The Engineering Aspects of Hill-Site Development

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ABSTRACT: In Malaysia, the construction of residential buildings on hill-site has increased tremendously for the last 15 years due to depleting flat land and other influencing factors like beautiful scenery, fresh air, exclusiveness, etc. Often hill-site development is related to landslides, and safety of building on hill-site is often a topic of discussions among engineers and public. The truth is hill-site development is safe with proper planning, design, construction and maintenance. This paper presents brief guidelines on the engineering aspects of hill-site development for non-engineers and answers to some of the common misconceptions.

INTRODUCTION

Safety of buildings and slopes on hill-site is often a topic of discussion among government officers in local authorities, engineers and public. The discussions intensify each time a landslide is being highlighted by media and this usually happens during the monsoon seasons. The collapse of Block 1 of Highland Towers in 1993, landslides at Bukit Antarabangsa in 1999, and the recent tragic landslide at Taman Hillview in November 2002 have worried the public particular those who are staying on a hill-site or planning to purchase a unit on one.

Hill-site development is safe with proper planning, design, construction and maintenance. Engineers whom have good engineering expertise on soil/rock slopes and foundation designs are usually engaged to design for hill-site development to safeguard the safety of the public from landslide hazards.

This paper presents brief guidelines on the engineering aspects of hill-site development for non-engineers and answers to some common misconceptions.

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

With the recent awareness of the difficulty and risks involved in building on hill-sites, a more systematic control of hill-site development is taking shape through public and private sectors. One of them is the position paper titled "Mitigating the Risk of Landslide on Hill-Site Development" (IEM, 2000) prepared by The Institution of Engineers, Malaysia.

In the IEM 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.

The general risk classification 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 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. (IEM, 2000; Gue & Tan, 2002).

From the review of several case histories of landslides in Malaysia, IEM (2000) summarises the causes of the failures as follows :-
Design - inadequate subsurface investigation and lack of understanding of analysis and design.
Construction - lack of quality assurance and quality control by contractors.
Site supervision and maintenance - lack of proper site supervision by consulting engineers during construction and lack of maintenance after construction.
Communication – lack of communication amongst various parties during construction.

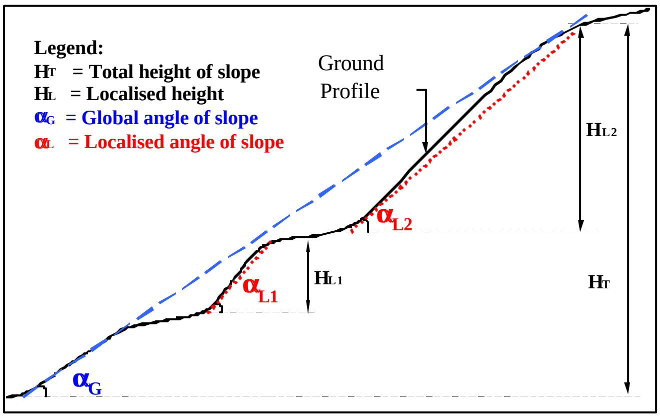

Figure 1 : Geometries of Slope (after IEM, 2000)

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 $\alpha_L \geq 30^o$ 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)

The position paper (IEM,2000) also recommends the following :-

a) To appoint qualified and experienced checking consultants to audit submitting engineers' designs for major development in higher risk areas.

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 construction safety. There should be deterrent imposition of penalties on the defaulting parties in the approval, design, supervision and the construction processes

The IEM position paper also proposes that a new federal department 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 unstable slopes and prevent loss of lives and properties.

GEOTECHNICAL INPUT FOR HILL-SITE DEVELOPMENT

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

- Planning
- Analysis and Design
- Construction
- Maintenance

PLANNING OF HILL-SITE DEVELOPMET

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

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

Desk Study & Site Reconnaissance

Desk study and site reconnaissance are very important to understand the present condition and histories of the site. The 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 the previous slope failure, etc. Site reconnaissance will confirm the information acquired from the desk study and also to obtain additional information from the site.

