Mitigating the Risk of Landslide on Hill-Site Development in Malaysia

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ABSTRACT: Construction of residential buildings on hill-site in Malaysia has increased tremendously for the last 15 years due to depleting flat land and other influencing factors like beautiful scenery, fresh air, exclusiveness, etc. Safety of building on hill-site is often a topic of discussions among engineers and public. The Institution of Engineers, Malaysia (IEM) has taken the initiative to form a taskforce in 1999 to formulate the policies and procedures for mitigating the risk of landslide on hill-site development. The simplified classification of risk to landslide for hill-site development and recommendations by IEM will be reviewed and discussed in this paper. This paper also presents four important stages of geotechnical input to safeguard the safety of the public from landslide hazards. These geotechnical input are planning, design, construction and maintenance. In this paper only soil slopes will be discussed with emphasis on the practical aspects of the works.

INTRODUCTION

The collapse of Block 1 of Highland Towers in 1993; one of the first highrise development on hill-site in Kuala Lumpur, has worried many people particular those who are staying on a hill-site or planning to purchase a unit of a development. Safety of building on hill-site is often a topic of discussions among engineers and public. The discussion intensifies each time after a landslide being highlighted by media.

Since frequent landslide problems at hill-site in residential areas have become serious public issues and concerns, appropriate policies and procedures to check the problems are imperative. The Institution of Engineers, Malaysia (IEM) has taken the initiative to form a taskforce in 1999 to formulate the policies and procedures for mitigating the risk of landslide on hill-site development. The report has been submitted to the Federal Government of Malaysia for implementation. The content of the policies and procedures will be discussed in this paper.

To safeguard the safety of the public from landslide hazards, proper geotechnical input by the engineers with geotechnical experience is very important. The geotechnical input includes four important stages namely, planning, design, construction and maintenance. This paper will also present a guideline for the four stages stated above for soil slopes only and with emphasis on the practical aspects of the works and some case histories.

POLICIES AND PROCEDURES FOR MITIGATING THE RISK OF LANDSLIDE ON HILL-SITE DEVELOPMENT

Frequent occurrences of slope failures at hill-site in residential areas during the rainy season have resulted in public fear for the safety of their lives and properties located in those areas.

Class	Description
1 (Low Risk)	For slopes either natural or man made, in the site or adjacent to the site not belonging to Class 2 or Class 3.
2 (Medium Risk)	For slopes either natural or man made, in the site or adjacent to the site where : o $6m \leq H_T \leq 15m$ and $\alpha_G \geq 27^o$ or o $6m \leq H_T \leq 15m$ and $\alpha_L \geq 30^o$ with $H_L \geq 3m$ or o $H_T \leq 6m$ and $\alpha_L \geq 34^o$ with $H_L \geq 3m$ or o $H_T \geq 15m$ and $19^o \leq \alpha_G \leq 27^o$ or $27^o \leq \alpha_L \leq 30^o$ with $H_L \geq 3m$
3 (Higher Risk)	Excluding bungalow (detached unit) not higher than 2-storey. For slopes either natural or man made, in the site or adjacent to the site where : o $H_T \geq 15m$ and $\alpha_G \geq 27^o$ or o $H_T \geq 15m$ and $\alpha_L \geq 30^o$ with $H_L \geq 3m$
H_T	= Total height of slopes = Total height of natural slopes & man made slopes at site and immediately adjacent to the site which has potential influence to the site. It is the difference between the Lowest Level and the Highest Level at the site including adjacent site.
H_L	= Height of Localised Slope which Angle of Slope, α_L is measured.
α_G	= Global Angle of Slopes (Slopes contributing to H_T).
α_L	= Localise Angle of Slopes either single and multiple height intervals.

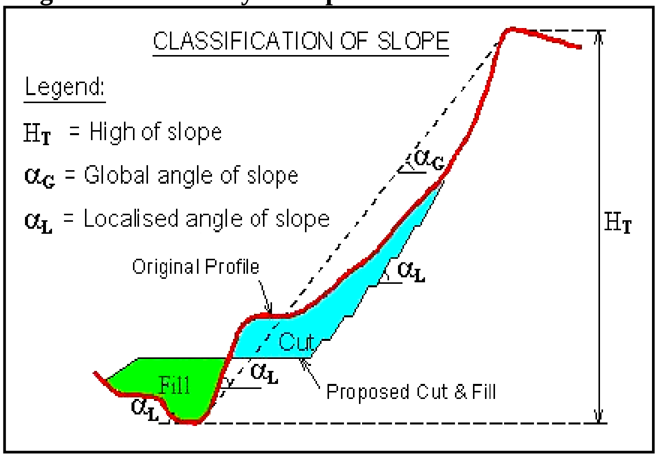
Table 1 : Classification of Risk of Landslide on Hill-Site Development. (after IEM, 2000)

Lacks of systematic regulatory measures to address the safety problems of hill-site development and existing legislations and guidelines on slope failure mitigation have not been adequate to produce a satisfactory solution. The policies and procedures for mitigating the risk of landslide on hill-site development (IEM, 2000) aims to provide uniform, consistent and effective policies and procedures for mitigating the risk of landslide on hill-site development for the consideration and implementation by the Federal Government of Malaysia.

