SLOPE ENGINEERING DESIGN AND CONSTRUCTION PRACTICE IN MALAYSIA

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Abstract: Slope engineering has been the main focus for housing and infrastructure developments on hilly terrain in Malaysia in recent years, as a result of a shortage of flat or undulating land. There have been a number of landslides in recent years since the notorious landslide incident occurred in 1993 which resulted in the collapse of Block 1 of the Highland Towers and claimed 48 lives. Improvements in slope engineering and slope management have been noticeable. One of them was the establishment of the Slope Engineering Branch under the Public Works Department (PWD) in 2004, after the rock fall failure at Bukit Lanjan near Kuala Lumpur in 2003 which resulted in a 6 months highway closure. The Slope Engineering Branch has also commissioned and developed a "National Slope Master Plan Study" which aims at improving current practices of slope engineering and slope management. This paper presents the current engineering practice in slope design and construction as well as highlighting the initiatives for developments in Malaysia for slope engineering and slope management.

Keywords : Slope Management; Slope Engineering; Policy and Legislation; Structure professional undergraduate education; Construction Control

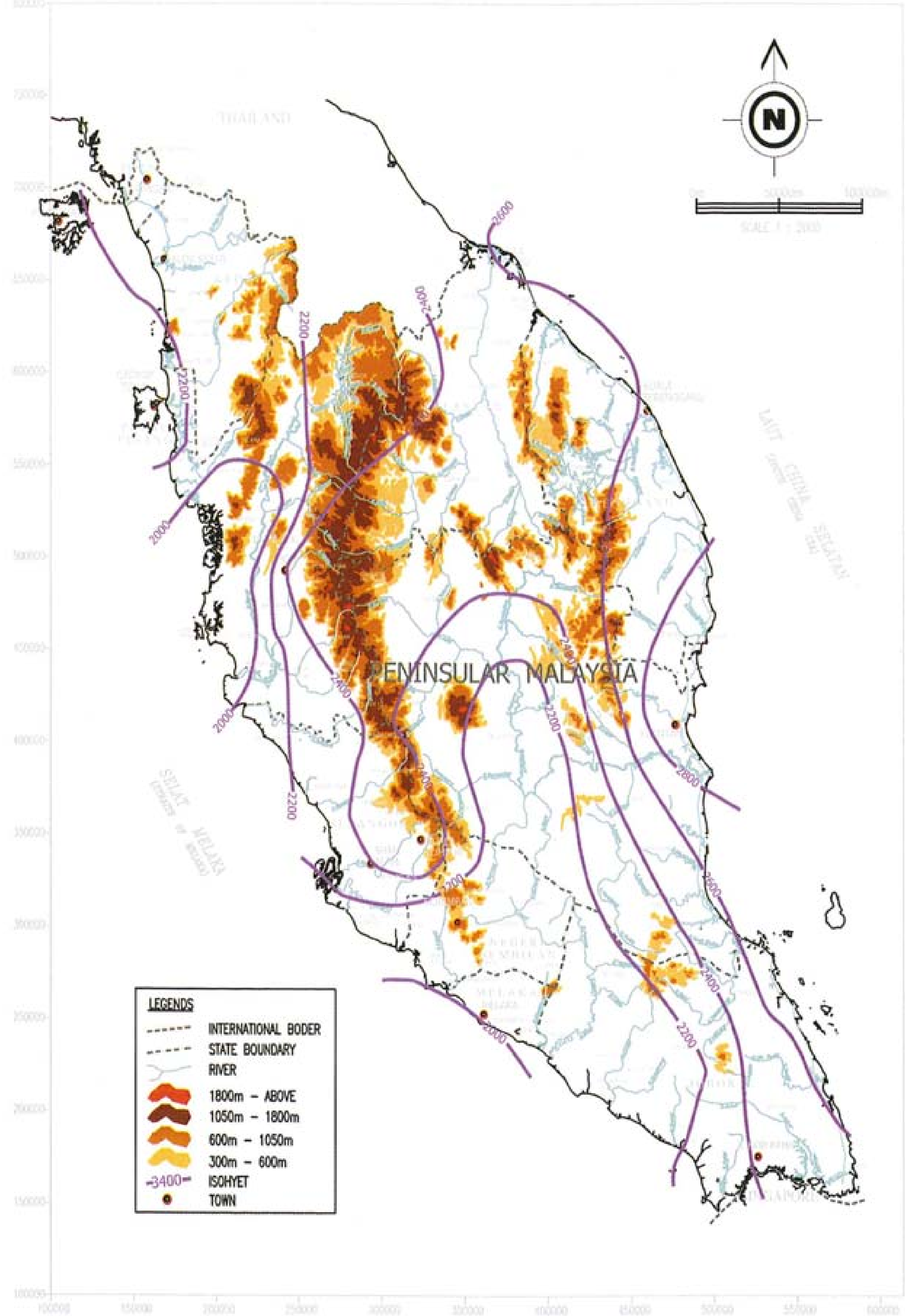
1 INTRODUCTION

Malaysia is located in Southeast of Asia, occupying about 330,200 km^2. The entire country is divided into two main regions, namely Peninsular Malaysia and East Malaysia. Peninsular Malaysia lies just south of Thailand and north of Singapore; while East Malaysia is at the northern one-third of the island of Borneo bordering Indonesia and Brunei (as shown in Figure 1). With a population of about 28.7 million (updated by the Department of Statistics Malaysia on 25th July 2009), the country has a multiracial society with a racial composition consisting of Malay, Chinese, Indigenous People, Indian and others at a proportion of 50%, 24%, 11%, 7% and 8%, respectively.

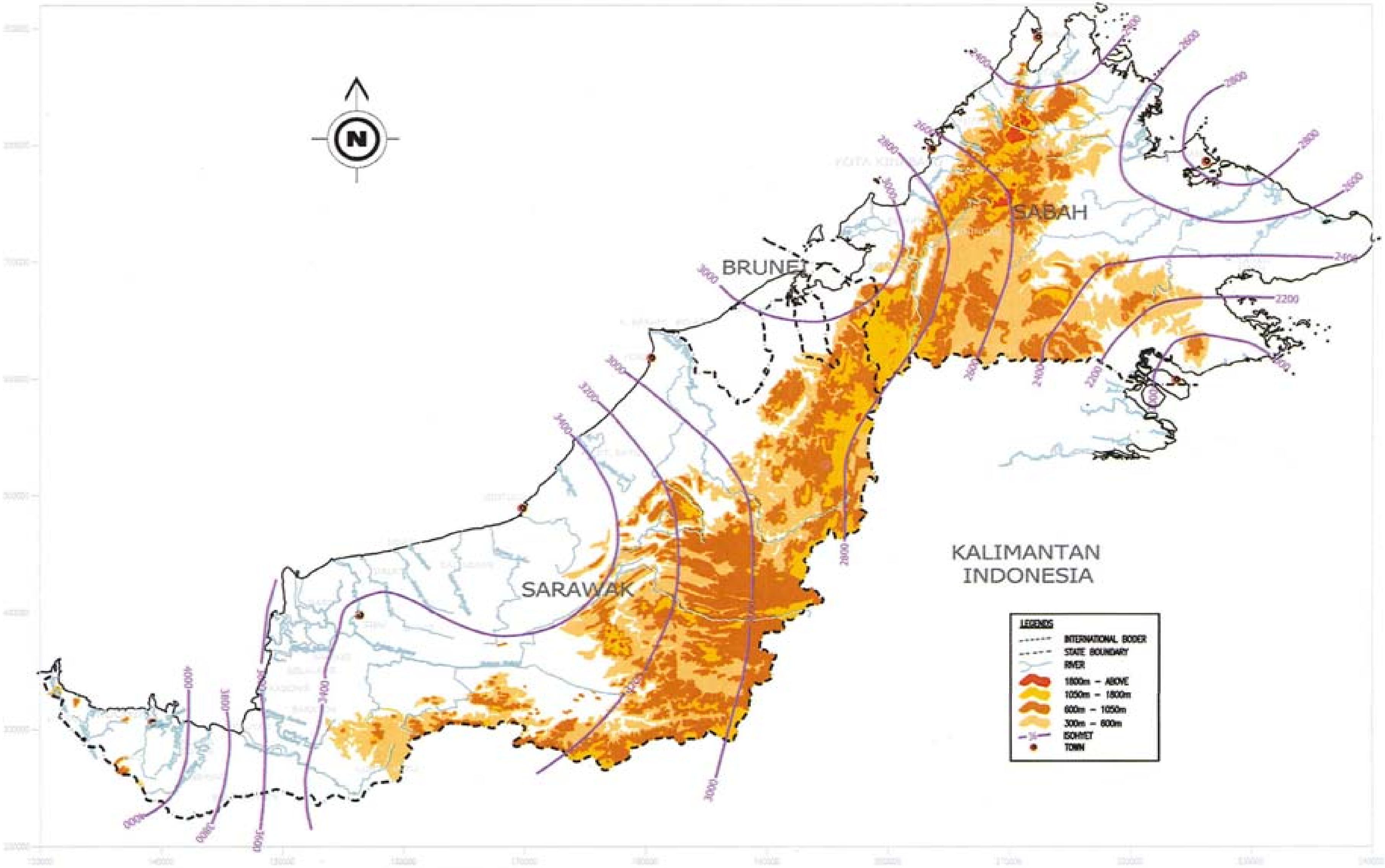
Figure 1: Geographical map of Malaysia

Malaysia is a tropical country with an average annual rainfall of around 2550mm, which is above the global average. The highest annual, daily and hourly rainfall ever recorded in the history of Malaysia is 5293.4mm, 929mm and 322.6mm respectively (NAHRIM, 2008). The country is also subjected to southwest (May to September) and northeast (November to March) monsoons, during which the maximum rainfall may go up to 4200mm. The annual rainfall distributed is as shown in Figure 2.

In Malaysia, approximately 60% of the total areas are coastal plains and inland lowlands of undulating terrain below RL300m. Meanwhile, about **35%** of the total land consists of hilly ranges at Reduced Level between **RL300m and RL1300m** and approximately **5%** consists of Mountains **above RL1300m**. An overview of mountain ridge distribution is shown in Figure 3. However, from an engineering point of view, the definition of hilly terrain should be coupled with slope gradients. Therefore, based on the current implementation policy of hillsite developments, slope terrain classification of individual development is mandatory to gauge the extent of necessary geotechnical engineering input.



(a): Peninsular Malaysia



(b): East Malaysia

Figure 2: Mean annual rainfall (mm) in Malaysia (after NAHRIM)

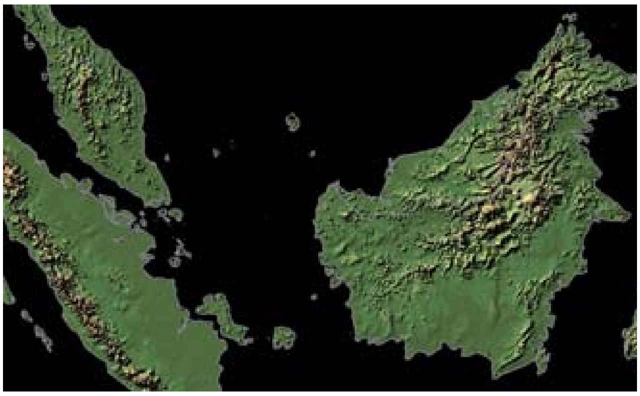


Figure 3: Overview of mountain ridge distribution in Malaysia

2 GENERAL GEOLOGY

2.1 Peninsular Malaysia

Peninsular Malaysia is divided into 4 geological domains. Langkawi Island, Perlis and northern Kedah represent one whole domain (Foo, 1983). The remaining areas are the Western Belt, Central Belt, and Eastern Belt (Khoo & Tan, 1983). Sedimentary rocks are the most common rock type across all domains. Igneous rocks, usually granite, are also frequent, and form most of the mountain ranges.

