in the context of construction. It has no equivalent counterpart in the Ipoh area. Note that the Kuala Lumpur Limestone and the Hawthornden schist are Lower Palaeozoic (Middle to Upper Silurian) in age, and the limestone is overlain unconformably by the Upper Palaeozoic (Permo-Carboniferous) Kenny Hill formation. In the more extensive and much thicker Kinta Limestone, the age spans from Lower Palaeozoic (Ordovician) to Upper Palaeozoic (Permian).

Derived from the similar geologic settings and rock formations noted above, the types of soil deposits encountered are also comparable: granitic residual soils, alluvial deposits, mine tailings and mining ponds. The occurrence of the Kenny Hill formation overlying the Kuala Lumpur Limestone has given rise to some unique soil problems highly relevant to foundation engineering, as discussed below.

Table 1. Geology/Stratigraphy of the Kuala Lumpur and Ipoh areas (after Yin,1976 and Ingham & Bradford, 1960).

Age	Kuala Lumpur	Ipoh
Quaternary	Alluvium (Young & Old Alluvium)	Alluvium (Young & Old Alluvium)
Triassic	Granite & Allied Rocks	Granite & Allied Rocks
Palaeozoic	-Kenny Hill formation (quartzite/phyllite) -Kuala Lumpur Limestone -Hawthornden schist	-Kinta Limestone (dominant) -basal schist

Subsurface geology

The subsurface geology is particularly important for a construction site, especially for high rise buildings in cities. Numerous construction projects in the two areas have revealed, either through data from numerous boreholes or actual excavations, the typical subsurface geologic features and soil profiles of these two urban areas. For example, limestone bedrock and its associated karstic or solution features are major concerns to the local construction industry. Highly irregular or pinnacled bedrock profiles, solution channels and cavities, arches, steep cliffs and overhangs, floaters, etc. are of major concern to the foundation engineers. The subject of foundations in limestone was one of the main themes of the 8th Southeast Asian Geotechnical Conference held in Kuala Lumpur in 1985, where papers on limestone were compiled by Chan (1986). A review of borehole data by Tan (1988a) also showed that the depth to limestone bedrock is much greater in the Kuala Lumpur area where depths of up to 50m are common (with extremes of up to 100m) than in the Ipoh area where the depth to limestone bedrock is generally less than 20m. Thus, piling depths are greater in the Kuala Lumpur area. The review of borehole data showed the size of cavities in the limestone bedrock, were mostly < 3m across.

Soil profiles in both Kuala Lumpur and Ipoh areas are similar in the sense that in general, in the plains, they comprise alluvium (fluvial deposits) and/or mine tailings overlying limestone bedrock. In contrast, the areas underlain by granite or the Kenny Hill formation (Kuala Lumpur only) show residual soil weathering profiles appropriate to each rock type.

Figure 1 shows typical examples of highly pinnacled limestone bedrock exposed by mining and quarrying activities in the Bandar Sunway area, a suburb of Kuala Lumpur that has undergone at least four land uses starting with mining for alluvial tin, quarrying for limestone bedrock, then development into a water theme park associated with a housing area. The later an example of good planning by the owners/developers of the parcel of land. In the water theme park (Sunway Lagoon), some of the large limestone pinnacles have been preserved for their aesthetic value and now serve as a permanent exhibit for engineering geologists and geotechnical engineers to view exellent examples of such karstic features. These exposed pinnacles of limestone bedrock have been appreciated by many visitors from overseas, especially during regional or international conferences dealing with limestone.

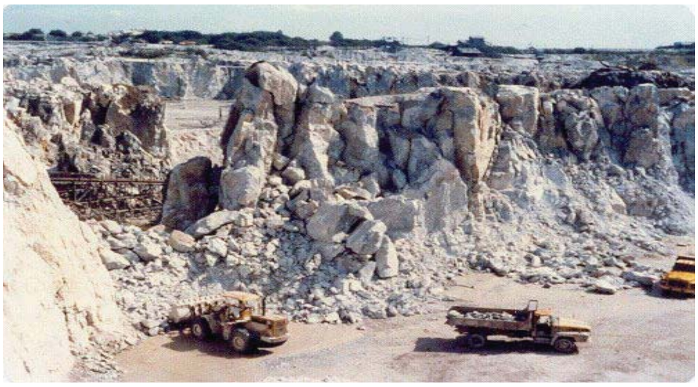

Figure 1. Highly pinnacled limestone bedrock, Sunway, Kuala Lumpur.