In the position paper, the slopes for hill-site development are proposed to be classified into three classes and the necessary requirements are as follows :-

(a) **Class 1 Development (Low Risk)**: Existing Legislation Procedures can still be applied.
(b) **Class 2 Development (Medium Risk)**: Submission of geotechnical report prepared by professional engineer to the authority is mandatory. The taskforce viewed the professional engineer for hill-site development as those that have the relevant expertise and experience in analysis, design and supervision of construction of the slopes, retaining structures and foundations on hill-site.
(c) **Class 3 Development (Higher Risk)**: Other than submission of geotechnical report the developer shall also engage an "Accredited Checker" (AC) in the consulting team. In the original proposal by the taskforce, the AC shall have at least 10 years relevant experience on hill-site and have published at least five (5) technical papers on geotechnical works in local or international conferences, seminars or journals.

Figure 1 : Geometry of Slopes used in the Classification



The classification is based on the geometry of the slopes such as height and angle for simplicity of implementation by less technical personnel in our local authorities. Although in actual condition there are many other factors affecting the stability of the slopes like geological features, engineering properties of the soil/rock, groundwater regime, etc, but in order to make the implementation of the classification easier, simple geometry has been selected as the basis for risk classification. Table 1 summarises the details of the classification and as shown in Figure 1.

From the review of several case histories of landslides in Malaysia, the IEM taskforce summarised the causes of the failures as follows :-

(a) Design - inadequate subsurface investigation and lack of understanding of analysis and design.
(b) Construction - lack of quality assurance and quality control by contractors.
(c) Site supervision and maintenance - lack of proper site supervision by consulting engineers during construction and lack of maintenance after construction.
(d) Communication – lack of communication amongst various parties involved in construction.

The IEM taskforce also recommended the following :-

(a) To appoint qualified and experienced checking consultants to audit submitting engineers' design for major development in higher risk area.
(b) To appoint a full time resident professional engineer to supervise construction.
(c) Developers, contractors and supervisors be made further accountable to the authorities for the construction safety. There should be deterrent imposition of penalties on the defaulting parties in the approval, design, supervision and the construction process.

The IEM position paper also proposes that a new federal department to be called "Hill-Site Engineering Agency" be formed under the Ministry of Housing and Local Governments to assist Local Governments in respect to hill-site development. The Agency is to assist local authorities to regulate and approve all hill-site developments. The Agency could engage or out source, whenever necessary, a panel of consultants to assist and expedite implementation. For existing hill-site development, the Agency should advise the local government to issue "Dangerous Hill-Side Order" to owners of doubtful and unstable slopes so that proper remedial and maintenance works can be carried out to stabilize the slopes and to prevent loss of lives and properties.

GEOTECHNICAL INPUT FOR HILL-SITE DEVELOPMENT

The geotechnical input for hill-site development generally can be categorise into four important stages as follows :-

- Planning
- Analysis and Design
- Construction
- Maintenance

For this paper, only soil slopes will be discussed.

PLANNING OF HILL-SITE DEVELOPMET

The planning of hill-site development can be divided into four major sections as follows :

- Desk Study
- Site Reconnaissance
- Subsurface Investigation
- Planning of Layout

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 development, construction activities, problem areas like previous slope failure, etc.

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 hill-site development, it is also very important to locate and study the outcrops to identify previous landslides or collapse that can act as an indicator of the stability of the existing slopes.

Subsurface Investigation

Subsurface investigation (S.I.) for hill-site development should usually be carried out in two stages or more. Preliminary S.I. usually consists of boreholes and sometimes also include geophysical survey. The locations of the preliminary S.I. field tests should be carried out with the intention to obtain the overall subsurface condition like general depth of soft soil, hard stratum, depth of bedrock, geological weak zones, clay seams or layers, and groundwater regime.

The general information on the subsurface profile and properties will be useful when planning the cut and fill and formation of the platform because the depths of hard stratum and bedrock will have major influence on the cost and construction time for earthworks.

Once the preliminary layout of the hill-site development is confirmed, the detailed S.I. should be carried out to obtain the necessary information for detailed geotechnical designs. In the detailed S.I. field tests can be carried out at the following locations :

- Areas of major cut and fill.
- Retaining walls.
- Buildings or Structures with Heavy Loading.

For details on the planning of subsurface investigation and interpretation of test results for geotechnical design, reference can be made to Gue & Tan (2000) and Gue (1995).