The general geological formation found in Peninsular Malaysia consists of the following components:

- Shale, Mudstone, Siltstone, Phyllite, Slate, Hornfels
- Sandstone/Metasandstone
- Conglomerate
- Limestone/Marble
- Schist

The central mountainous ridges are mainly underlined with Interbedded sandstone, siltstone and shale. Meanwhile, the coastal areas are underlined with Marine deposits consisting of clay, silt, sand and peat. For Selangor state in particular, which is nearest to Kuala Lumpur, where construction activities are most active, a wide range of geological formations are detected, consisting of the following:

- Alluvium
- Granite Formation (Vein Quartz, Granitic Rock)
- Kenny Hill Formation (Quartzite and Phyllite)
- Kajang Formation (Schist and Phyllite)
- Kuala Lumpur Limestone
- Hawthornden Formation (Phyllite and Schist)

2.2 East Malaysia

East Malaysia consists of the states of Sabah and Sarawak. Active tectonism around Borneo since the Mesozoic has resulted in a geologically complex structure in the region. Sabah can be divided into two major areas, east coast and west coast, where the Crocker Range is located. Both the areas are dominated by sedimentary rocks. The east coast area consists of volcanic and volcano-clastic materials, which consist mainly of clastic sediments (Chand 1993). Quaternary deposits/alluvium also surround the whole coastal area and some of the main river basins, which are mainly deposited by clay, silt, sand and peat. Approximately 40% of the east coast area of Sabah is dominated by slump breccias and sequences of interbedded mudstones, tuff, tuffaceous sandstone, shale, conglomerate. Meanwhile, the northern part of east coast area is dominated by Labang formation, with the main lithology of sandstone, mudstone, and limestone lenses (Tongkul, 2005). The central portion of Sabah to the south bordering Kalimantan in the east coast area is largely covered by Miocene formations consisting of mudstone, siltstone, sandstone, conglomerate, limestone, and rare beds of coal and marl (JMG, 1985). Approximately 60% of west coast part of Sabah is dominated by Crocker formation. Crocker formation represents flysch-type sandstone, shale, agglomerate, limestone, breccia, and siltstone with rare tuff (Tongkul, 2005).

The geology of Sarawak is recognized as belonging to three distinct provinces, corresponding to three main geographic regions, namely West Sarawak, Central and North Sarawak. West Sarawak is mainly underlain by the early Cretaceous Mélange and in places underlain by Tertiary sedimentary basin and Tertiary intrusive (Chand, 1993). West Sarawak is made up of Early Cretaceous Mélange. The mélange is consisting of Sarawak block which is made up of schist, limestone and volcanic rock. The tightly folded and faulted sedimentary rocks of the mélange are mainly the alternations of shale Pedawan Formation and the Bau Limestone Formation (Tongkul, 2005). This region is rich in economic minerals such as gold, silver and bauxite. Central Sarawak is underlain by a very thick, tightly folded turbidite. These are mainly the alternations of phyllite and slate interbedded with sandstone. The northern part of Sarawak is underlain by Neogene of the Northwest Borneo Basin.

3 BACKGROUND OF HILLSITE DEVELOPMENT

Hillsite development in Malaysia started from Fraser Hill (mean altitude of RL1524m) which was developed as a tourist destination in 1917 by the British. Another popular highland destiny is the Cameron Highlands. At an altitude of RL1500m, Cameron highlands started development in 1925, famous for its richness in flora and fauna. Today, the highlanders are mainly involved in the tourism and agricultural industries. From there, hillsite development has gained in popularity for the past three decades in densely populated cities like Kuala Lumpur and Penang. As the area of flat and undulating lands within these cities became limited, housing/commercial developments moved gradually into hilly terrain, and often for high-end developments for their exclusivity, fresher air and better scenery.

Meanwhile, from another prospective, hillsite development also includes the construction of illegal squatters, where temporary accommodations were built on highly hazardous hills and mountains. This group of people are mainly involved in the agricultural and forestry industries and are highly vulnerable as they have virtually no awareness of the possible risks of non-engineered slopes. This phenomenon is particularly prominent in Sabah in which logging is one of the main sources of income.

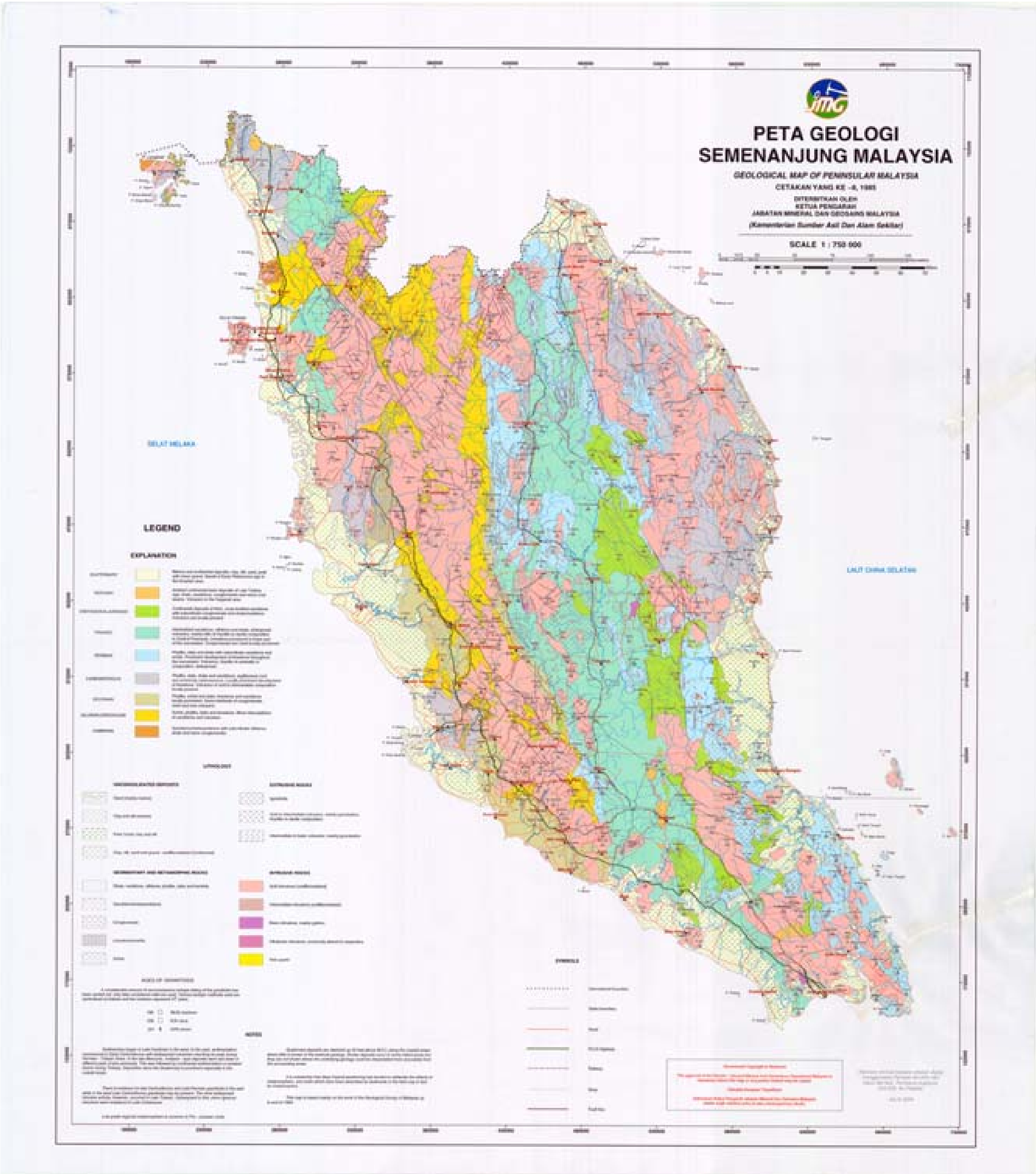


Figure 4: General geological map of Peninsular Malaysia (by Minerals and Geoscience Department Malaysia)

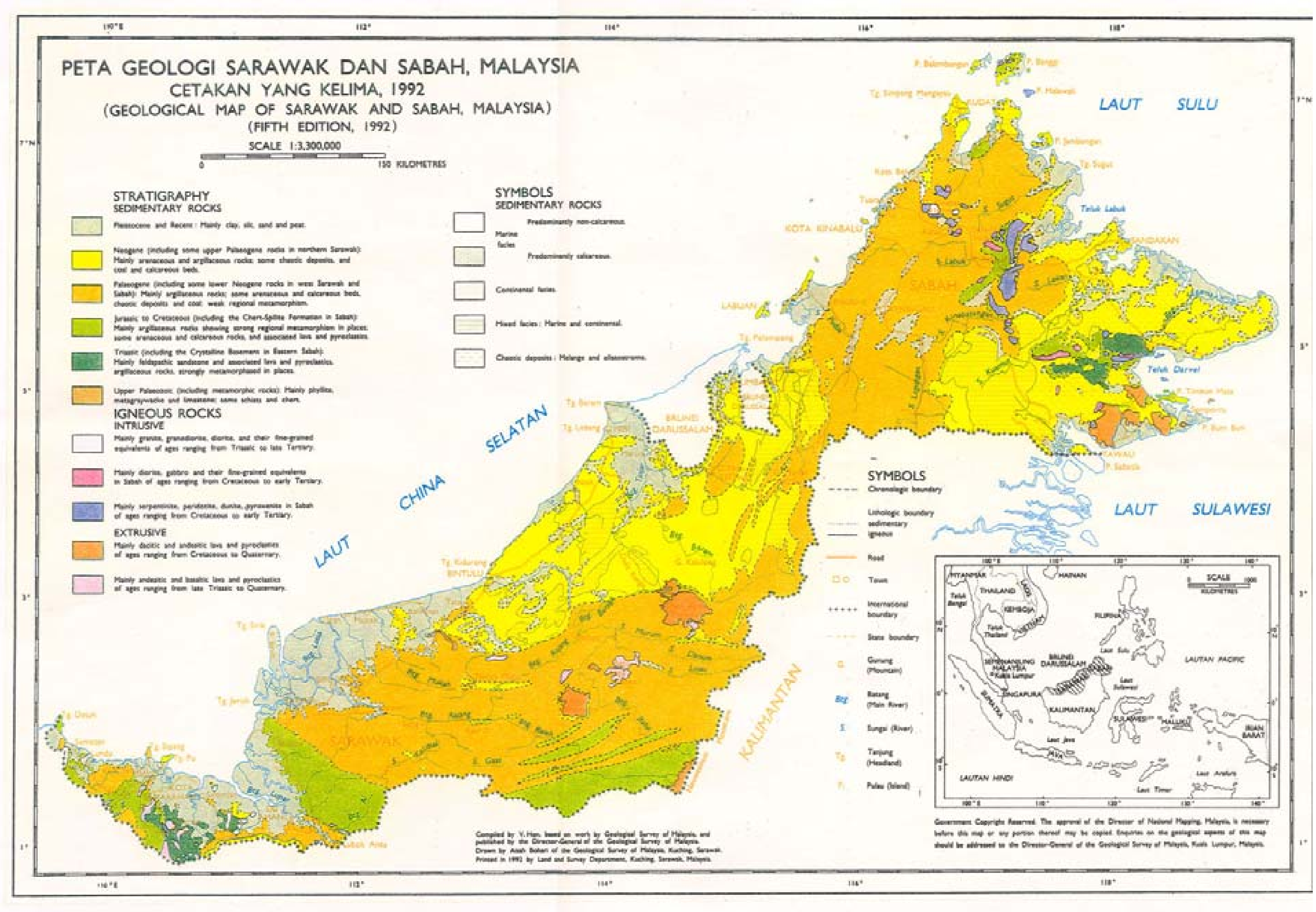


Figure 5: General geological map of East Malaysia (by Minerals and Geoscience Department Malaysia)