ENGINEERING GEOLOGIC PROBLEMS

As a consequence of the similar geological setting of the Kuala Lumpur and Ipoh areas, several engineering geological problems are frequently encountered in both areas and some of these problems are discussed below.

Collapsed weak soil zone above limestone bedrock (S.P.T. ~0)

The occurrence of a very weak collapsed soil zone immediately above the limestone bedrock is a phenomenon that is now well recognised in Malaysia, Ting (1985), Tan & Ch'ng (1986), Tan (1988b). The problem was first identified in the construction of tall buildings (>20 storeys) in downtown Kuala Lumpur in the early 1980's. The very weak or soft collapsed soil zone immediately above the limestone bedrock was identified by the very low Standard Penetration Test, S.P.T., values of this zone, where S.P.T. values are typically ~ 0, Figure 2. Since then, many other building sites on limestone in Kuala Lumpur have also encountered a similar weak soil zone, including the site of the Petronas Twin Towers (the tallest twin towers in the world). Similar conditions have been encountered in the Ipoh area, although to a lesser extent. It is important to recognise that in the Kuala Lumpur area, this collapsed soft soil zone can be overlain by stiff to hard residual soils of the Kenny Hill Formation (quartzite and phyllite) which have S.P.T. values of 30-50 or even >50 – thus presenting a potentially dangerous situation to an unwary engineer. Thus boreholes must go to sufficient depths to penetrate the Kenny Hill Formation, through the collapsed soil zone, and into the limestone bedrock to define accurately the site's sub-surface characteristics for foundation design and construction.

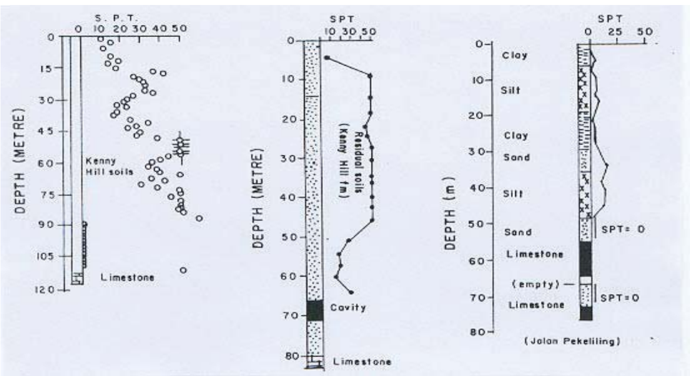

Figure 2. Collapsed weak soil zone above limestone bedrock, S.P.T. = 0, Kuala Lumpur.

The occurrence of this collapsed soil zone in the Kuala Lumpur area is typically close to, or along, the Kenny Hill Formation – limestone contact zones, because along these contact zones the Kenny Hill Formation is thinner and forms a relatively thin "blanket" overlying the limestone. The thickness of the collapsed soil zone ranges from several metres to approximately 10 metres. Ting (1985) discussed possible engineering solutions to deal with this collapsed soil zone as well as cavities in the limestone. The improvement of the collapsed soil by jet grouting and compaction grouting has been successfully implemented for some high rise projects, including the Petronas Twin Towers.

Subsidence and sinkholes

Subsidence or land settlement and sinkholes are common engineering geologic problems in the Kuala Lumpur and Ipoh areas due to widespread limestone bedrock, a history of mining and deposits of mine tailings. Several ground conditions give rise to land subsidence, including the widespread occurrence of soft mining slimes in the ex-mining areas upon which housing projects and roads are built. Similarly subsidence occurs following construction over former garbage dumps. This type of land subsidence is due to consolidation of the underlying slime/soft clay/domestic waste upon loading, and proceeds at a gradual or slow rate. Although it causes severe damage to houses and infrastructure, often leading to their demolition or the need to resurface roads, it is not as dangerous as sudden collapse due to the collapse of cavities in limestone.

Sinkhole formation or emergence is much more sudden and catastrophic. Numerous incidents of the sudden formation of sinkholes in the Kuala Lumpur and Ipoh areas have been reported, often affecting houses, roads, railways and other structures. Sinkhole development is related to the underlying highly irregular or pinnacled limestone bedrock with its associated subsurface troughs and trenches, the collapsed soil zone described above, cavities in the limestone bedrock, subsurface erosion of mine tailings, and lowering of the groundwater table sometimes caused by dewatering and excavation activities during mining and construction. Typical examples of sinkhole occurrences in the Ipoh area have been documented by Shu (1982, 1986), and in the Kuala Lumpur area by Shu (1986). These incidents are thought to be related to the dewatering of deep, open-cast mines, although attempts at correlation have been inconclusive. Many of these sinkholes are small with diameters of several metres, vertical sides and variable depths. Several sinkholes may occur at a site, often following a particular alignment or trend that is related to subsurface linear trenches controlled by fractures such as major joints or faults in the limestone bedrock.