Planning of Layout

The planning of platform layout for hill-site development should try to suit the natural contour and minimise cut and fill of earthworks. If possible, try to avoid using retaining walls as this will be more costly than normal earthwork solution. It is also very important to orientate the building layout to minimise potential differential settlement especially if the buildings are on filled ground. This can be achieved by arranging the longitudinal axis of the building parallel to the contour lines of the original topography, in which the building is underlain by fill of uniform thickness and therefore less differential settlement. When using piles to support buildings on fill, the design engineer should evaluate negative skin friction (down drag) acting on the piles if the ground is going to settle with time. Slip coating of the piles with bitumen coating or surcharging of the fill to eliminate future settlement are options to eliminate the negative skin friction. However, this option is more complex and costly. Other more cost effective option is to use the floating piles system.

ANALYSIS AND DESIGN OF SLOPES

Although local geology and rainfall characteristics differs in different countries, generally the phenomenon of slope failure occurs in much the same way throughout the world with the fundamental causes do not differ greatly with geological and geographical locations. Therefore, the same methods of assessment, analysis, design and also remedial measures can be applied. The only difference is that in tropical areas, the climate is both hot and wet causing deep weathering of the parent rocks and the slopes are of weaker materials.

For the design of the slopes, correct information on soil properties, groundwater regime, geology of the site, selection and methodology for analysis are important factors that require special attention from design engineer.

Information Required for Analysis of Slopes

Detailed information on the topography, geology, shear strength, groundwater conditions and external loadings are required for the analysis of the slopes.

<u>*Topography*</u>

The contour of the site, positions of the subsurface investigation holes, proposed layout of the development and proposed cut and fill have to be accurate and correct so that proper cross-sections can be analysed.

<u>*Geology*</u>

The knowledge on the geology of the site will assist the engineer to foresee the types of slope failures likely to occur before embarking into the investigation and analyses. The Geological conditions should also be reviewed during construction to validate the formation and to ensure irregularities and surprises (if any) are taken into reassessment such as clay seams or layers that can induce perched water table.

<u>*Shear Strength*</u>

For cut slope, effective stress (drained or long term condition) is normally more critical than total stress (undrained) condition. Therefore, effective stress strength parameters c' and ϕ', determined from testing of representative samples of matrix materials are used in the analysis. In Malaysia, normally Isotropic Consolidated Undrained Triaxial Tests (CIU) were carried out on large diameter undisturbed soil samples (from Mazier sampler without trimming or side drains). It is important that the soil samples are tested at stresses comparable to those in the field, and should be saturated. It is appropriate to measure strength parameters on saturated soil samples because the residual soils are usually of high permeability (usually 10^{-4} to 10^{-6} m/sec), prolong and high intensity of rainfall especially during the two monsoon periods every year allows rainwater infiltrates with ease into it and likely that saturation conditions will be approached at shallow depths in the field during the service life of a slope.

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

$$\tau_f = c' + \sigma_{nf}' \tan\phi'$$

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

Figure 2 shows the typical bonding and dilatant characteristic of the residual soil at low stress range (low confining and consolidation pressure) which exhibits a peak shear strength envelope in terms of effective stress which has a apparent cohesion intercept (c') if the Mohr-Coulomb c'-ϕ' failure line is used. As the consolidation pressure in the laboratory test prior to shearing increases, the bonds are destroyed and the residual soil will likely to behave like normally consolidated or slightly overconsolidated transported soil. The critical state friction angle is represented as ϕ_{cv}.

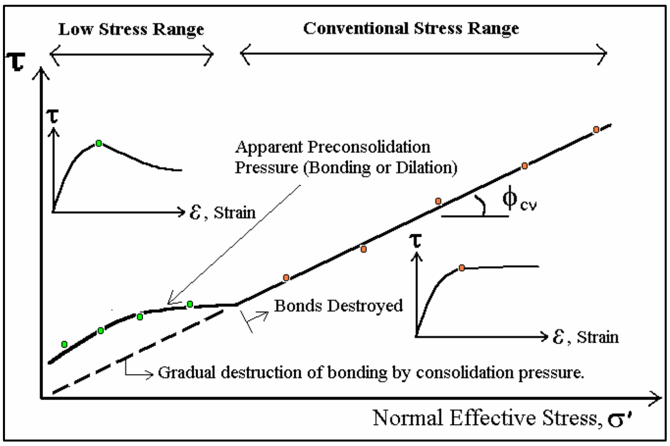


Figure 2 : Effect of Boding on the Apparent Cohesion Intercept of a Drained Strength (Effective Stress) Failure Envelope.

The c' and ϕ' parameters are not intrinsic soil properties, but are merely coefficients in the simplified design model and should only be assumed to be constant within the range of stresses for which they are evaluated as shown in Figure 2. Brand (1995) states that most of the critical slip surfaces in residual soils slopes are commonly shallow with effective stress of typically of about 30 to 200kPa. He also reported that there is some evidence suggesting that the strength envelopes for some residual soils are curved at low effective stresses, and that the straight-line projection of strengths measured at high stresses underestimates that shear strengths in the low stress range. Therefore, for different stress range, different shear strength envelopes (c' and ϕ' values) can be adopted using either of the two different method shown in Figures 3 and 4 respectively.