Subsurface Investigation (S.I.)

Subsurface investigation (S.I.) for hill-site development shall be properly planned to obtain representative subsurface condition of the whole site such as general depth of soft soil, hard stratum, depth of bedrock, geological weak zones, clay seams or layers, and groundwater regime. The planning of exploratory boreholes shall take into consideration the terrain instead of following a general grid pattern.

The general information on the subsurface profile and properties is very important 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 the Layout for roads network and platforms

Different from a normal flat ground development, the planning of platform and roads network for hill-site development shall be geotechnical engineering driven with close coordination among developers, planners, architects, civil & structure engineers. With this, a terrain friendly (less disturbance to the existing vegetated slopes), safe, ease of construction and cost effective development can be achieved. The planning of platform layout for hill-site development shall try to suit the natural contour and minimise cut and fill. Although retaining walls or soil nailing are generally more costly than normal earthwork solution, however with proper planning, the use of these retaining systems at critical areas will be effective to reduce significant earthworks that are more expensive as shown in Figure 2.

Buildings on slopes

It is a good practice to construct buildings with extended columns above the stable slopes instead of filling a platform on slopes as shown in Figure 3. This is to reduce the load acting on the slopes that could reduce the stability of slopes.

If a flat platform is preferred, then it is very important to orientate the building layout to minimise potential differential settlement especially if buildings are on filled ground. This can be achieved by arranging the longitudinal axis of the buildings parallel to the contour lines of the original topography, in which the building is underlain by fill of more uniform thickness and therefore have less differential settlement. Figure 4 shows two different arrangements of buildings on filled ground, the designer if possible shall refrain from arranging a long building perpendicular to the contour.

When piles are used 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 options include the use of floating piles system and rearrangement of layout to reduce differential settlement.