Figure 6: Collapse of Block 1 of the Highland Tower Apartments

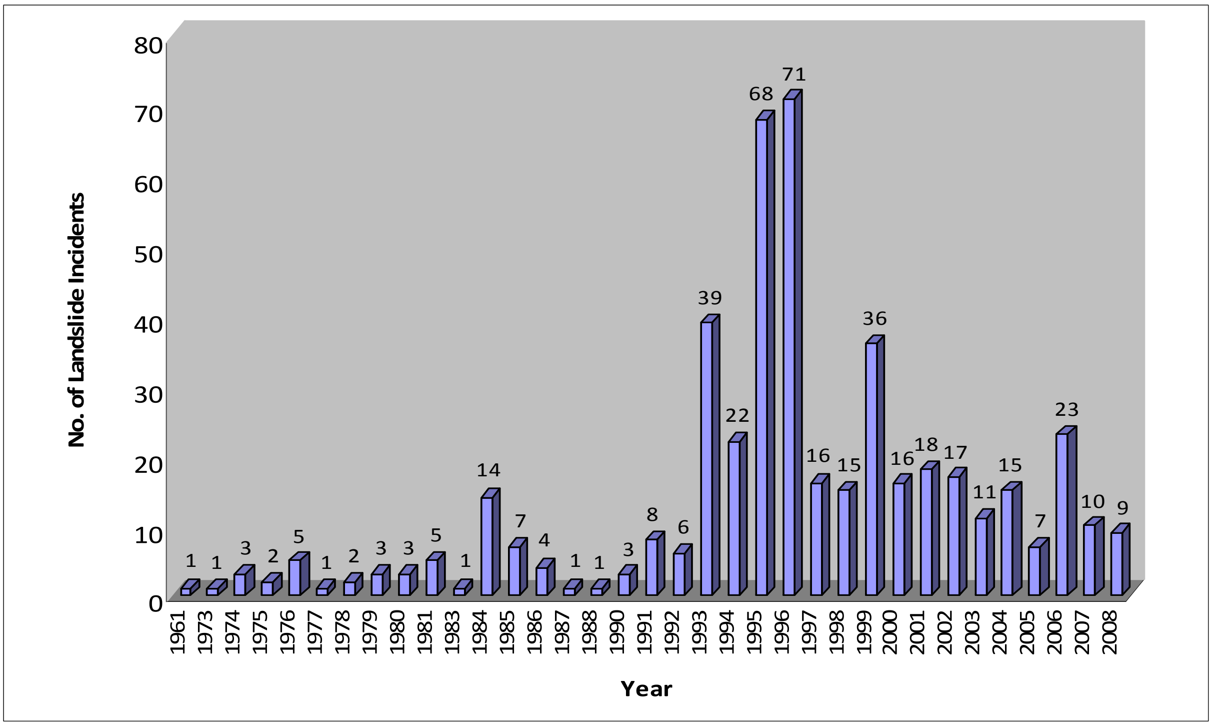


Figure 7: Number of landslide events in Malaysia, 1961 – 2008 (after PWD (2008) with additional landslide statistics for the year 2008 by the Authors)

However, concerns and awareness on the hazards of hillsite developments only begun after the collapse of Block 1 of the Highland Towers on 11th December 1993 that killed 48 people (Figure 6). Since than, numerous landslide incidents have occurred both at the surrounding areas of Highland Towers, and in other parts of the country.

Table 1 gives some significant historical landslide events and Figure 7shows the total number of reported landslides between 1961 and 2008 in Malaysia. In December 2008, another large scale landslide had occurred in Bukit Antarabangsa, where five residents were killed, 14 bungalows were destroyed and 2000 residents were evacuated from their homes (Figure 8).

Table 1 - Historical Landslides in Malaysia [after CDM (1999) with additional landslide statistics for the year 2008 by the Authors]

Date of Occurrence	**Landslide Location (Name)**	**Fatality (Nos)**	**Injury (Nos)**	**Highway Closure**
1 May 1961	Ringlet, Cameron Highlands	16	-	
11 Dec 1993	Highland Towers	48	-	
30 Jun 1995	Genting Sempah	20	22	
6 Jan 1996	Km 303.8, Gua Tempurung	1	-	✓
29 Aug 1996	Pos Dipang, Perak	44	-	
26 Dec 1996	Keningau, Sabah	238		
20 Nov 2002	Taman Hillview	8		
26 Oct 2003	Km 21.8, Bukit Lanjan	-	-	✓
12 Oct 2004	Km 303, Gua Tempurung	-	1	✓
10 May 2006	Taman Bukit Zooview, Selangor	4	-	
8 Feb 2006	Kampung Sundang Darat, Sandakan, Sabah	3	2	
3 Jun 2006	Jambatan Sg Mandahan, Sabah	3	-	✓
7 Nov 2006	Kuari, Kedah	2		
11 Nov 2006	Kg Bukit Sungai Seputeh, Ampang, Selangor	1		
23 Mar 2007	Putrajaya	-	-	✓
4 May 2007	Jln Sultan Salahuddin, Kuala Lumpur	-	-	✓
13 Nov 2007	Pulau Banding, Perak	-	-	
26Dec 2007	Kg Cina , Sarawak	4	-	
30 Nov 2008	Ulu Yam, Selangor	2		
6 Dec 2008	Bukit Antarabangsa, Kuala Lumpur	5	14	✓

Figure 8: Landslide at Bukit Antarabangsa 2008 (after Tan & Chow (2009)

Furthermore, based on 49 cases investigated by Gue & Tan (2006), 60% of failed man-made slopes were due to inadequacy in design alone. This inadequacy in design is generally the result of a lack of understanding and appreciation of the subsoil conditions and geotechnical issues. In addition, failure due to construction errors alone either on workmanship, materials and/or lack of site supervision contributed to 8% of the total cases of landslides. About 20% of the landslides investigated were caused by a combination of design and construction errors. The results clearly reveal that the majority of these failures were avoidable if extra care was taken and input from engineers with relevant experience in geotechnical engineering was sought from the planning to the construction stages.

The increase in media attention has also led to the formation of guidelines and policies by governmental departments and relevant associations to ensure stringent approval procedures for hillsite developments. More importantly, the occurrence of the rock fall at Bukit Lanjan in 2003, which led to a six-month highway closure, triggered the formation of the Slope Engineering Branch under PWD in 2nd February 2004. Other initiatives include the introduction of Accredited Checkers by the Board of Engineers, Malaysia (BEM) for geotechnical and structural designs of hillsite developments with the aim of mitigating the risk of landslides and improving slope management and engineering.

4 POLICIES & LEGISLATION

The first authority to document hillsite development in Malaysia was the Urban and Rural Planning Department in 1997. The guideline addressed the issues of planning and development in highlands on slopes, natural waterways, and water catchment areas (Abdullah et al., 2007). In June 2002, the Minerals and GeoScience Department Malaysia (JMG) produced guidelines on hillsite development. The guidelines considered the angle of natural slopes, type of terrain, type of activities, previous slip history, severity of erosion, etc. The areas were then classified into four categories termed Classes I, II, III and IV. Class I is the least severe in terms of terrain grading where slope angles are less than 15°. Class II is reserved for slopes between 15° and 25° and Class III is for slopes between 25° and 35°. Slopes with angles greater than 35° are classified as Class IV which poses the highest risk. Since the formulation of such a terrain classification by JMG, no development has been allowed in areas with Class IV slopes.

Apart from this, there are also numerous other guidelines and regulations related to slope management from the following governmental and private agencies: -

a) Department of Environment (DOE)
b) Minerals and GeoScience Department (JMG)
c) Majlis Perbandaran Ampang Jaya (MPAJ) (Local Authority)
d) Ministry of Housing and Local Governments (MHLG)
e) Urban and Rural Planning Department (JPBD)
f) The Institution of Engineers, Malaysia (IEM)
g) Kumpulan Ikram Sdn Bhd (IKRAM)

However, some of these guidelines and regulations are unclear and do not cover safety enhancement, slope stability and protection, environment friendliness and sustainability of engineering projects. Furthermore, the guideline proposed by JMG may seem be comprehensive, but it is too complicated for implementation by the approving authority as it is subjected to various interpretations. Therefore, a simplified version is urgently needed.

In 1999, under its own initiative, IEM has formulated policies and procedures for mitigating the risk of landslides for hillsite developments. IEM (2000) produced a position paper titled, “The policies and procedures for mitigating the risk of landslide on hill-site development” with the aim of providing uniform, consistent, and effective policies and procedures for consideration and implementation by the Government of Malaysia. In the published position paper by IEM, the slopes for hillsite developments are proposed to be classified into three classes. Depending on the classification of risk for the slope, necessary approval requirements have been laid down.

The proposed classification of IEM is based on the geometry of the slopes such as height and angle for simplicity of implementation by non-technical personnel in our local authorities. Although in actual conditions there are many other factors affecting the stability of the slopes like geological features, engineering properties of the soil/rock, groundwater regime, etc. In order to make the implementation of the classification easier, simple geometry has been selected as the basis for risk classification.

However, after the major landslide incident at Bukit Antarabangsa on December 2008 (as mentioned section 3.0), the Selangor government, during their Executive Council Committee meeting on 2nd April 2008, decided to ban all development on Class III and IV slopes. As such, Selangor became the first and only state in the country where no housing development is allowed on slopes with gradient steeper than 25°. Due to such newly implemented restrictions, the stakeholders involved (inclusive of the implementation Authorities, submitting engineers, land owners, etc) were confused and dejected by the ‘blanket’ restriction when dealing with individual project submission.

Therefore, these numerous guidelines and regulations should be harmonized into unified guidelines for good practices in the planning, design, construction, site supervision, maintenance and monitoring of slope engineering projects. In fact, IEM has reviewed their earlier classification of slope terrain based on three classes to the common four classes with further safety enhancement for hill site developments in Malaysia.

5 SLOPE ENGINEERING PRACTICES ON HILL SITE DEVELOPMENTS

As hill site development has gained in popularity, good practice for slope engineering and slope management is vital for the formation of safe slopes both during construction and throughout the service life of the structure. Therefore, sound engineering practice is required on all stages of implementation from planning, analysis, design, construction to maintenance.

Based on ACT 133, the Street, Drainage and Building Act 1974 and the Uniform Building By-Laws 1984 (UBBL), it is the responsibility of the submitting professional engineer to supervise the construction work. The submitting professional engineer for the work should certify various stages of completion including setting out, completion of foundations and certificate of fitness for occupation. In all these certifications, the submitting professional engineer has to certify that the work has been carried out according to the design, requirements of the by-laws; construction drawings as well as supervision and take full responsibility of the work (Gue, 2001). Furthermore, the responsibility of the submitting professional engineer on the supervision of work also includes supervision for subsurface investigation. The level of supervision is left to the submitting person to decide. It is generally expected that the submitting person will delegate significant parts of the supervision to his team that he or she has a direct control over with a system to ensure construction compliance to the drawings and specifications.

However, supervision of Subsurface Investigation (SI) and construction works by consultant's representatives is often lacking in compliance despite the fact that these are necessary under the act. Hence, the Authors have recommended strengthening measures in this aspect.

5.1 Subsurface Investigation

The two most important parameters needed to analyse and design cut slopes in residual soils are the effective stress strength parameters (c' & ϕ') and the groundwater level. This key information is generally obtained from triaxial tests on Mazier samples. Meanwhile, boreholes on slopes in potentially high risk areas are installed with standpipes to obtain the groundwater profile allowing groundwater monitoring in boreholes during and after S.I. field works, and even over a period of at least one monsoon. However, monitoring over one monsoon is a challenge. In fact, frequent reminders are required for all practicing engineers to insist on the importance of such groundwater monitoring especially for areas with major cut and fill slopes.

For local practices, effective stress strength parameters (c' & ϕ') for residual soils are often obtained from undisturbed soil samples collected from boreholes using a Mazier Sampler (Retractable triple-tube Core-barrel) with a sample diameter of 72mm. Foam drilling is sometimes used to improve the recovery of Mazier sampling. In situations where Mazier sampling recovery is bad/insufficient and foam drilling is not feasible, another method of obtaining "undisturbed" soil samples from stiff residual soils is the use of the Thick Wall sample (sample diameter of 70mm) which is hammered into the hard soil. Although the sampling process using thick walls will cause some disturbance, the effect is not significant for stiff residual soils and the samples collected can still be used for laboratory strength tests as an alternative. Undisturbed soil samples are sometimes collected at shallow depth using block sampling which is very useful for collecting quality undisturbed soil samples during the excavation of slopes. These undisturbed residual soil samples are used for triaxial tests as well as the soil classification tests.

For cut slopes, the effective stress condition (drained or long term condition) is more critical than the total stress (undrained or short term) condition. Therefore, the effective stress strength parameters c' and ϕ', determined from the representative samples of a soil layer, are used in the analysis. Despite its limitations, Isotropic Consolidated Undrained Triaxial Tests with pore pressure measurement (CIU) are commonly carried out on the 72mm diameter soil samples from a Mazier sampler without trimming and side drains. The cost for a set of 72mm diameter CIU test is about RM1000 per set of three specimens. It is important that soil samples are tested at stresses comparable to those in the field, and should be saturated. Prolonged and high intensity rainfall, especially during the two monsoon periods every year, infiltrates into the soil as expected and it is likely that the saturation condition is approached at shallow depth in the field during the service life of a slope.