Figure 3 illustrates a typical stress-strain curve for residual soil. A sample is isotropically consolidated (Point A) then sheared to reach the peak strength (Point B) at low stress range and continue shearing until the critical state strength (Point C). Normally the peak strength is obtained at a relatively small strain and after continue shearing, the critical state strength (ϕ_{cv}) is obtained at a larger strain. The critical state usually occurs in 10% to 30% strain range where the soil sample continue to shear at constant volume and constant effective stress. The critical state strength is also called the ultimate strength (Atkinson & Bransby, 1978) or the fully softened strength (Skempton, 1970). The critical state strength is different from residual strength (Skempton, 1964) which is lower and it occurs after very large movement on the slip/failure surface. The residual strength is also associated with highly polished slip surfaces in which the soil particles have become aligned in directions parallel with the direction of sliding and is relevant only after displacements of the order of several meters (Crabb and Atkinson, 1991).

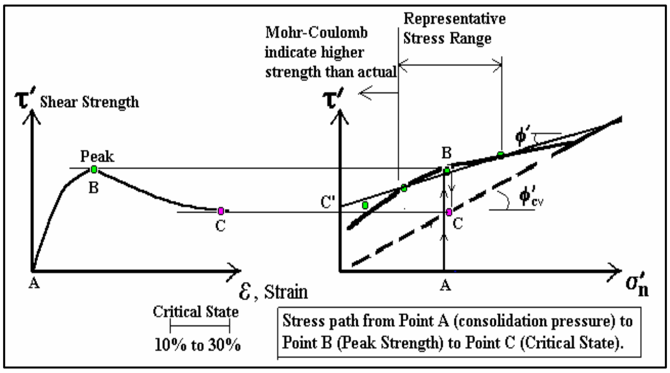


Figure 3 : Typical Shearing Characteristic of Residual Soil and the Tangent Method in Selection of Shear Strength Envelope.

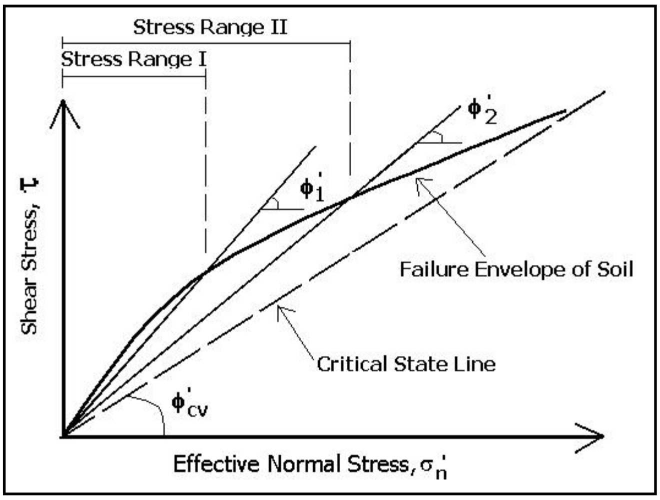


Figure 4 : Secant Method in Selection of Shear Strength Envelope.

As shown in Figure 3, the critical state strength fall on a straight line through the origin. The conventional interpretation of peak failure strength is the Mohr-Coulomb envelope (c'-ϕ') at the stress range concern using the tangent method. It should be noted that ϕ' is different from ϕ_{cr} (critical state); and c' is simply the intercept of the peak failure envelope on the shear stress axis, τ'. It is important to note that c' does not imply that at zero effective stress, the strength is c' (kPa). Therefore, at low effective confining stress (outside representative stress range), Mohr-Coulomb failure envelope (c'-ϕ') might overestimate the strength of the soil. On the other hand, if critical state strength is used, the strength value will be underestimated. Therefore, if the in-situ stress range and the stress path followed during shearing is correctly determined, the c'-ϕ' shear strength envelope will be representative of the field condition.

Another method of determining the shear strength envelope is through the secant method for the stress range concerned as shown in Figure 4. In this method, generally, the c' is taken at 0 (zero) unless there are sufficient test results to obtain the representative c'. Usually the c' should not exceed 10kPa. This method will yield a more conservative (lower) peak strength value compared to tangent method at the low stress range and both will yield same results at high stress range. Therefore, if the stress range at site during design cannot be confirmed, then secant method shall be used instead of tangent method

The 'critical state' angle of friction (ϕ_{cv}') which delineates the lower limit of shear strength. The typical ϕ_{cv}' values of granitic residual soils in Malaysia generally ranges from 27^o to 35^o. Generally, the c' is taken at 0 (zero) unless there are sufficient test results to obtain the c'. Usually the c' should not exceed 10kPa.