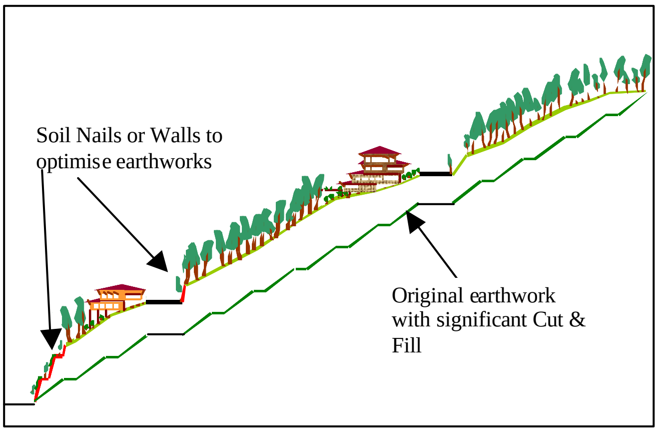

Figure 2 : Method to Optimise Earthworks

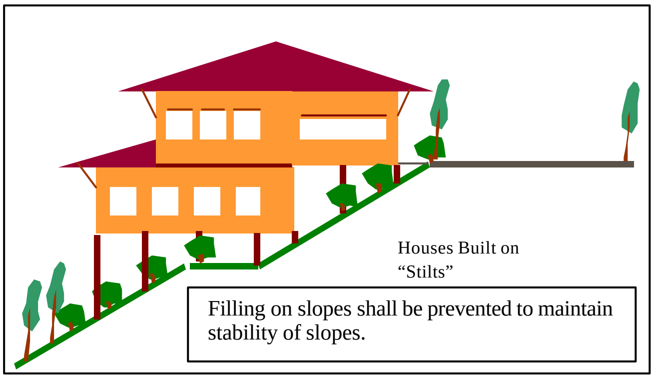

Figure 3 : Typical Building on Cut Slope

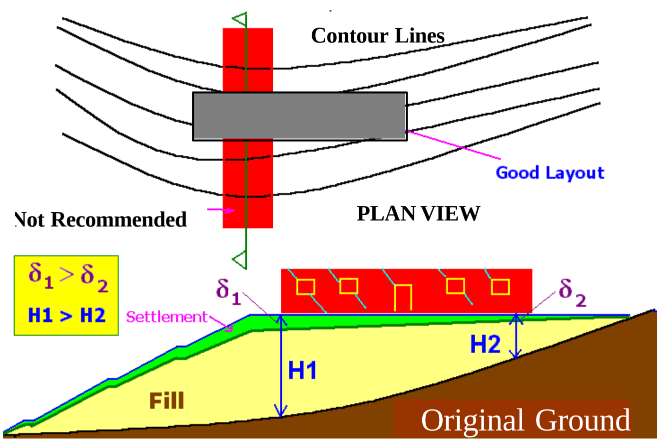

Figure 4 : Different Layout of Building on Filled Ground

ANALYSIS AND DESIGN OF SLOPES

Anatomy and Analyses of a Slope

Figure 5 shows a typical slope consisting of (i) ground profile with some vegetation, (ii) ground water table, (iii) partially saturated soil above ground water table, (iv) saturated soil below ground water table and (v) weathered and/or competent rock.

In the analysis of slope stability to determine whether a slope is safe, potential slip surfaces (Figure 6) are postulate on a slope cross-section. These slip surfaces are analysed in terms of the total driving forces and total resisting forces. The factor of safety (FOS) is determined from the ratio of resisting forces to driving forces. The lowest FOS is the critical stability of the slope.

There are many factors influencing the stability of slopes. Here, only the common important factors are covered and explained. Firstly, the properties of the soil such as friction angle, apparent cohesion and unit weight are important in slope stability. As an illustration, consider these two extremes: The first is a near vertical rockface with a building on top and is able to do so without much stability concerns (Figure 7). The second is gentle beach at a seaside where the gradient is very gentle and yet is not stable to build a structure directly on it (Figure 8). These two examples illustrates that stronger soil or rock can support a building/load compared to weaker soil or rock.

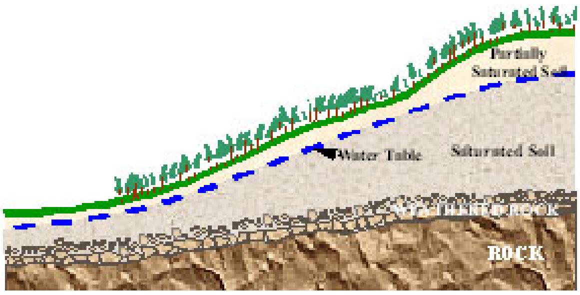

Figure 5: Anatomy of a Typical Slope

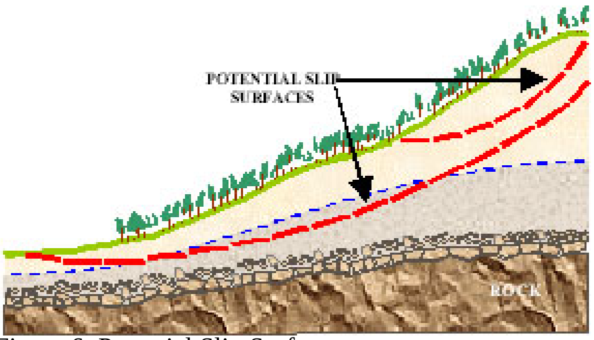

Figure 6: Potential Slip Surfaces


Figure 7: Building on Steep Rockface


Figure 8: Gentle Beach

Secondly, slope geometry is important as illustrated in Figure 9. Low and gentle slope is safer than high and steep slope for similar soil. This is because the latter has more mass on the upslope acting as driving forces (F) compared to that of a gentle slope.