A recent spate of sinkholes, totally about 40 in number, appeared in an area south of Ipoh within the Kinta Valley soon after the major earthquake off Sumatra on 26th December 2004. These sinkholes were correlated with tremors from the Sumatran earthquake, Chow (2005). However, the geologic conditions where these sinkholes developed, namely limestone bedrock overlain by mostly sandy mine tailings, were such as to have a high potential for the formation of sinkholes and the earthquake tremors supplied the triggering factor to initiate their development. It was reported that the same earthquake also triggered a spate of sinkholes in Thailand, Chow (2005).

Landslides

Landslides are a common problem in the Kuala Lumpur and Ipoh areas. In both areas landslides are associated with mining and ex-mining ground which are highly susceptible to landslides due, in part, to the loose sands and soft slimes/clays in the mine tailings areas. The method of mining using gravel pumps with hydraulic jets and its various associated artificial landforms (tailings bunds, mining ponds, etc.) also increase the potential for landslides. Rapid dewatering of mining ponds can trigger slope failures leading to destruction of adjacent properties and infrastructure (houses, roads, etc.), a typical example was the Taman Bukit Indah housing project in Cheras, Kuala Lumpur, Tan (1987a). Figure 3 shows the result of a rapid draw-down slope failure in this area. The landslide destroyed totally a row of newly completed double storey linked houses built on the bank of the ex-mining pond which was being dewatered.

Figure 3. Slope failure due to dewatering of ex-mining pond, Cheras, Kuala Lumpur.

A significant number of major landslides associated with mining (one in the Ipoh area, and another in the Kuala Lumpur area) in 1980 prompted the Ministry of Primary Industries to set up a Committee on Mine Safety to study the problem. The report by the Technical Subcommittee, Ministry of Primary Industries (1982), contains conclusions and recommendations with respect to mine slope stability, among which are: the nature of the slides were mostly flow slides associated with soft slimes/loose sands (tailings), obsolete rule-of-thumb methods had been used to design mine slopes, and geotechnical investigation and design of mine slopes were inadequate and, hence, there was a need for geotechnical engineeering based design.

Another common occurrence of landslides is associated with hillside or hill slope development, in particular in the Kuala Lumpur area where many housing projects, condominiums and associated infrastructure are sited on hilly terrains. Slope failures involved either cut slopes or fill slopes (in particular fill slopes). Materials involved are either the residual soils/weathered rocks derived from granite, quartzite or phyllite, or fill materials derived from the excavation of these soils and rocks. It is reasonable to infer that colluvial deposits are also involved. Characteristic examples of slope failures associated with hillside development have been documented by Tan (1987b, 1988c). The dramatic collapse of the Highland Towers Condominium Block 1 in a suburb of Kuala Lumpur which took 49 lives has been attributed to a series of retrogressive landslides as the main causative or at least a contributing factor, MPAJ (1994).

Rockfalls

The Kinta Valley where Ipoh is located encompasses 40 limestone hills. Their sub-vertical limestone cliffs range in heights from 60m to 600m. Incidents of rockfalls are quite common, and have, at times, resulted in fatalities as well as damage to property. Typical examples have been documented by Shu & Lai (1980), Shu et al. (1981). In the major rockfall at Gunung Cheroh, Ipoh, documented by Shu & Lai (1980), the rockfall involved the collapse of the entire cliff face as a single slab measuring some 33 m in length and weighing 23,000 tonnes. It resulted in 40 human fatalities and as well as numerous cows.

Figure 4. Tambun Tower, Ipoh.