The shear strength of soil is conveniently represented graphically on a Mohr diagram. For simplicity of analysis, it is conventional to use a c'-ϕ' soil strength model for saturated soil as expressed in the following equation:

$$\tau_f = c' + \sigma_{nf}' \tan\phi' \text{ (for Saturated Soils)} \quad \text{.... Eq. 1}$$

where
τ_f = shear strength of soil
σ_{nf}' = effective normal stress at failure
ϕ' = effective angle of friction (degree)
c' = apparent cohesion (kPa)

Meanwhile, unsaturated shear strength of soil has not been adopted for design as it has included soil suction which will give higher shear strength compared to saturated soils. In fact, most steep cut slopes with low or inadequate factors of safety did not fail because of the presence of soil suction, but if the suction is lost due to prolonged and high intensity rainfall, these slopes will likely fail. The most obvious example is that a slope can stand at a very steep angle (even near vertical) immediately after excavation but with time or after rain, the slope will collapse. In view of the great uncertainty of relying on the stability of slopes with soil suction, it should be ignored.

For the interpretation of shear strength of soil, the simpler MIT (Massachusetts Institute of Technology) stress path is preferred and commonly used by local practitioners. The vertical and horizontal axes are as follows:

$$t = \frac{(\sigma_1 - \sigma_3)}{2} = \frac{(\sigma_1' - \sigma_3')}{2} \quad \text{(Vertical Axis)} \qquad \text{... Eq. 2}$$

$$s = \frac{(\sigma_1 + \sigma_3)}{2} \text{ and } s' = \frac{(\sigma_1' + \sigma_3')}{2} \text{ (Horizontal Axis) …Eq. 3}$$

where σ_1 = total major principal stress at failure
σ_3 = total minor principal stress at failure
σ_1' = effective major principal stress at failure
σ_3' = effective minor principal stress at failure

Figure 9 shows the MIT stress path plot for effective stress path (ESP) and total stress path (TSP), while u_b is the excess pore water pressure generated during shearing. For the determination of shear strength (c' & ϕ'), the following equations are adopted (Figure 10):

$$\tan \theta = \frac{t'}{s} = \sin \phi'$$

$$\kappa = c' \cos \phi' ; \quad c' = \frac{\kappa}{\cos \phi'} \qquad \text{…. Eq. 5}$$

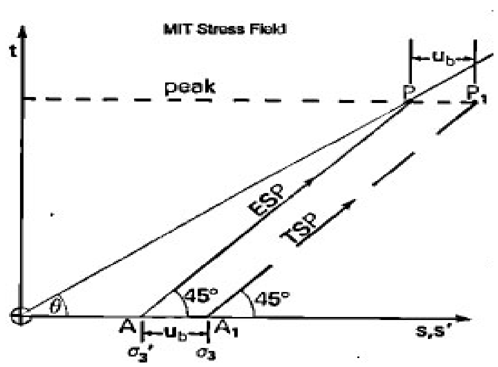


Figure 9: General MIT stress path Soils

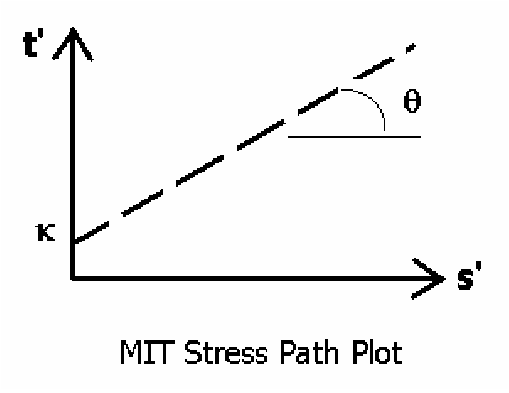


Figure 10: s-t plot for MIT stress path

Figure 11 shows the typical bonding and dilatant characteristics of the residual soil at a low stress range (low confining and consolidation pressure) which exhibits a peak shear strength envelope in terms of effective stress which has an apparent cohesion intercept (c') if the Mohr-Coulomb c'-ϕ' failure line is used. As the consolidation pressure in laboratory tests prior to shearing increases beyond its yield stress, the bonds are destroyed and residual soil will likely behave like normally consolidated or slightly overconsolidated soil. The critical state friction angle is represented as ϕ_{cv}. If critical state strength is used in the normal stress range of a slope, the streng`th value will be underestimated, giving an unrealistically low Factor of Safety (FOS). Therefore, when the in-situ stress range and the stress path during shearing is correctly determined, the c'-ϕ' peak shear strength envelope will be representative of the field conditions.

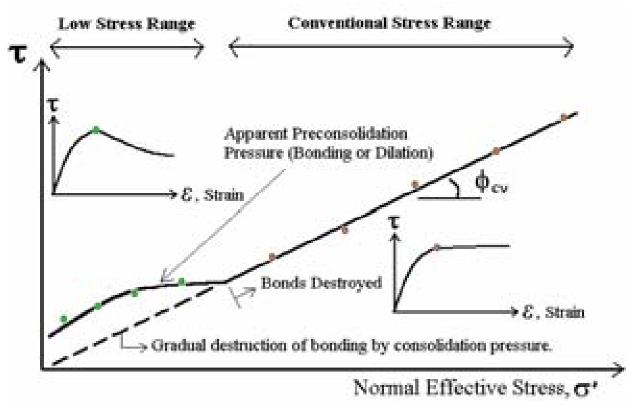


Figure 11: Effect of Bonding on the Apparent Cohesion Intercept of a Drained Strength (Effective Stress) Failure Envelope (after Gue & Tan 2006)

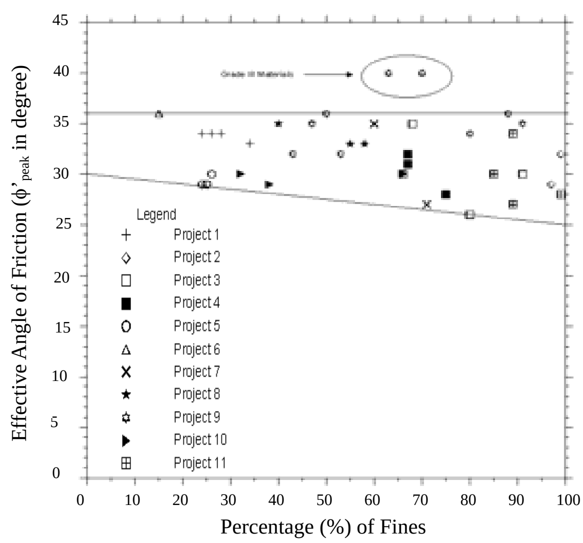


Figure 12: ϕ'_{peak} versus percentage of fines in residual soils

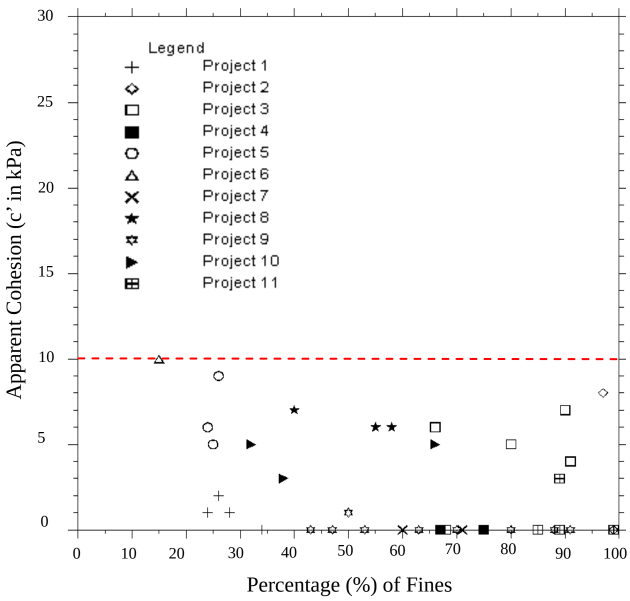


Figure 13: c' versus percentage of fines in residual soils

Figure 12 shows the relationship between the peak effective angle of friction (ϕ'_{peak}) and the percentage of fines (silt & clay) in the residual soils obtained from thirteen (13) different sites. It is observed that the value of ϕ'_{peak} generally falls between 26^o to 36^o and there is a trend showing reduction of ϕ'_{peak} with increasing fines content. Therefore, during selection of ϕ' for design, it is important to be aware of the common range of values for the type of soils. Figure 13 shows c' obtained from thirteen (13) different sites. It is obvious that the c' value is generally less than 10kPa and zero for soil with low fines content. However for weathered rock, the c' value could be higher.

5.2 Analysis & Design

Analysis and design of rock and soil slopes in Malaysia has mainly followed the recommendations by Geotechnical Manual for Slopes (GEO, 2000) of Hong Kong, with minor modifications to suit local conditions. However, the prescriptive method by forming 1V:1H (45°) slopes regardless of geological formation and slope height is not uncommon. As such, the country has suffered from numerous landslide incidents in the past decades as a result of inadequate or improper geotechnical input. However, since the establishment of the Slope Engineering Branch in 2004 and the implementation of the Accredited Checker programme, better practices on slope design and management are observed and more stringent approval and implementation procedures are also exercised.

5.2.1 Soil Slope Designs

The vertical height of slopes between intermediate berm is usually about 5m to 6m. GEO (2000) recommends that the vertical interval of slopes should not be more than 7.5m. The berm width is at least 1.5m wide for easy maintenance. The purpose of having berms with drains is to reduce the volume and velocity of runoff on the slope surface and the consequent reduction of erosion potential and infiltration. The adopted slope gradient depends on the results of analysis and design based on moderately conservative strength parameters and representative groundwater levels.

5.2.2 Slope Strengthening Works

Soil nail is commonly used both as a stabilization measure for distressed slopes, and for very steep cut slopes. The popularity of soil nail is due to its technical suitability as an effective slope stabilization method, its ease of construction and the fact that it is relatively maintenance free. As such, soil nail slopes of up to more than 25m high have been used for highways, basement excavation and hillsite development projects (after Chow & Tan 2006). For soil nail slopes steeper than 1V:1H, reinforced shotcrete surface is commonly adopted. Typical drawings of the configuration of soil nail slopes with individual nail heads are shown in Figure 14. However, the slope may also be of grid beam option to allow landscaping around the soil nail (see Figure 15). Figure 16 shows one of the sites with an individual nail head system before and after landscaping. Meanwhile, Figure 17 shows a project sites with grid beam system before and after fully grown vegetation.

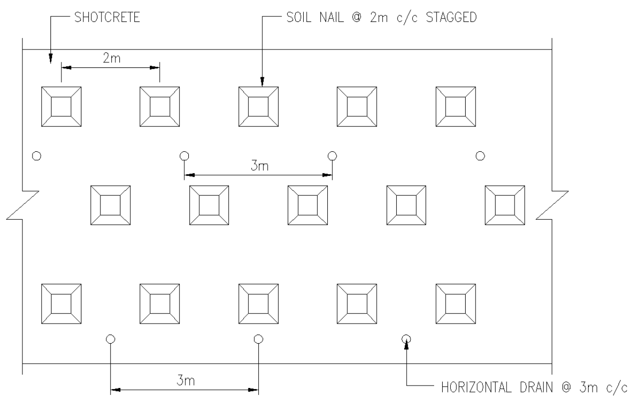


Figure 14: Typical soil nail slope configuration with shotcrete/Gunite facings (after Liew, 2005a)

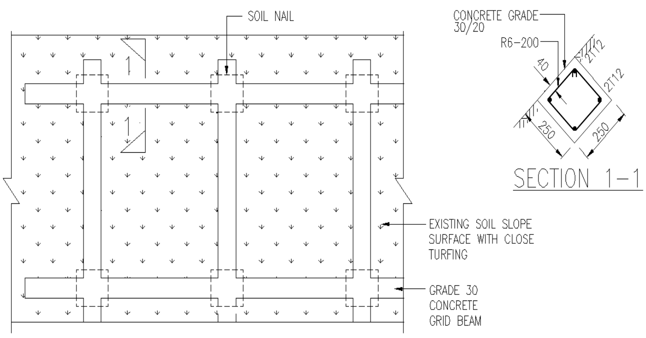


Figure 15: Grid Beam System

Figure 16: Individual nail head system before and after growth of vegetation (after Liew, 2005a)

Figure 17: Grid beam system before and after fully grown vegetation (after Liew, 2005a)

Figure 18: Fully shotcrete soil nail slope in Kuala Lumpur

As for project sites with boundary constraints, steeply cut slopes of 25m to 30m at 4V:1H are constructed in Malaysia. Figure 18 shows a fully shotcreted soil nail slope at a project site in Kuala Lumpur. For slopes with gradients ranging from 45° to 30° and with only moderate heights, the active pressure acting on the shotcrete surface is insignificant. However, for soil nail slopes with gradients of about 60° or more, the active pressure acting on the shotcrete surface is significant. In addition to face failure, proper design of the soil nail facing is also important as it affects the development of bond resistance along the nails. Therefore, an inadequately designed facing will also result in a reduced Factor of Safety (FOS) in addition to potential face failure (Tan & Chow, 2009) as shown in Figure 19.