High c' obtained from laboratory tests is often due to the rate of strain or time of shearing to failure is too short. The rate of strain should be estimated from the results during consolidation. Side drains should not be used as this has shown to produce inconsistency in the sample (Tschebotarioff, 1950 and GCO, 1991). Multistage tests should not be used as the second test will be significantly affected by the failure surface formed in the first test (GCO, 1991). Further details on the laboratory tests can be obtained from Head (1986).

To date it is not advisable to include soil suction (negative pore pressure) in the design of the long term slopes in view of many factors that can cause the loss of the suction (e.g. prolong and high intensity rainfall, etc.)

Groundwater and Pore Water Pressure

Figure 5 shows the possible hydrological effects of rainfall on a permeable slopes. Some of the rain water runs off the slope and may cause surface erosion if there is inadequate surface protection. In view of the high soil permeability, majority of the water will infiltrates into the subsoil. This causes the water level in the slope to rise or it may cause perched water table to be formed at some less permeable boundary (e.g. clay seams). Above the water table, the degree of saturation of the soil increases thus reduces the soil suction (i.e. negative pore pressure).

Failures in residual soils cut slopes might be caused by 'wetting-up' process by which the decrease in soil suction and hence the decrease in soil strength due to the suction. There is also evidence suggesting that transient rises in groundwater table are responsible for some rain-induced landslides (Premchitt et al, 1985).

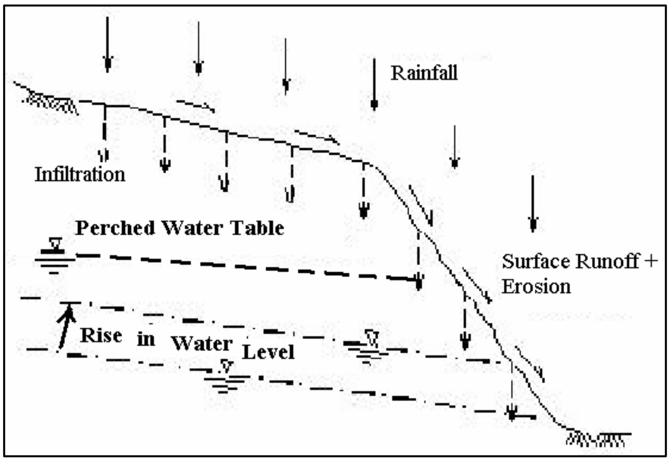


Figure 5 : Effects of rainfall on high permeable slope (from Brand, 1995)

GCO (1991) recommends that slopes should be designed for the groundwater conditions resulting from a ten-year return period rainfall or representative groundwater level through observation and estimation. Slopes in the high risk-to-life category should be checked to determine the sensitivity of the water levels to the stability of the slopes and this required prediction of the worst groundwater conditions.

Sometimes leakage from services, such as sewers, drains or water mains can cause rising of groundwater level. Services on hill-site should be properly protected from leakage to prevent contributing to a failure of the slopes.

In some cases, subsurface drainage (e.g. horizontal drains, vertical wells, etc.) can be used to reduce the groundwater levels thus increase the Factor of Safety against failure on any potential slip surface which passes below the water table. If subsurface drainage system is employed, regular maintenance is required to prevent reduction of efficiency caused by siltation, deterioration of seals or growth of vegetation blocking the outlet.

External Loading

Loadings from traffic, building foundations, retaining walls, spoil heaps , etc. that can influence the stability of the slopes should be correctly determined and included in the analysis. During construction, it is important not to overload the slope due to temporary dumping of spoils.

Methods of Stability Analysis

Highly and completely weathered rocks (Grade IV to VI) behave as soil in terms of engineering properties thus the stability of the slopes shall be assessed for a wide range of potential failure surfaces. Since generally shear strength in a residual soil profile increases with depth, slope failures can be expected to occur on relatively shallow slip surfaces.

Majority of the methods of stability analysis for soil slopes are based on limit equilibrium. For cut slopes, usually circular slips would only take place when the there is deep layer of residual soils without structural features (e.g. relict discontinuities) or the presence of intermediate hard layer. For circular slip surfaces, Simplified Bishop Method (1955) can be employed. However, failures frequently occur along surfaces dictated largely by relict joints or by boundaries between weathering zones where clear boundaries exists. This is more so when the subsoils are weathered from highly fractured rocks. Janbu (1972) or Morgenstern & Price (1965) methods are recommended for the check on non-circular and wedge failure mode. In practice, it is advisable to check for both circular and non-circular failure modes in designs.