The limestone hills in the Kinta Valley have been subjected to detailed field mapping to delineate sites of past rockfalls and potential future rockfall sites, Tan (1988a). Both structural features (such as joints, faults, bedding planes) and solution features (caves, cavities, solution channels, basal under cuts, overhangs) were mapped. The survey of rockfalls indicates that: a) the process of rockfalls represents a natural process for all the limestone hills regardless of size – it gradually reduces the limestone hill till its ultimate “disappearance” from the ground surface; b) the rockfalls are structurally controlled by joints, faults or bedding planes, with the sub-vertical structures more likely to give rise to rockfalls; c) solution features such as basal grooves or under cuts and solution channels can contribute to rockfall occurrence; d) stalactites which are usually encountered hanging down from overhanging cliff faces can also be a source of rockfalls, even though they are minor in size; e) quarry blasting is a common contributory or triggering cause of rockfalls in the area – many incidents of rockfalls appear to be associated with quarry operation/blasting.

For the mixed development of Tambun, a suburban area of Ipoh, a similar survey of the limestone cliffs was conducted to assess the stability of individual limestone cliffs and to guide development around the hills, Tan (1998). The results of this survey indicated to the developer where there are safe zones to develop, and where there are hazardous zones to avoid. In this particular suburban area of Ipoh, the bedding planes of the limestone were the main controlling feature on cliff stability. Figure 4 shows the scenic Tambun Tower in the Ipoh area where the stability of the hills was controlled mainly by the sub-vertical bedding planes. Similarly in the Batu Caves limestone hill in the Kuala Lumpur area, a recent assessment of limestone cliff stability was conducted for a housing and water tank construction site, using a similar approach, Tan (2005), Figure 5.

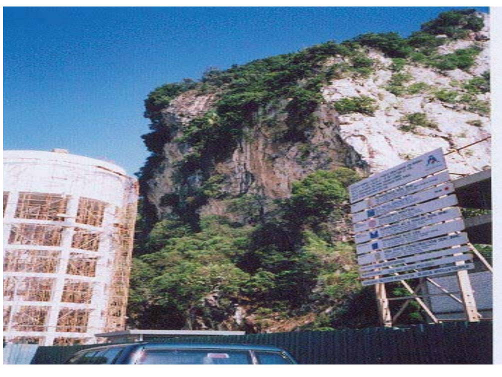

Figure 5. Limestone cliff adjacent to water tank, Batu Caves, Kuala Lumpur.

Detailed surveys of limestone cliffs are necessary to allow urban development near these limestone hills, in contrast to the approach adopted by the Geological Survey Department of Malaysia (now renamed the Department of Minerals and Geoscience, Malaysia) which stipulates a safety buffer zone of 2 x height of cliff where buildings should not be sited. This stipulation sterilises large tracts of land around limestone hills with regard to development, which may not be practical where land is at a premium for urban development. The Batu Caves limestone hill in Kuala Lumpur, for example, is now surrounded by numerous housing development projects, with many buildings located well within the 2 x cliff height safety buffer zone, Figure 6.

Figure 6. Batu Caves limestone hill surrounded by housing developments (aerial photo).

CONCLUSIONS

Similarities in the geologic settings of Kuala Lumpur and Ipoh account for the similar engineering geological problems that are encountered in these two cities. Karstic geology, both surface and subsurface, is the dominant influence. Thus, subsidence, sinkhole formation, and rockfalls are frequent. The common mining heritage and inheiritance of mining deposits also contribute to landslide occurrences and problematic soils for the geotechnical engineer to contend with in both areas. A detailed survey and assessment of limestone cliff stability is necessary to allow urban development projects such as housing projects to encroach safely upon these limestone hills.

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REFERENCES

CHAN, S.F. (ed) 1986. *Foundation problems in limestone areas of Peninsular Malaysia*. Institution of Engineers Malaysia, Sept. 1986, 98 pp.

CHOW, W.S. 2005. Sinkholes in the Kampar area, Perak. *Sinkholes Night*, Geological Society Malaysia, 30th March 2005, Kuala Lumpur.

INGHAM, F.T. & BRADFORD, E.F. 1960. The geology and mineral resources of the Kinta Valley, Perak. *Memoir Geological Survey Dept.*, Fed. Malaya, 9, 347 pp.

LEGGET, R.F. 1973. *Cities and geology*. McGraw Hill, New York, 624 pp.

LEGGET, R.F. & KARROW, P.F. 1983. *Handbook of geology in civil engineering*. McGraw Hill, New York.

MINISTRY OF PRIMARY INDUSTRIES, MALAYSIA. 1982. *The report of the Technical Sub-Committee on mine safety*. Committee on mine safety, Feb. 1982, 130 pp.

MPAJ 1994. *Report of the Inquiry Committee into the collapse of Block 1 and the stability of blocks 2 and 3 Highland Towers condominium, Hulu Klang*. Majlis Perbandaran Ampang Jaya (MPAJ), Selangor.