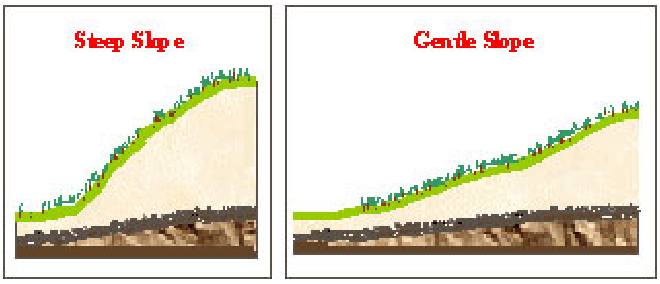

Figure 9: Effect of Slope Geometry

Thirdly, ground water table profile is an influencing factor in slope stability. The ground water table for hillslopes is generally low and fluctuates with time and rainfall events. Figure 10 shows two general types of ground water table profile which may be found in a slope. High ground water table increases the risk of failure as the shear resistance in the potential failure plane decreases due to increased water pressure between soil particles. In addition, the ground water table on the upslope acts as additional driving forces. All these factors decrease the FOS of a slope.

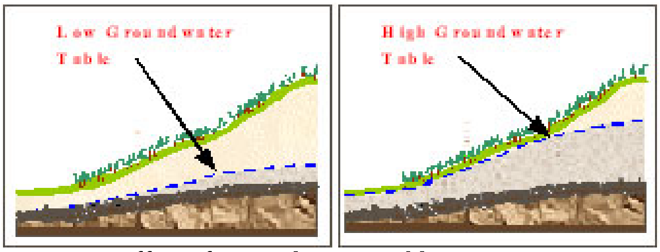

Figure 10: Effect of Ground Water Table

In general, Geotechnical Manual for Slopes published by Geotechnical Engineering Office (formerly known as Geotechical Control Office) of Hong Kong has been widely used with some modifications to suit local conditions by geotechnical engineers in Malaysia (Gue & Tan, 2002). Presently 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 during prolong and high intensity rainfall, especially during the monsoons that occur at least twice a year.

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

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)

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). If characteristic values are not available due to insufficient statistical data then conservative strength parameters should be used.

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 strengthening or modification to the existing slopes should comply to the recommended FOS in Table 2.

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.

Design of Cut Slopes

The vertical interval of slopes between intermediate berm is usually about 6m in Malaysia. GCO (1991) recommends that the vertical interval of slopes should not be more than 7.5m. The typical stable gradient is 1V:1.75H to 1V:1.5H depending on the types of soil and groundwater regime. 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 indicated 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 about 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 materials used as fills.

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 designed slopes through reduction of infiltration and erosion caused by heavy rain especially during monsoon seasons. Runoff from both the slopes and the upslope catchment area should be cut-off, 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 for some cases, 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 closed 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. 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 is unsuitable 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 a 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. 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 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 to 450mm 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 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 and 7 days during the dry and wet season respectively) after the bulk excavation or filling for each berm. All cut slopes should be graded to form suitable horizontal groves (not vertical groves) using suitable motor grader 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.

MAINTENANCE OF SLOPES

Although lack of maintenance of slopes and retaining walls are not a direct cause to failure. However, failure to maintain slopes 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.

Malaysia has at least two monsoon seasons, Routine Maintenance Inspections (RTI) by layman should be carried out 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). 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 that 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.

Slope maintenance is also an important factor. Poorly maintained slopes can lead to slope failure. These may include, amongst others, damaged/cracked drains, inadequate surface erosion control and clogged drains. Eventually, erosion of the slopes allow the formation of gullies (Figure 11) or cause localised landslips (Figure 12) which will propagate with time into bigger landslides if erosion control is ignored.