Figure 19: Example of facing failure (after Tan & Chow, 2009)

5.2.5 Rock Slope Design

During construction of high cut slopes in sedimentary or meta-sedimentary formations, it is important to carry out confirmatory geological slope mapping of the exposed slopes by experienced engineering geologists or geotechnical engineers to detect any geological discontinuities that may contribute to the following potential failure mechanisms, namely planar sliding, anticline sliding, active-passive wedges, toppling and also 3-D wedges.

All these discontinuities cannot be fully addressed during the design and analysis stage as they are still not yet exposed and field tests such as boreholes or trial pits are not able to detect these discontinuities adequately for incorporation into designs. Typical examples of rock bedding, and discontinuities are shown in Figure 20. Therefore during the design stage, the design engineer should make moderately conservative assumptions for the soil/rock parameters and also the groundwater profile to ensure adequacy in design and only carry out adjustments on site if necessary based on the results of the geological slope mapping and re-analyses of the slopes.

In addition, formation of high rock slopes usually involves soil and rock with varying degrees of weathering (see Figure 21). As a result, varying slope strengthening strategy should be used. For a project in Selangor, combination of soil nail slope and anchored reinforced concrete wall were chosen (see Figure 22). Proper sampling and testing of such materials, especially weathered rock is very difficult and the design of such slopes is usually critical to the project in terms of public safety and also cost. The Authors recommend that in the absence of reliable test data and past experience on similar structures and materials, the estimation of the equivalent Mohr-Coulomb parameters for slope design should be guided by the method proposed by Hoek et al. (2002). The equivalent Mohr-Coulomb parameters obtained are based on the Hoek-Brown failure criterion for rock mass and are derived based on strength parameters (uniaxial compressive strength) and site observations (e.g. rock surface conditions and structure). The equivalent Mohr-Coulomb can now be easily computed with the availability of free software, “RocLab”, which is available on the internet (www.rocscience.com).

(a) Joints with infilling material (b)Bedding of cut slope day-lighting plan

Figure 20: Typical example of joint infill and bedding (after Liew, 2005b)

Figure 21: Exposed slope with varying degrees of weathering (after Liew et al, 2004)

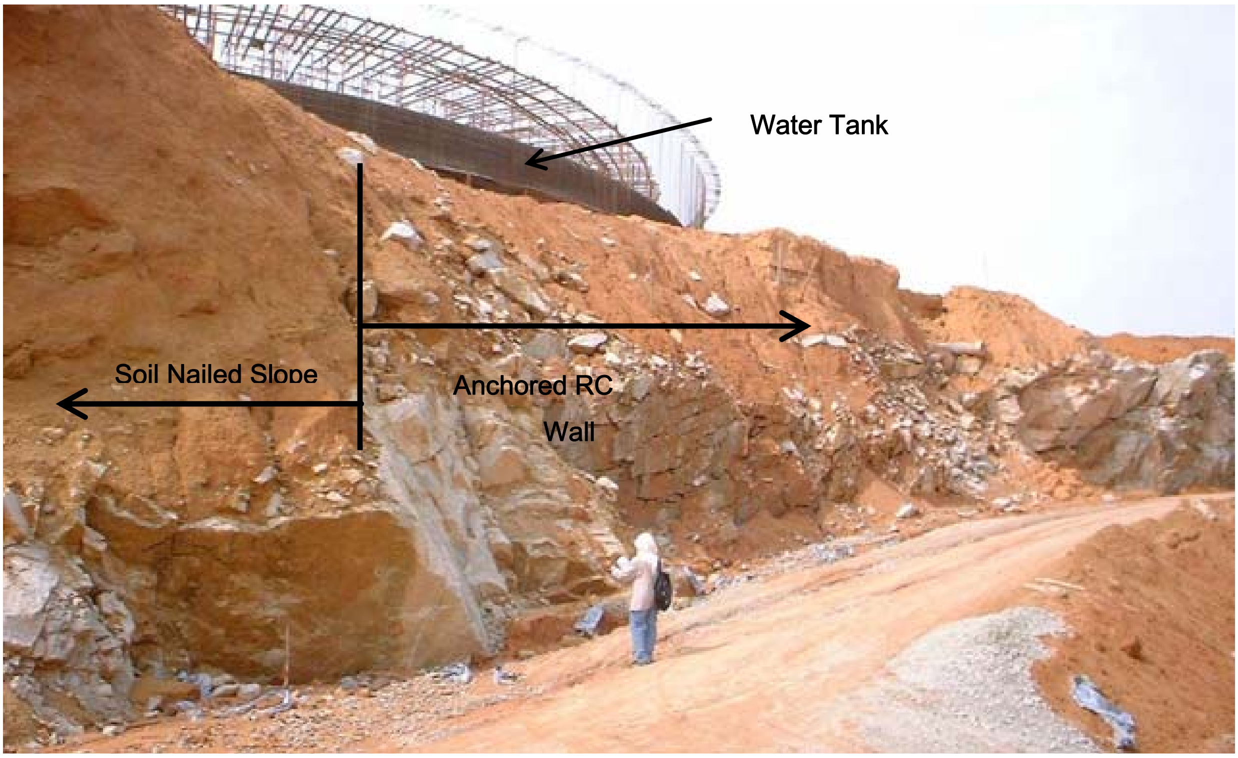


Figure 22: Varying slope strengthening works within the same area (after Liew et al, 2004)

Figure 23: Formation of Rills and Gullies (after Gue & Tan, 2004)

Figure 24: Localized landslips (after Gue & Tan, 2004)

5.3 Construction

Construction quality control is particularly important for hillsite development as the variation of material weathering may be large and the change in terrain and its associated problems maybe significant. Therefore, full time site supervision is mandatory in all hillsite projects. In fact, in recent development approval, the government has spelled-out the requirements of experienced geotechnical engineers or engineering geologists in site supervision during earthworks and infrastructure works for all major hillsite development projects. However, there is a significant lack of non-compliance in policy enforcement due to limitation of resources or manpower with the appropriate knowledge.

5.4 Maintenance

Malaysian practice on slope maintenance has always referred to the guidelines from Hong Kong GEO, for both Routine Maintenance Inspections by laymen and Engineer's Inspections. Detailed recommendations for the necessary maintenance regime are stated in Geoguide 5 (2003). However, such a maintenance scheme has only gained popularity recently after it has been identified as one of the root causes of landslide incidents. These include damaged/cracked drains, inadequate surface erosion control and clogged drains. Based on lessons learned from case history, blockage of drains will cause large volumes of water to gush down a slope causing erosion to the slope and the formation of gullies. These gullies will further deteriorate into big scars on the slopes and will finally lead to landslides.

Figure 23 shows the formation of rills and gullies and Figure 24 shows localized landslips caused by erosion which will propagate with time into landslides if erosion control is ignored. If proper maintenance is carried out, then all these small defects would have been rectified and landslides caused by erosion would have been prevented.

6 THE WAY FORWARD

By understanding the current Malaysian practice on slope engineering, the Author has recommended areas for improvement focusing on intensifying undergraduate education, structured training for practitioners and construction control and enforcement. In addition to this, the Authors have also proposed strategies to streamline and harmonise existing policies and legislation to provide practical guidelines for project approval and control. Figure 25 summarises the identified key areas where improvement and initiatives are needed in slope management and engineering.

6.1 Improvements on Policies and Legislation

As elaborated in section 4.0, the current implementation policy for hillsite development is in a confused state due to the current ruling of no development on Class III and IV slopes. As such, the Author urged that the current legal and regulatory framework to be reviewed and enhanced, including policies and legislation on landslide risk reduction management, mechanisms and processes in ensuring legal accountability, mechanisms for effective implementation, enforcement etc. In the aspect of development planning, the relevant policy should cut across development in both urban and rural areas for housing, infrastructure, agricultural, forestry, mining, etc.

For the enhancement of technical issues related to slope engineering, the Authors suggest the establishment of a centralised agency to support the 146 local authorities including city councils, other federal agencies and ministries across the country (Gue & Chow, 2009). The objective of the centralised institution/agency is to ensure sustainable hillsite development by breeding a group of experts through structured professional training after the basic undergraduate education. Such a centralised agency should aim at formulating simplified and practical hillsite development guidelines/procedures and ensuring consistency in policy implementation and enforcement while maintaining an expert advisory role without taking over the existing authorisation held by individual governmental agencies/ministries.

Procedures and guidelines on planning and implementation should incorporate an effective risk assessment and mitigation system with attention to possible environmental impact, mitigation, enhancement and sustainability. The Malaysian legal framework can be enhanced by emulating certain provisions in the legal and regulatory framework for development planning used by Hong Kong (Chan, 2007), Italy (Casale and Margottini, 1999), etc (Gue et al, 2008). As the Slope Engineering Branch of PWD has already started with ground mapping to compute hazard maps at sensitive areas like Ulu Klang, usage of such hazard maps should be incorporated into the current system of development approval and enforcement. From there, development of more hazard maps is encouraged followed by formation of risk maps to facilitate planning of land use and government control.

The main stakeholders involved in the harmonization and standardization of policies and legislation are illustrated in Figure 26. Participation from these stakeholders is very important for the success of developing comprehensive policies and regulations for subsequent implementation.

In order to achieve profound improvements in landslide mitigation and risk reduction, success at the implementation stage is vital. As such, two different stages of implementation are identified before, during and after a landslide event. The two major stages are the preparedness stage and the mitigation stage. In the preparedness stage, the appropriate laws and regulations, implementation and enforcement policies and guidelines for development planning, training schemes for stakeholders and promotion schemes for community awareness should be geared towards effective landslide mitigation and risk reduction management.