SHU, Y.K. & LAI, K.H. 1980. Rockfall at Gunung Cheroh, Ipoh. Geological Survey Malaysia, *Geological Papers*, vol.3, 1-9.

SHU, Y.K. 1982. A sinkhole occurrence in Bt. Merah new village, Menglembu, Ipoh. Geological Survey Malaysia, *Report E(F)1/1982*.

SHU. Y.K. 1986. Investigations on land subsidence and sinkhole occurrence in the Klang Valley and Kinta Valley in Peninsular Malaysia. *Proc. LANDPLAN II conf.*, Kuala Lumpur, 15-28.

SHU, Y.K., CHOW, W.S. & ZAKARIA MUDA. 1981. Rockfall danger related to limestone hills in the Kinta Valley, Perak. *Annual Report*, Geological Survey Malaysia, 1981, 184-197.

TAN, B.K. & BATCHELOR, B. 1981. Foundation problems in limestone areas – a case study in Kuala Lumpur, Malaysia. *Proc. Int. Symp. On Weak Rocks*, Int. Soc. For Rock Mechanics, 21-24 Sept. 1981, Tokyo, 1461-1463.

TAN, B.K. & CH'NG, S.C. 1986. Weak soil zone above limestone bedrock. *Newsletter*, Geological Society Malaysia, vol. 12, n.2, Mar-April 1986, 51-57. (in Malay).

TAN, B.K. & IBRAHIM KOMOO. 1990. Urban geology: case study of Kuala Lumpur, Malaysia. *Engineering Geology*, 28(1990), 71-94, Elsevier Science Publishers, Amsterdam.

TAN, B.K. 1987a. Geology and urban development of Kuala Lumpur, Malaysia. Proc. LANDPLAN III Symp., 15-20 Dec. 1986, Hong Kong, *Geological Society of Hong Kong Bulletin* no.3, Oct. 1987, 127-140.

TAN, B.K. 1987b. Landslides and hillside development – recent case studies in Kuala Lumpur, Malaysia. Proc. LANDPLAN III Symp., 15-20 Dec. 1986, Hong Kong, *Geological Society of Hong Kong Bulletin* no.3, Oct. 1987, 373-382.

TAN, B.K. 1988a. Engineering geology of the Ipoh area, Perak. *Final Report, Research Project No. 7/86*, Sept. 1988, Univ. Kebangsaan Malaysia, 74 pp. (in Malay).

TAN, B.K. 1988b. A short note on the occurrence of a soft soil zone above limestone. *Proc. Int. Conf. On Calcareous Sediments,* March 15-18, 1988, Perth, vol.1, 35-39.

TAN, B.K. 1988c. Engineering geologic studies of landslides in residual soils and rocks, Peninsular Malaysia. *Proc. Vth Int. Symp. On Landslides*, 10-15 July 1988, Lausanne, 325-329.

TAN, B.K. 1990a. Subsurface geology of Ipoh area, Perak, Malaysia. Proc. Conf. On Karst Geology in Hong Kong, 5-7 Jan. 1990, Hong Kong, *Geological Society of Hong Kong Billetin* no.4, 1990, 155-166.

TAN, B.K. 1990B. Engineering geology of Ipoh, Perak, Malaysia. *Proc. IAEG Congress*, Aug. 1990, Amsterdam, 1733-1738.

TAN, B.K. 1991. Role of geology in geotechnical engineering. Proc. 4-day course on Geotechnical Engineering, Institution of Engineers Malaysia, 9-12 Sept. 1991, vol.3, 28 pp.

TAN, B.K. 1998. Engineering geolgical survey of limestone cliffs in the Tambun area, Perak, Malaysia. *Proc. 8th IAEG Congress*, Vancouver, vol. II, 1359-1366.

TAN, B.K. 2005. Assessment of limestone cliff stability – a case study in Batu Caves, Kuala Lumpur. *Proc. IEM-GSM Oktoberforum 2005: Case Histories in Engineering Geology & Geotechnical Engineering*, 4th Oct. 2005, Petaling Jaya, Malaysia, paper 17.

TING, W.H. 1985. Foundation in limestone areas of Malaysia. Special Lecture*, Proc. 8th S.E.Asian Geotechnical Conf.,* Kuala Lumpur, vol. II, 124-136.

YIN, E.H. 1976. Geologic map of Selangor, Sheet 94 (Kuala Lumpur). Scale 1: 63360.