Factor of Safety

For hill-site development in Malaysia, normally the Factor of Safety (FOS) against slope failure recommended by Geotechnical Manual for Slopes (GCO, 1991) of Hong Kong is adopted. When selecting the FOS to be adopted in the stability analysis, the two main factors to be considered are :

(a) Risk-to-life or Consequence to life (e.g. casualties)
(b) Economic Risk or Consequence (e.g. damage to properties or service)

There are three level of risk in each factor (negligible, low and high) as defined in details by GCO (1991). The engineer has to use his judgement when selecting the seriousness of the consequence for both loss of life and economic loss.

Generally the slopes are divided into three categories namely:

- New Slopes
- Existing Slopes
- Natural Slopes

For new slopes, the recommended FOS for slopes with groundwater conditions resulting from a ten-year return period rainfall or representative groundwater conditions as recommended by GCO (1991) are listed in Table 2 for different level of risk. In addition, slopes of high risk-to-life category should have FOS of 1.1 for the predicted worst groundwater conditions using moderately conservative strength parameters (characteristics values).

Existing slope should be analysed to check its stability and to determine the extent of any remedial or preventive works required. If the engineer has the opportunity to examine the geology and subsoil conditions of the slope closely and can obtain more realistic information on the groundwater, the FOS for existing slopes recommended FOS in Table 3 may be used. Otherwise or substantial modification to the existing slopes is required, the recommended FOS in Table 2 shall be adopted.

It is very important to be aware that not all natural slopes are safe. It is very common for natural slopes to fail during a monsoon even there is no activity like clearing of trees or development around it. Therefore the stability of the natural slopes in or adjacent to the site should be evaluated. Usually it is not advisable to disturb the natural slopes and vegetation just to achieve marginal improvement in stability unless the slope is unsafe. It is important not to locate buildings at areas that could be affected by landslide.

Economic Risk	Risk-to-Life		
	Negligible	Low	High
Negligible	>1.0	1.2	1.4
Low	1.2	1.2	1.4
High	1.4	1.4	1.4

Note :

1. The FOS above is based on Ten-Year Return Period Rainfall or Representative Groundwater Conditions.
2. A slope in the high risk-to-life category should have a FOS of 1.1 for the predicted worst groundwater conditions.
3. The FOS listed are recommended values. Higher or lower FOS must be warranted in particular situations in respect to both risk-to-life and economic risk.

Table 2 : Modified Recommended Factor of Safety for New Slopes (modified from GCO, 1991)

FOS against Loss of Life for a Ten-year Return Period Rainfall		
Negligible	Low	High
>1.0	1.1	1.2

Note :

1. These FOS are minimum values recommended only where rigorous geological and geotechnical studies have been carried out, where the slope has been standing for considerable time, and where the loading conditions, slope remain substantially the same as those of the existing slope.
2. Should the back-analysis approach be adopted for the design of remedial or preventive works, it may be assumed that the existing slope had a minimum FOS of 1.0 for the worst known loading and groundwater conditions.
3. For a failed or distressed slope, the causes of the failure or distress must be specifically identified and taken into account in the design of the remedial works.

Table 3 : Modified Recommended FOS for Existing Slopes (modified from GCO, 1991)

Design of Cut Slopes

The vertical interval of slopes between intermediate berm is usually about 5m to 6m in Malaysia. GCO (1991) recommends that the vertical interval of slopes should not be more than 7.5m. The typical slopes normally encounter is 1V:1.75H to 1V:1.5H depending on the results of analysis and design based on moderately conservative strength parameters. The berms must be at least 1.5m wide for easy maintenance. The purpose of berms with drains is to reduce the volume and velocity of runoff on the slope surface and the consequent reduction of erosion and infiltration. Cut slope should be designed to the recommended FOS in Table

2 taking into considerations representative geotechnical parameters, geological features (e.g. clay seams) and groundwater regime.

Design of Fill Slopes

Similar to cut slopes, berms of 1.5m wide at 5m to 6m vertical slope interval are commonly used for fill slopes in Malaysia. Usually the fill slope is at one vertical to two horizontal angle (1V:2H) depending on the subsoil conditions and the material used for filling.

Before placing of fill, the vegetation, topsoil and any other unsuitable material should be properly removed. The foundation should also be benched to key the fill into an existing slope. Sometimes a free-draining layer conforming to the filter criteria may be required between the fill and natural ground to eliminate the possibility of high pore pressures from developing and causing slope instability especially when there is an existing surface stream or creek. 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 slopes.

Surface Protection and Drainage

Surface drainage and protection is necessary to maintain the stability of the designed slopes through reduction of infiltration and erosion caused by heavy rain especially during monsoon seasons. Runoff from both the slopes and the catchment area upslope should be cutoff, collect and lead to convenient points of discharge away from the slopes.

When designing surface drainage on steep slopes, it is important to make sure the drains have sufficient capacity to carry the runoff. General guideline for design of permanent surface drainage is based upon a hundred-year return period rainfall and temporary drainage is based upon a ten-year return period.