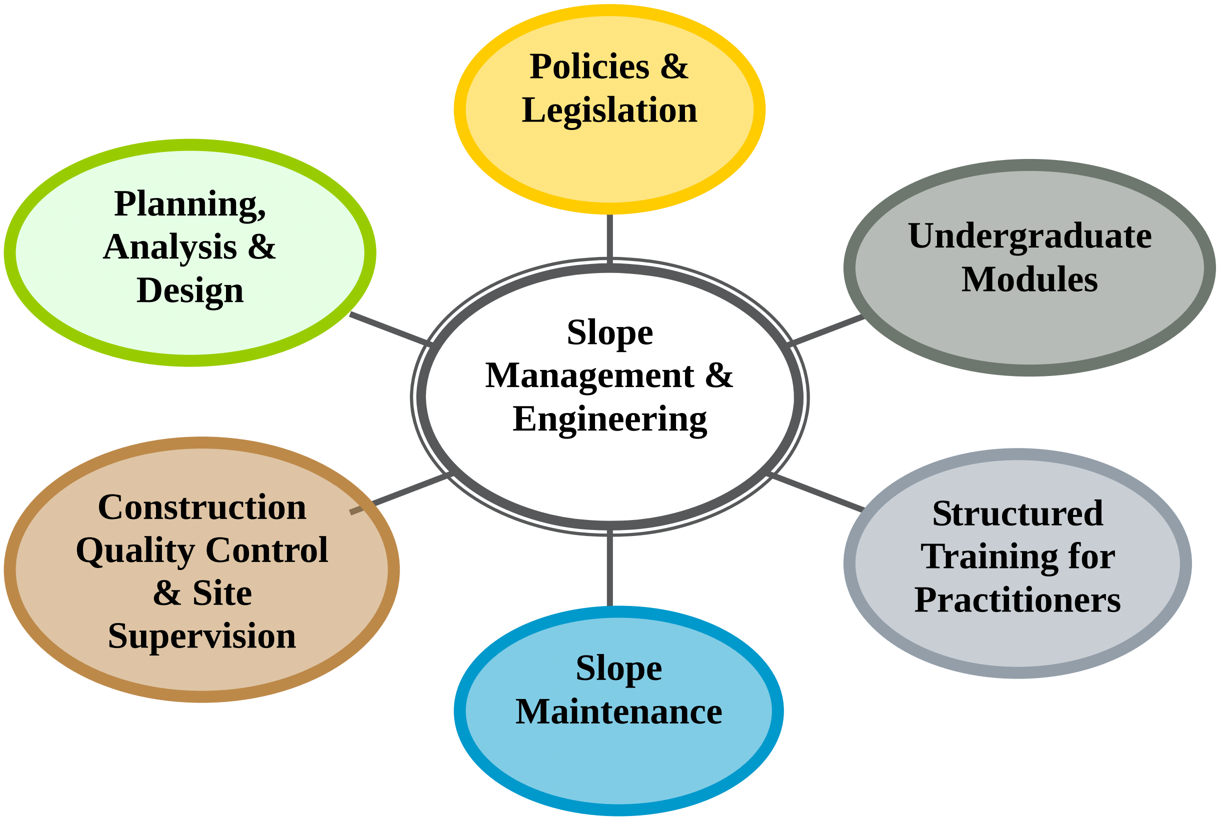


Figure 25: Key areas for improvement in slope management and engineering

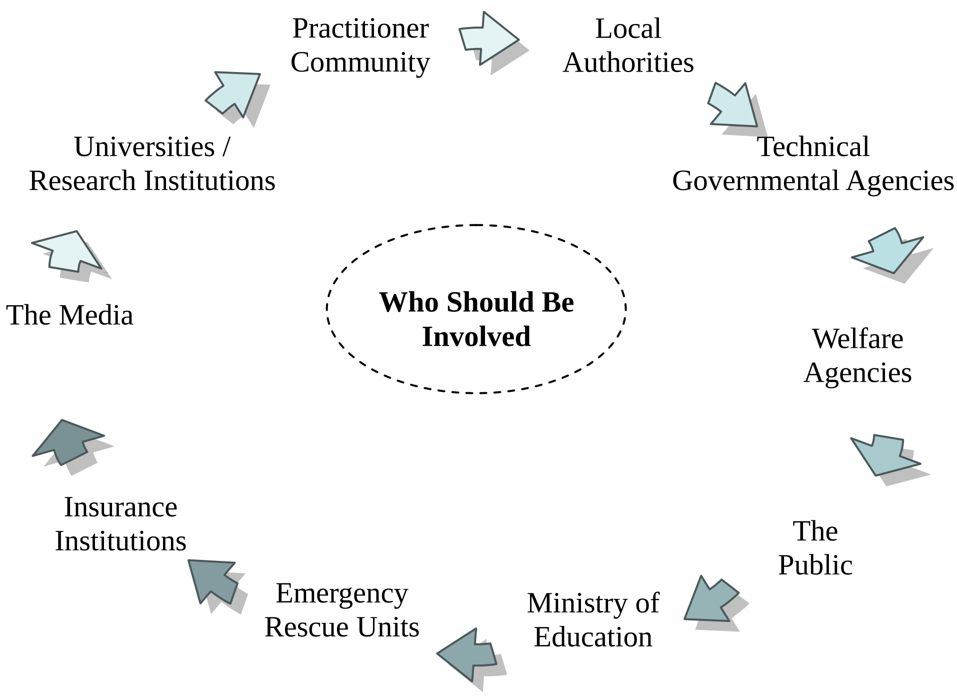


Figure 26: Formation and Implementation of a National Slope Master Plan (after Gue *et al.*, 2008)

In the mitigation stage, significant resource allocation from the main stakeholders is essential as this consists of planning and enforcement of good practices in new development, retrofitting of existing areas at risk, research and development and exploring advancement in technology and methodology. A similar approach has been very successfully used in Hong Kong where landslide mitigation and risk reduction have been incorporated into two components, first in planning control of new development, and subsequently in retrofitting existing slopes at risk (Chan, 2007). Figure 27 illustrates the success of Hong Kong's Geotechnical Engineering Office (GEO) in reducing the risk of landslides (Gue, 2008). Such policies have contributed significantly to landslide mitigation and risk reduction in Hong Kong with tremendous success. Furthermore, the entire implementation procedure should be entrenched with a "check and review" benchmarking system for continuous policy refinement. With that, the formulated template of a National Slope Master Plan may become a flagship programme, serving as a blueprint for a structured and systematic implementation plan.

6.2 Structured Professional Training

As Engineers are the professionals involved in specifying the required landslide mitigation measures, providing structured training to practitioners would be the best way to improve slope engineering practices. Such training should also serve as a reminder to practitioners and professionals who are involved in slope engineering works to practice ethically and professionally, and only practice in the area of their expertise to ensure the safety of the design. Therefore, the continuing professional development (CPD) scheme implemented by the Board of Engineers, Malaysia (BEM) should be adopted as a training programme for practising engineers. Furthermore, collaboration and working partnership should be established between professional bodies like the Institution of Engineers, Malaysia (IEM), technical agencies, academia, federal, state and local governments, private industry, Non-Governmental Organisations (NGOs) involved in slope engineering and management, to recognize and accredit professionals and/or semi-professionals undergoing the structured training. Through the structured training programmes, a certification and accreditation system should also be implemented to update and improve the capacity, competency and professionalism of stakeholders involved in slope engineering and management.

In terms of training programmes for government agencies, the emphasis should be in three stages:

1. Approval Stage: Training programmes on legal framework to enhance the knowledge and capabilities of the local authorities with the process flow of land development such as planning, application, approval, design, construction and maintenance. This is important to ensure proper enforcement of loss reduction measures in accordance with laws and regulations.
2. Preparedness and Mitigation Stage: Training programmes on guidelines and technical modules on analysis, design, construction control, site supervision and maintenance of slopes
3. Response and Recovery Stage: Training programmes on administrative management of the guidelines for responding to landslide disasters and providing scientific and technical information needed for response and recovery.

Training of different stakeholders, gathering of comments on conflicts and weaknessness of existing guidelines or procedures can facilitate standardisation or harmonisation o f practices/procedures and formulation of relevant guidel ines related to slope engineering and management. With appropriate and sufficient training, the adoption of best practices and technology (which needs to be updated fr om time to time) can be on par with international stan dards. International best practices can be adopted and/or adapted to local conditions to mitigate landslides/slope f ailures and their related consequences.

6.3 Undergraduate Training in Slope Engineering

Apart from improving the policies and legislation for implementation by the government on slope engineering and management, emphasis should also be given to improve undergraduates' understanding of slope engineering fundamentals. This is currently lacking, and is one of the most important components of improving slope engineering.

As such, the proposed strategy is to develop training modules for the undergraduate curriculum and course notes for engineering undergraduates. The training modules should have adequate fundamentals on slope engineering, which include planning of S.I. works, compiling and interpreting soil parameters and water profiles from the S.I. works, followed by analysis, design, specifications, site supervision, construction control, monitoring and maintenance.

Government and private universities should review and update the undergraduate syllabus on slope engineering from time to time with the assistance of active, experienced practitioners to ensure graduates possess enough fundamentals to meet industry needs. The regular updates may be further improved by pooling resources from a group of universities and passionate practitioners to ease the workload of the lecturers so that the content and quality of the lecture modules are not compromised. Knowledge sharing between lecturers and practitioners can also be achieved through workshops and forums to share experiences on landslide mitigation and risk reduction.

6.4 Planning, Analysis and Design of Slopes

6.4.1 Desk Study

Desk study includes reviewing of geological maps, memoirs, topographic maps and aerial photographs of the site and adjacent areas so that the engineers are aware of the geology of the site, geomorphology features, previous and present land use, current developments, construction activities, problem areas such as previous slope failures, etc.

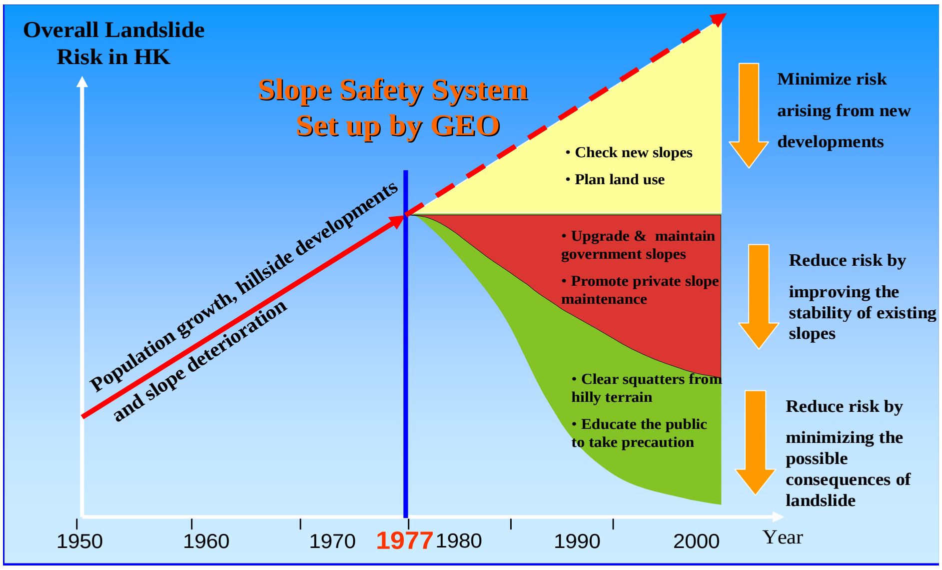


Figure 27: Landslide Risk Reduction Strategy (after Malone, 2007)

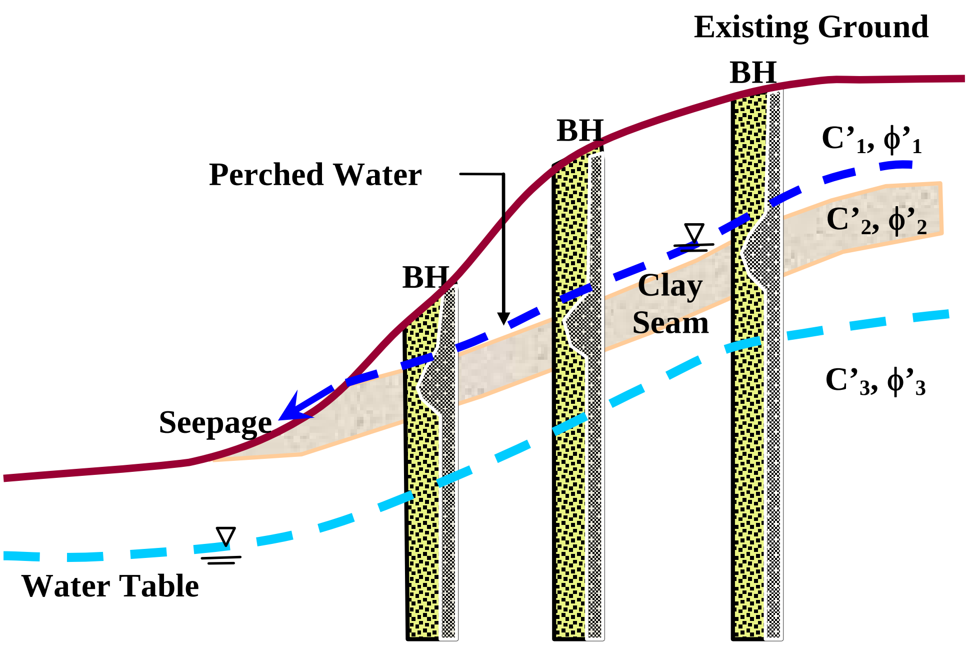


Figure 28: Potential clay seam on slopes

6.4.2 Site Reconnaissance

Site reconnaissance is required to confirm the information acquired from the desk study and also to obtain additional information from the site. For a hillsite development, it is also very important to locate and study the existing landslip features that can act as indicators of the stability of the site.

6.4.3 Subsurface Investigation

During the course of SI, the design engineer must attempt to identify clay seams with the potential of inducing perch water. This could be done by superimposing the classification of subsoil in proportion on the cross-section of a slope, as shown in Figure 28 to examine its influence on the stability of a slope.

6.4.4 Analysis and Design of slopes

For the design of the slopes, correct information on soil properties, groundwater regime, site geology, selection and methodology for analysis are important factors that require the special attention of the design engineer. A detailed analysis of soil slopes can be found in Tan & Chow (2004) and Gue & Tan (2000).

For the selection of Factor of Safety (FOS) against a slope failure, the recommendations by Geotechnical Manual for Slopes (GEO, 2000) of Hong Kong, with minor modifications to suit local conditions, are normally selected with consideration to two main factors, namely, Risk-to-life or Consequence to life (e.g. casualties) and Economic Risk or Consequence (e.g. damage to property or services). Further details on selection of FOS can be found in Gue & Tan (2004).

6.4.5 Design Fill Slopes

For fill slopes, the vegetation, topsoil and any other unsuitable materials are removed before placing the fill. The founding layers are also benched to key the fill into an existing slope. A free-draining layer conforming to the filter criteria is normally required between the fill and natural ground to eliminate the possibility of high pore pressures developing and causing slope instability, especially when there are existing intermittent streams and depressions. Sufficient numbers of discharge drains should be placed to collect the water in the filter layer and discharge it outside the limits of the fill and away from the slope. Horizontal groves are often formed on the bare surface of the slopes to prevent the formation of gullies due to surface run-off (see Figure 29).