Figure 11: Gullies on Slopes

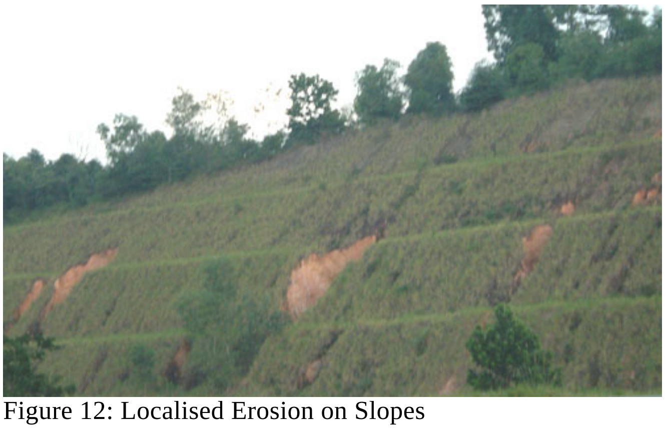

Figure 12: Localised Erosion on Slopes

Excavation or unengineered activities at the toe of the slope could also cause slope instability. These activities disturb the stabilising soil mass at the toe of hill and hence reducing the FOS of the slope. In addition, activities such as stockpiling earth which imposes surcharge loads at the top/crest of the slope also decreases the FOS of a slope as this surcharge increases the driving forces.

COMMON MISCONCEPTIONS

This paper also attempts to debunk some of the common misconceptions often appear in our media about slope safety and explain why they are misconceptions.

(1) The first misconception is **"Soil tests showed that the slope is safe"**. Soil tests are factual reports of the soil properties at the location in which the test is carried out. Soil tests alone do not tell us whether a slope is safe. An engineer needs to study the overall slope and carry out engineering analyses of the slope using the soil test results, groundwater table and slope geometry to determine the FOS of a slope. As iterated earlier, slopes are complex and they are not man made materials, hence its geology and composition can vary significantly over a short distance. Geological features, soil types/properties and groundwater table have significant influence on slope stability. Hence detailed investigations and analyses should be carried out to ensure safety. Soil tests only provide the parameters for analyses and designs of slopes.

(2) **"Heavy rain causes slope failure"**. This is not correct, although it triggers landslips. Increased rainfall raises the ground water table and decreases the FOS of the slope. The minimum FOS generally ranges from 1.2 to 1.4 depending on the risk to life and economical ramifications. The threshold value at failure is unity. A simple analogy of FOS can be illustrated using the example of weight lifting. Suppose the maximum weight a person could lift is 50 kg, and when the person is given 50 kg, then the FOS at failure or threshold is 1.0 (50 divided by 50). If the person is given 40 kg, then the FOS is 1.25 (50 divided by 40).
However, properly engineered slopes should not fail as the slopes should have been designed for the most probable water table during heavy rainfall. The exception is when the actual rainfall is greater than the designed return period of rainfall.

(3) **"Erosion will not cause slope failure"**. This statement is also not entirely correct. Erosion can propagate a slip and cause a bigger landslide. There are two types of slope failures due to erosion. One type is an erosion that starts at the toe of the slope, propagates upslope and eventually trigger the slope to fail. The other type is a propagation of erosion from slope crest towards downslope. In both cases, the small and localised erosion is further eroded by rainfall and surfacial water flow, causing more soil mass to fail. This is repeated until the whole slope is unstable and slides. Therefore uncontrolled erosion can lead to slope failure.

(4) **"Retaining walls always prevent slope failure"**. The public may think that structural solutions like retaining wall is very strong and hence can retain soil mass of the slope without problems. However, this may not be the case. Un-engineered walls can cause slope failures as shown in Figures 13 and 14. A properly designed retaining wall by a professional engineer should not fail as the retaining wall has been properly designed to the codes of practice to retain the soil mass and ground water table.

Figure 13: Collapsed Rubble Wall

Figure 14: Failed RC Wall

(5) **"Slopes are maintenance free"**. Slopes are not always maintenance free. The maintenance such as clearing of clogged drains and patching up localised erosion spots are required. Poorly maintained slopes could lead to slope failures. Clogging increases water pressure build-up through seepage and localised erosion can propagate landslides. Slopes should be regularly maintained following a maintenance manual.