For proper slope drainage, runoff should be channelled by the most direct route away from vulnerable area of the slope, particularly runoff from behind the top of the slope. Cast-in-situ reinforced concrete berm drains instead of precast drain should be constructed at all the berms. The berm drains should be suitably reinforced to prevent them from cracking. Cracked berm drains will induce water seeping into the slopes thus could reduce the factor of safety of slopes against slip failure.

For large slopes, several stepped channels (e.g. cascading drains) should be employed instead of concentrating into one or two channels only. Since the flow in stepped channels is turbulent, sufficient freeboard must be allowed for splashing and aeration, or sometime energy breaker should be provided. Special attention should also be given to the design of the junctions (e.g. catchpit or sump) of channels due to inevitable turbulence, splashing and vulnerable to blockage by debris.

Surface protection should be applied to slopes formed in materials susceptible to rapid surface erosion or susceptible to weakening by infiltration. The most common surface protection used in Malaysia is close turfing or hydro-seeding (slope vegetation). Establishment of vegetation on a slope is governed by several factors such as steepness and material composition of the slopes and weather. The steeper the slope, the greater the effort required to establish vegetation. Generally cut slopes can be regarded as relatively infertile and appropriate fertilisers should be added at the time of planting. If turfing is carried out in the dry season, frequent watering is required to enable the growth of the grass.

If slope vegetation cannot be carried out or not suitable for the slope, rigid protection measures would be required. The most common rigid protection measures used in Malaysia is sprayed concrete (shotcrete and gunite) reinforced with BRC and with proper drainage weepholes.

CONSTRUCTION CONTROL

It is very important for the Consultant to properly supervise the construction of hill-site development. The personnel supervising hill-site development especially on the formation of cut and fill slopes, should have sufficient knowledge and experience in geotechnical engineering to identify any irregularities of the subsurface condition (e.g. soil types, surface drainage, groundwater, weak plane, etc.) that might be different from that envisaged and adopted in the design stage. 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 site condition. This should be carried out effectively during construction to prevent failure and unnecessary remedial works in the future. 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, 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 like date, weather conditions or irregularities of the subsoil conditions observed during excavation.

Whenever possible, construction programmes should be arranged such that fill is placed during the dry season, when the moisture content of the fill can be controlled more easily. When filling, tipping should not be allowed and all fill should be placed in layers not exceeding 300mm thick (unless compaction trails proved thicker loose thickness is achievable) in loose form per layer and uniformly compacted in near-horizontal layer 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.

Cutting of slopes is usually carried out from top-down followed by works like drains and turfing. When carrying out excavation of the slopes (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 outlet and suitable dissipators before bulk excavation is carried out or before continue to excavate next bench.

For all exposed slopes, slope protection such as turfing or hydroseeding should be carried out within a short period (not more than 14 days) after the bulk excavation or filling for each berm interval as initiated. All cut slopes should be graded to form suitable horizontal groves (not vertical groves) using suitable motor grader before turfing or 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.

MAINTENANCE OF SLOPES

Although lack of maintenance of slopes and retaining walls is not a direct cause to failure. However, failure to maintain particularly after erosion may propagate and trigger landslides. Therefore regular inspection and maintenance of the slopes are necessary.

Awareness alone is not sufficient, engineers and personnel involved in slope maintenance should also know how to properly carry out the work, they need a set of standards of good practice slope maintenance to follow. A good guideline from GEO of Hong Kong like "Geoguide 5 – Guide to Slope Maintenance" (1995) for engineer and "Layman's Guide to Slope Maintenance" which is suitable for the layman should be referred.

Geoguide-5 (1995) recommends maintenance inspections be sub-divided into three categories:

(A) Routine Maintenance Inspections, which can be carried out adequately by any responsible person with no professional geotechnical knowledge (layman).
(B) Engineer Inspections for Maintenance, which should be carried out by a professionally-qualified and experienced geotechnical engineer.
(C) Regular Monitoring of Special Measures, which should be carried out by a firm with special expertise in the particular type of monitoring service required. Such monitoring is only necessary where the long term stability of the slope or retaining wall relies on specific measures which are liable to become less effective or deteriorate with time. This measure is seldom carried out in Malaysia.

Malaysia which has at least two monsoon seasons, Routine Maintenance Inspections (RTI) by layman should be carried out as a minimum twice a year for slopes with negligible or low risk-to-life. For slopes with high risk-to-life, more frequent RTI is required (once a month frequency). In addition, it is good practice to inspect all the drainage channels to clear any blockage by siltation or vegetation growth and repair all cracked drains before the monsoon. Inspection should also be carried out after every heavy rainstorm.

Category B Engineer Inspection for Maintenance, should be taken to prevent slope failure when the Routine Maintenance Inspection by layman observed something unusual or abnormal, such as occurrence of cracks, settling ground, bulging or distorting or wall or settlement of the crest platform. Geoguide-5 (1995) recommends as an absolute minimum, an Engineer Inspection for Maintenance should be conducted once every five years or more as requested by those who carry out the Routine Maintenance Inspections. More frequent inspections may be desirable for slopes and retaining walls in the high risk-to-life category.