6.4.6 Surface Protection and Drainage

Surface drainage and protection are necessary to maintain the stability of the designed slopes through reduction of infiltration and erosion caused by heavy rain, especially during monsoon seasons. Runoffs from both the slopes and the catchment areas upslope should be effectively cut off, collected and led to convenient points of discharge away from the slopes. Details on surface protection and drainage can be found in Gue & Tan (2004).

6.4.7 Catchment Study

Catchment study should be carried out for the provision of surface drainage capacity to carry the runoffs to a safe discharge point. Under-provision of surface and subsurface drainages can lead to infiltration and spillage of the surface runoffs to the slopes, cause saturation of slopes, surface erosion and could result in slope deterioration over time.

Figure 29: Example of Horizontal Groves

6.4.8 Fill Slopes Over Depressions or Valleys

Depressions or valleys are the preferred water path of natural surface runoffs. Streams or intermittent streams are usually formed at these depressions and valleys, especially during heavy rain. Intermittent streams at depressions or valleys also transport sediments from upstream and deposit these sediments at the depression or valley and form a layer of soft or loose material and debris. For slopes which are formed by filling over a depression or valley, the possibility of saturation of slopes and slip planes through the pre-existence of weak, soft or loose layers with debris is high.

Therefore, extra care should be exercised on the fill slopes over depressions or valleys by adopting the following measures to mitigate risk of slope failures: -

1) To provide adequate surface drainage by calculating the capacity required based on catchment study to reduce infiltration of surface runoffs to slopes.
2) Subsurface drainages should be adequately provided to drain water from slopes to avoid saturation and rising of the groundwater level. Increase in ground water level will reduce the FOS of slopes.
3) To replace shallow and weak materials with good compacted fill material during the filling works to enhance the slope stability.

6.4.9 Slopes Next to Water Courses

For slopes adjacent to water courses such as river bank slopes, beaches, pond side slopes, etc, the slopes should be robustly designed by considering the probable critical conditions such as saturated slopes with rapid drawn-down conditions, scouring of slope toes due to flow and wave action, etc. Properly designed riprap or other protection measures are needed over the fluctuating water levels.

6.5 Construction Control

Further to the problem highlighted in section 5.3, independent site supervision personnel are important as consultant's representatives and provide impartial decisions to ensure satisfactory construction quality. In addition, all earthworks and infrastructure contract should have also included appropriate contractual requirements and penalty clauses such that the Contractor's responsibility is clearly stated and accounted for during the tender stage. Such an approach is able to facilitate fair and transparent tender procedures for the benefit of all parties involved.

6.5.1 Site supervision and Coordination

Supervising personnel should have sufficient knowledge and experience in geotechnical engineering to identify any irregularities in the subsurface conditions (e.g. soil types, surface drainage, groundwater, weak planes such as clay seams etc.) that may be different from those envisaged and adopted in the design. Close coordination and communication between design engineer(s) in the office and supervising engineer(s) are necessary so that modification of the design to suit the change of site conditions could be carried out when needed. This should be carried out effectively during construction to prevent failure and unnecessary remedial works during the service life of the slope. Site staff should keep detailed records of the progress and the conditions encountered when carrying out the work, in particular, if irregularities like clay seams or significant seepage of groundwater are observed. Sufficient photographs of the site before, during and after construction should be taken. These photographs should be supplemented by information such as dates, weather conditions or irregularities of the subsoil conditions observed during excavation.

6.5.2 Construction Control via Contractual Measures

For all earthworks, there would be contractual provisions in protecting the environment against inappropriate ground disturbance by contractors for both temporary and permanent works. Such legal provisions should be included in the relevant Earthworks Specification. An extract from a sample Specifications for Earthworks is shown Figure 30, in which clause 12.7 specifies the Engineer's requirements on temporary works (see Figure 30a), clauses 24.3 and 24.4 specifies protection of borrow pits (see Figure 30b), clause 33.5 specifies turfing and clause 33.21 specifies penalties imposed for non-compliance (see Figure 30c) (Gue & Wong, 2008).

Furthermore, contractors are required to quote temporary slope protection works (see extracted sample in Figure 31a) so that the Engineer's specifications for temporary protection are not compromised. With that, the contractor would be penalised for not providing the required precautionary measures during the course of works, especially on the protection of borrow pits (see extracted sample in Figure 31b). The control on temporary works should also be included in the construction drawings as drawing notes. In addition, the construction drawings should also include the appropriate construction sequence for cut and fill slopes, as shown in Figures 32a and 32b, respectively.

In the event a borrow pit was used, the Engineers should ensure it is cut to a gentle and stable gradient to allow for appropriate discharge of surface run-off. Meanwhile, the slopes should be closed turfed to minimise soil erosion which may cause slope instability or washing away of fine particles, hence, clogging downstream drainage system. The above requirements should be made known to the contractor through specifications, as per clause 24.3 and 24.4 in Figure 30b.

6.5.3 Filling of Slopes

Whenever possible, construction works should be arranged such that fill is placed during the dry season, when the moisture content of the fill can be more easily controlled. When filling, tipping should not be allowed and all fill should be placed in layers not exceeding 300mm to 450mm thick depending on the type of compacting plant used (unless compaction trails proved that thicker loose thickness is achievable) in loose form per layer and uniformly compacted in near-horizontal layers to achieve the required degree of compaction before the next layer is applied. The degree of compaction for fill to be placed on slopes is usually at least 90% to 95% of British Standard maximum dry density (Standard Proctor) depending on the height of the slope and the strength required.

6.5.4 Cutting of Slopes

Cutting of slopes is carried out from top-down followed by works like drains and closed turfing. When carrying out excavation of cut slopes, care must be taken to avoid overcutting and loosening of the finished surface which may lead to severe surface erosion. Minor trimming should be carried out either with light machinery or by hand as appropriate. It is also a good practice to construct first the interceptor drains or berm drains with proper permanent or temporary outlets and suitable dissipators before bulk excavation is carried out or before continuing to excavate the next bench.

6.5.5 Surface Protection of Slopes

For all exposed slopes, protection such as closed turfing or hydroseeding should be carried out within a short period (not more than 14 days and 7 days during the dry and wet seasons respectively) after the bulk excavation or filling for each berm. All cut slopes should be graded to form horizontal groves (not vertical groves) using suitable motor graders before hydroseeding. This is to prevent gullies from forming on the cut slopes by running water before the full growth of the vegetation, and also to enhance the growth of vegetation.

12.0 TEMPORARY WORKS

12.1 The Contractor shall allow in the tender for the cost of providing the necessary design, statutory submission, construction, testing and monitoring of all temporary works, including the subsequent removal of all recoverable temporary structures, for the satisfactory completion of the earthworks. He shall be responsible for the overall adequacy and safety of all temporary works. All temporary works shall comply with requirements of BS 5975.

12.2 Temporary works means all planning and works carried out by the Contractor to construct the permanent works designed by the Consultant complying with all specifications, drawings and workscope. This includes but not limited to necessary field and laboratory tests, temporary tracks, excavation, filling, proper cover and protection to exposed slopes, sequence and timing of works, necessary temporary drainage, pumping of water, emergency contingency measures, safety of site, rectification and strengthening measures, methodology and method statement of all works, and etc.

12.3 The scope of temporary construction shall include but not limited to:

(a) Life safety measures such as hoardings, barricades, nettings, signboards, etc.

(b) Ground improvement and/or ground water cut off systems using jet grout piling, etc.

(c) Ground water recharging systems, surface and groundwater drainage system using surface or subsoil drains, sumps, etc.

(d) All other measures necessary for the safe performance of the temporary works, such as maintaining, adding, upgrading, strengthening, adapting, modifying, re-positioning, taking down and re-fixing from time to time, etc.

12.4 Temporary works shall be the sole responsibilities of the Contractor. S.O.'s approval or consent of Contractor's method statement on all temporary works shall not relieve the Contractor's sole responsibilities to ensure all temporary works comply to good engineering practice, and Contractor's own time and cost to rectify ...
the temporary works or ...

12.5 The Contractor shall en...
calculations and constru...

12.6 The Contractor shall ma...
clearances and the sta...
construction of the temp...

12.7 All temporary works es...
and shall not ...
completion o...
works by Contractor s...
(e.g. slope angle, comp...

12.8 Temporary works by the ...
way, the S.O. will order remedial works to be provided immediately at the Contractor's own expense with not additional performance time. Such instruction will not relieve the Contractor of his sole responsibility for the temporary works. The remedial works carry out shall comply to all requirements, specifications, drawings and workscope of similar type of permanent works (e.g. cut, fill, retaining walls, strengthening works, etc).

12.7 All **temporary works** especially but not limited to temporary accesses and temporary earthworks (temporary cut or temporary fill) shall not cause failure and shall not induce instability or serviceability problems in the long term. All temporary cut and fill by Contractor that will be left behind after completion of permanent works shall have the **same Factor of Safety on stability and Serviceability conditions as permanent works**. These temporary works by Contractor shall also comply with all requirements, specifications, drawings and workscope applicable for similar type of permanent works (e.g. slope angle, compaction of fill, surface drainage, retaining structures, strengthening measures if necessary, etc).

Figure 30a: Extract from the Specifications for Earthworks (Clauses 12.0: Temporary Works) (after Gue & Wong, 2008)

24.2 Fill materials for use in forming fill platforms shall be the suitable material obtained from excavation in cuttings. Where the quantity of such materials is inadequate, the Contractor shall obtain suitable materials from the designated borrow pits or from his own borrow pits which have been approved by the S.O.

Borrow Pit

24.3 The Contractor shall be responsible for locating borrow pits. Designated borrow pits shown on the Drawings only indicate to the Contractor potential areas for borrow. ...
ascertain the suitability of the ...
Contractor s... pay all neces...
keep the bor... free fr...
protection meas...

24.4 The contractor shal...
After cutting or dumpi...
protection method. Provi...
statement.

Soft Spots

24.5 Where any undue moveme...
the bottom of the fill, it shall ...
The resulting excavation ...
exceeding 225mm thick an...

24.6 The Contractor shall allow ...
necessary compaction.

Filling under Floors, Aprons ...

24.7 Filling shall be provided a... hereinbefore, deposited in loose lifts not exceeding 150mm loose thickness, and each loose lift well watered where necessary, rammed and compacted. No Generally, clay shall be used for filling under floors and aprons unless with the approval by the S.O. At

Borrow Pit

24.3 The Contractor shall be responsible for locating borrow pits. Designated borrow pits shown on the Drawings only indicate to the Contractor potential areas for borrow. Whether the Contractor obtains materials from the designated or his own borrow pit, it shall be his responsibility to ascertain the suitability of the pit with respect to the quantity and quality of the materials, which shall be subject to the approval of the S.O. The Contractor shall pay all necessary fees, taxes or royalties to the appropriate authorities and observe all relevant regulations. The Contractor shall keep the borrow pits free from ponding water and the excavation neat and tidy and shall carry out necessary erosion and environmental protection measures following the agreed method statement or as instructed by the S.O.

24.4 The contractor shall submit method statement on cutting or filling and turfing at the borrow pit or dump site for approval of the S.O.. After cutting or dumping, all the slopes shall be formed to a stable gradient and close turfed or protected by other approved surface protection method. Provision of drainage, siltation pond and preventive measures of pollution shall also be included in the method statement.

Figure 30b: Extract from the Specifications for Earthworks (Clauses 24.0: Protection of Borrow Pit) (after Gue & Wong, 2008)

33.0 PROTECTIVE VEGETATION FOR EROSION CONTROL

33.1 If specified in the drawings, directed by the Engineer or required to be used by the Contractor to protect the slope via vegetation, the following sections shall be adhered to unless otherwise directed by the Engineer.

33.2 If due to unforeseen circumstances turfing or hydroseeding cannot be carried out within the duration as specified hereafter, temporary protection/cover (eg. plastic sheets or equivalent) shall be laid on exposed slopes by the Contractor.