(6) **"The slope has been standing for more than 10 years! So it is safe!"**. This is not necessarily true as natural slopes can fail suddenly without warning even though it's been standing for years. Natural slopes may be currently standing up without signs of failure but the factor of safety could be low and near the threshold. Hence it is not safe to assume that natural slopes are usually safe. It has to be investigated and analysed.

(7) **"EIA report ensures slope stability"**. An EIA report is a study of the environmental impact for a proposed development will have in the area and surroundings. It is used as a planning tool for a development. However, it does not examine the engineering of the slopes in detail to determine whether a slope is safe and the required stabilisation measures, if any. Detailed investigation, analysis and design would only be carried out after the approval of EIA report but before the approval of earthwork plans.

(8) **"Geological report shows that the slope is safe"**. Geological report covers the history of the soil and the underlying bedrock to explain the geological formation of the site and highlight its geological features, types of rock present, soil stratification, weathering grade and minerals present. It does not cover the engineering and design of slopes.

In the face of the public perceptions of these reports, only an engineer's report or a geotechnical report with interpretation of field and laboratory tests and detailed analyses for slopes, will show whether a slope is safe. If the natural slopes with its proposed platforms do not have adequate factor of safety, then strengthening measures such as regrading of slope, retaining walls and soil nails should be recommended. Construction drawings and specifications would then be prepared for implementation. Site supervision by the team from the design consultant is a prerequisite component to ensure slope safety.

CONCLUSION

The geotechnical engineering input for hill-site development is very important to achieve a safe and cost-effective hill-site development. The input should be obtained during preparation of layout for roads and platforms. Four key engineering processes involved are planning, design, construction and maintenance.

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 high cost remedial works in the future.

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

REFERENCES

GCO (1988). Guide to Rock and Soil Descriptions : Geoguide 3. Geotechnical Control Office, Hong Kong, 295p.

GCO (1991). Geotechnical Manual for Slopes (2nd ed.). Geotechnical Control Office, 301p.

GEO (1995). Guide to Slope Maintenance : Geoguide 5. Geotechnical Engineering Office, Hong Kong, 84p.

GEO (1996), Layman's Guide to Slope Maintenance. Geotechnical Engineering Office, Hong Kong, 24p.

Gue, See Sew & Fong, Chew Chung (2003). "Slope Safety : Factors and Common Misconceptions". Buletin Ingenieur, Vol. 19, The Board of Engineers Malaysia.

Gue, S.S. & Tan, Y.C. (2002), "Mitigating the Risk of Landslide on Hill-Site Development in Malaysia", Special Lecture, 2nd World Engineering Congress, IEM Kuching Branch, Kuching, Sarawak, 22nd – 25th July, 2002

Gue, See Sew & Tan, Yean Chin (2000). "Hill-Site Development – Planning, Design, Construction & Maintenance Considerations". Seminar on Geotechnical Engineering, The Institution of Engineers, Malaysia, Penang, Malaysia.

Gue, See Sew & Tan, Yean Chin (2000). "Subsurface Investigation and Interpretation of Test Results for Geotechnical Design". Seminar on Geotechnical Engineering, The Institution of Engineers, Malaysia, Penang, Malaysia.

Gue, See Sew (1999) (Interview) "Face to Face with the Man Who Knows Landslides". The Edge Capital, November, 1999.

Gue, See Sew (1995). "Geotechnical Assessment for Hillside Development". Proc. of Dialogue Session on Geological and Geotechnical Considerations in Civil Works, Geological Survey Department Malaysia, Kuala Lumpur, pp. 27-34.

Institution of Engineers, Malaysia (2000) "Policies and Procedures for Mitigating the Risk of Landslide on Hill-Site Development"

Janbu, N. (1972) "Slope Stability Computations". Embankment Dam Engineering: Casagrande Vol., John Wiley & Sons, New York, pp.47-86.

Jabatan Perancangan Bandar dan Desa Selangor Darul Ehsan (1997) "Garispanduan Perancangan Pembangunan Kawasan Bukit".