CASE HISTORY OF HIGHLAND TOWER CONDOMINIUM COLLAPSE

On 11 December 1993, Block 1 of the Highland Towers Condominium in Hulu Klang, Selangor suddenly toppled over and collapsed. A total of 48 people were killed. Figure 6 shows the picture of the Block 1 when it started to topple.

Figure 6 : Block 1 Starts to Topple (from MPAJ, 1994)

Investigation carried out by the experts and specialist assembled by Majlis Perbandaran Ampang Jaya (Ampang Jaya Municipal Council) and published in the report titled "Report on the Inquiry Committee in the Collapse of Block 1 and The Stability of Blocks 2 and 3 Highland Towers Condominium, Hulu Klang Selangor Darul Ehsan" in 1994 concluded that the most probable cause of collapse of the tower was due to the buckling and shearing of the rail piles foundation induced by the movement of the soil. The movement of the soil was the consequence of retrogressive landslides behind the building of Block 1.

According to the report (MPAJ, 1994), the landslide was triggered by inadequate drainage on the hillslope that had aggravated the surface runoff. Slope and rubble walls behind and in front of Block 1 were also found to be not properly designed with Factor of Safety of less than 1, nor their construction properly supervised. Figure 7 shows the original cross-section through Block 1 before failure and Figure 8 shows the sequence of retrogressive failures that took place causing large soil movement.

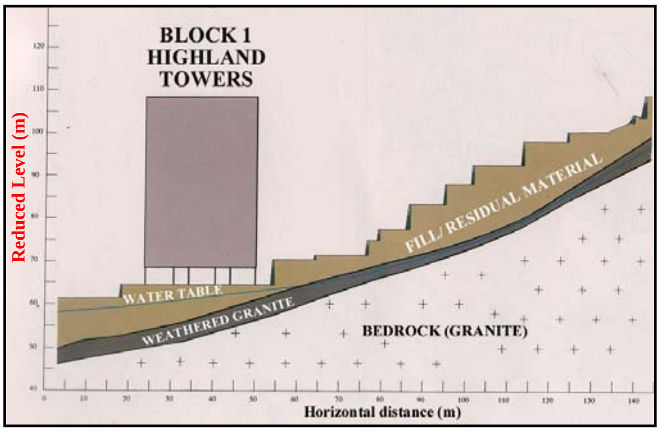


Figure 7 : Original Cross-Section through Block 1 (from MPAJ, 1994)

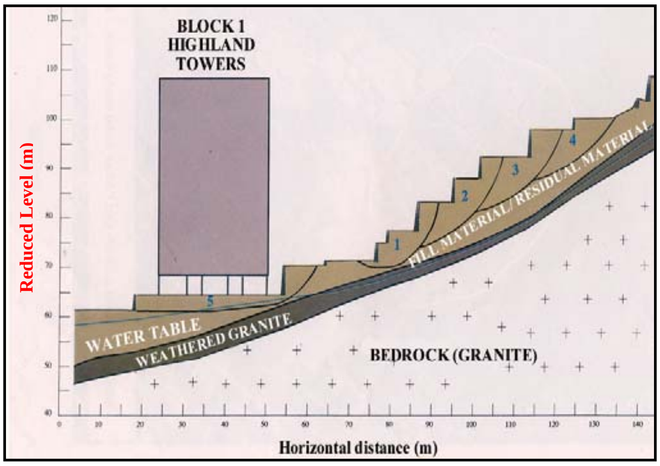


Figure 8 : Sequence of Retrogressive Landslides (from MPAJ, 1994)

From this case history, it is evident that improper design and lack of supervision during construction and is the major factors contributing to the failures of the Block 1 of Highland Towers Condominium. Therefore, the main objectives of the IEM position paper (IEM, 2000) are to prevent this type of catastrophic failure which is preventable from occurring in the future.

CONCLUSION

Geotechnical input by the engineers with geotechnical experience during planning, design, construction and maintenance is very important to produce safe and cost effective hill-site development in Malaysia. Desk study, site reconnaissance and site investigation are essential to obtain the necessary information for the planning of the layout and design of the geotechnical works for hill-site development. Proper design of the cut and fill slopes are imperative to prevent slopes failures. It is important for the Consultant to send personnel with knowledge on geotechnical engineering to supervise hill-site construction so that any irregularities of the subsoil condition different from that adopted in the design can be identified and rectified. 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 site condition can be carried out effectively during construction to prevent failure and unnecessary remedial works in the future.

Finally, even with correct design and proper construction, lack of maintenance of slopes and retaining walls can also trigger landslides. Owners and engineers should regularly inspect and maintain their slopes.

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