Topsoil

33.3 Topsoil stockpiled for the W… 50mm as directed by the En…

33.4 Topsoil stockpiled for the V… spread and lightly compacte… be turfed and/or hydroseed… other purposes.

Turfing

33.5 Turfing shall be carried ou… shown in the Drawings and/… the right t… accordingly fr… alternative type as… weeds.

33.6 Turf shall be obtained in … approximately 250mmx250… placed in position as soon a…

33.7 Turf sods shall be stacked and watered when they cannot be laid immediately after cutting. The surfaces to be turfed shall be trimmed and thoroughly wetted. The turf shall then be carefully laid to form a complete and uniform cover as shown on the Drawings. Turf laid on slopes steeper than 1(vertical) : 3 (horizontal) shall be pegged down with bamboo stakes approximately 250mm

33.5 Turfing shall be carried out within seven (7) days after formation of the final slope profile as shown in the Drawings and/or where directed by the Engineer. Otherwise, the Engineer reserves the right to engage external party to carry out the work and deduct the additional cost incurred accordingly from the contract. The type of turf shall be as indicated in the Drawings or other alternative type as approved by the Engineer and shall be free of lallang and essentially free of weeds.

Penalty

33.21 The Contractor who fails to implement the Works as per above Sub-sections 2.2.8.1, 2.2.8.2 and 2.2.8.3 shall bear the time and cost of turfing/hydroseeding works carried out by others under the direction of the S.O.

Figure 30c: Extract from the Specifications for Earthworks (Clauses 33.0: Protective Vegetation for Erosion Control and Penalty for Non-compliance) (after Gue & Wong, 2008)

Item No.	Description	Unit	Quantity	Rate	Amount RM
1	**TEMPORARY WORKS** "Temporary works" means all planning and works carried out by the contractor to construct the permanent works designed by the consultant complying to all specifications, drawings and wo… This includes but not limited to necessary … tests, temporary … proper cover a… slopes, sequen… necessary temp… water, emergen… safety of site, re… measures, me… statement of all … "Temporary wo… responsibility of… approval or th… method stateme… shall not relie… responsibilities to ensure all temporary works comply to good engineering practice, and contractor's own time and cost to rectify and defects, non-compliance to good engineering practice or possible long term instability/failure and serviceability problems of the temporary works or caused by temporary works. All temporary works particularly but not limited to temporary access and temporary earthworks (temporary cut or temporary fill)	L.S.			

Temporary Works

All temporary works particularly but not limited to temporary access and temporary earthworks (temporary cut or temporary fill) shall not cause failure and shall not induce instability or serviceability problems in the long term. All temporary cut and fill by contractor that will be left behind after completion of permanent works shall have the same factor of safety on stability and serviceability conditions as the permanent works.

Figure 31a: Sample Bill of Quantities for quotation of temporary works (after Gue & Wong, 2008)

Item No.	Description	Unit	Quantity	Rate	Amount RM
2	**Borrow Pit**				
	The contractor shall submit method statement on cutting or filling and turfing at the borrow pit or dump site for approval of the S.O.. After cutting or dumping, all the slopes shall be formed to a stable gradient and close turfed or protected by other approved surface protection method. Provision of drainage, siltation pond and preventive measures of pollution shall also be included in the method statement. Failure to implement the Works as per specification shall bear the time and cost of turfing/hydroseeding works carried out by others under the direction of the S.O.	L.S.			

Figure 31b: Sample Bill of Quantities for Borrow Pit protection (after Gue & Wong, 2008)

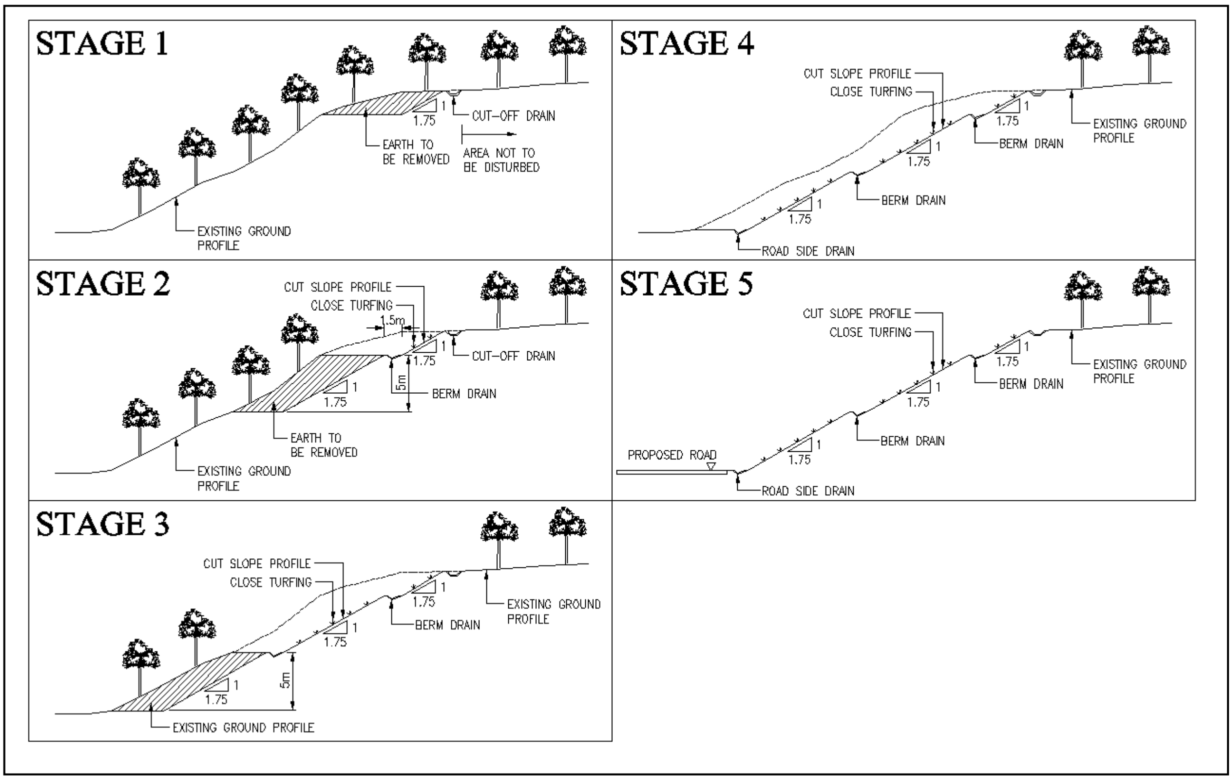


Figure 32a: Sample construction drawing on construction sequence for cut slopes (after Gue & Wong, 2008)

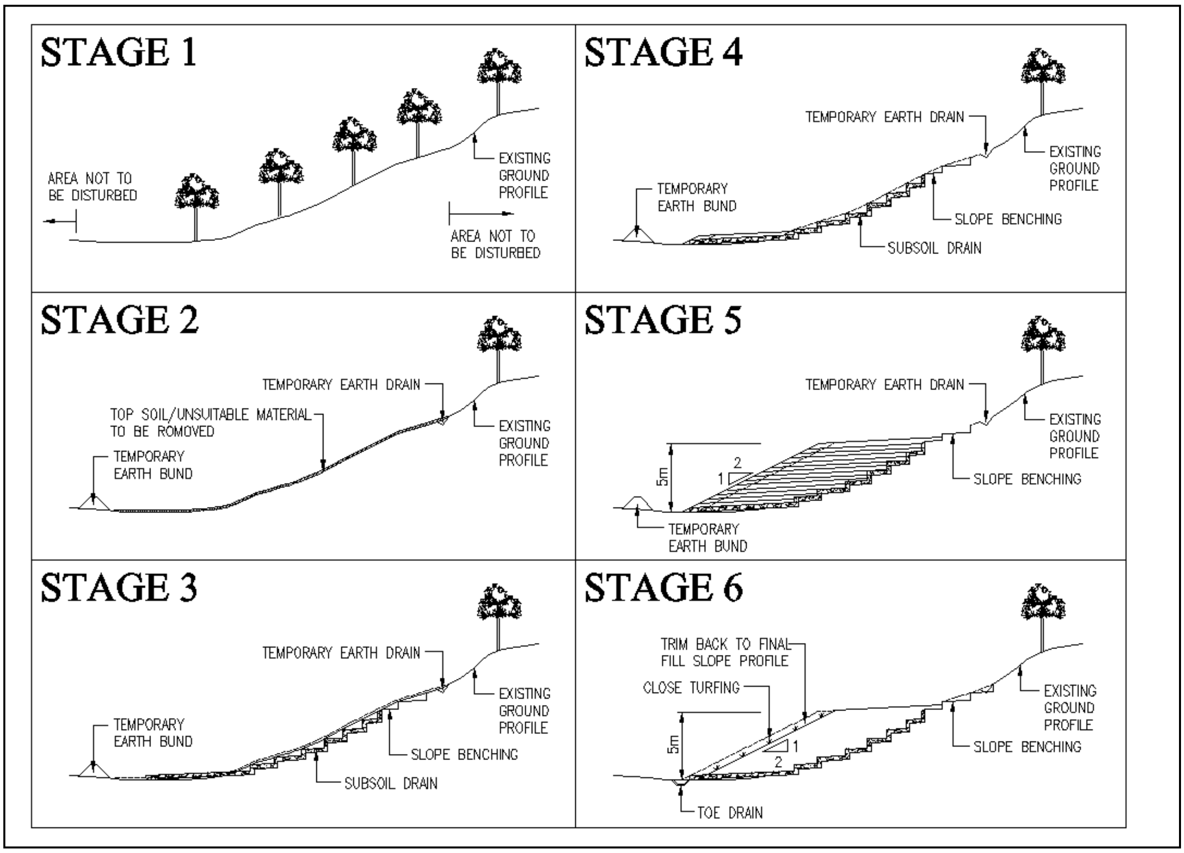


Figure 32b: Sample construction drawing on construction sequence for fill slopes (after Gue & Wong, 2008)

6.6 Research & Development

Apart from structured training modules, all practitioners can take another step ahead with Research and Development (R&D) to enhance safety, environmental protection and sustainability, speed of construction and economical aspects related to slope engineering and management.

Among others, R&D on a simplified laboratory test to derive soil properties would be beneficial. This is particularly useful in establishing a framework of relationship between friction angle and soil descriptions. In addition, effort could also be channelled to correlate soil friction angle against percentage of fines. By understanding such inversely proportional relationships, practitioners may be able to appreciate the change in material behaviour and its sensitivity toward material particle size distribution. However, the above proposed R&D topics would not be achievable without high quality sampling and testing techniques. Therefore, these are the challenges in the current slope engineering industry waiting to be tackled by practitioners and academicians.

As slope stability analyses are heavily dependent on the accuracy of groundwater level estimation, the behaviour of groundwater fluctuation during dry and wet seasons should be evaluated through research and development. Such understanding of ground water fluctuation for countries with tropical weather like Malaysia would be highly beneficial as terrestrial rainfall is known to be highly unpredictable. The knowledge of groundwater fluctuation can help formulate design procedures for subsoil drainage systems, like horizontal drain spacing.

In addition, we should leverage on sharing and tapping knowledge, experience and innovation of practices of other countries through their centres-of-excellence (COEs). The International Consortium on Landslides (ICL) also provides a useful platform through the World Landslide Forum (Sassa, 2005). Collaboration on practices and R&D with the region is particularly value-adding and beneficial.

7 CONCLUDING REMARKS

Malaysia has experienced an increase in landslide incidents due to more hill site developments since the 1900s and the severity in term of casualties peaked in 1990s. Based on 49 cases investigated by Gue & Tan (2006), 60% of failed man-made slopes are due to inadequacy in design alone. These findings revealed that the majority of these failures were avoidable if extra care was taken and input from engineers with relevant experience in geotechnical engineering was sought in all stages of project implementation, from planning, design, construction through to maintenance.

However, since the occurrence of a few significant landslide disasters which resulted in major loss of lives and properties, improvements to project approval and implementation have been observed. The increase in media attention has hastened the formation of guidelines and policies by governmental departments to ensure stringent approval procedures for hill site developments. More importantly, occurrence of the rock fall at Bukit Lanjan in 2003, which lead to a six-month highway closure, triggered the establishment of the Slope Engineering Branch under PWD in February 2004. Other initiatives include the introduction of Accredited Checkers by Board of Engineers, Malaysia (BEM) for geotechnical and structural designs of hill site developments with the aim of mitigating the risk of landslides and improving slope management and engineering.

Further improvements are required in following areas:

- Improvements and harmonisations on policies and legislation
- Setting-up of structured professional training for practitioners in the private sector and government agencies
- Strengthening of undergraduate education on slope engineering
- Sharing and knowledge management of good practices on planning, analysis and design of slopes
- Strengthening of construction control and enforcement
- Investment in research and development

Leverage and collaboration with other countries through their COEs is vital for sharing and tapping of knowledge, experience and innovation of practices. For that, ICL provides an excellent platform for collaboration on practices and R&D within the region.

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