Hill-Site Development – Planning, Design, Construction and Maintenance Considerations

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ABSTRACT: The construction of residential buildings on hill-site has increased tremendously for the last 10 years due to lack of suitable flat land and other factors like beautiful scenery, fresh air, exclusiveness, etc. This paper presents a brief guideline for the planning, design, construction and maintenance considerations for hill-site development. The simplified classification of risk to landslide for hill-site development and recommendations by the Institution of Engineers, Malaysia were also reviewed and discussed.

1 INTRODUCTION

In Malaysia, the construction of residential buildings on hill-site has increased tremendously due to lack of suitable flat land and other factors like beautiful scenery, fresh air, exclusiveness, etc. However, the collapse of Block 1 of Highland Towers, one of the first highrise development on hill-site has worried many, 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.

To safeguard the safety of the public from landslide hazards, geotechnical input by the engineer is very important. The geotechnical input includes four important stages namely, planning, design, construction and maintenance. This paper presents a brief guideline for the four stages stated above with emphasis on the practical aspects of the works. Only soil slopes will be discussed in this paper.

2 CLASSIFICATION OF RISK TO LANDSLIDE

Frequent occurrences of slope failure at hill-site in residential areas during the rainy season have resulted in public fear for the safety of 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 $6m \le H_T \le 15m$ and $\alpha_G \ge 27^o$ or o $6m \le H_T \le 15m$ and $\alpha_L \ge 30^o$ with $H_L \ge 3m$ or o $H_T \le 6m$ and $\alpha_L \ge 34^o$ with $H_L \ge 3m$ or o $H_T \ge 15m$ and $19^o \le \alpha_G \le 27^o$ or $27^o \le \alpha_L \le 30^o$ with $H_L \ge 3m$
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 $H_T \ge 15m$ and $\alpha_G \ge 27^o$ or o $H_T \ge 15m$ and $\alpha_L \ge 30^o$ with $H_L \ge 3m$
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 effective to produce a satisfactory solution. The Institution of Engineers, Malaysia has taken the initiative to form a taskforce in 1999 to prepare the policies and procedures for mitigating the risk of landslide on hill-site development (IEM, 2000). The report will be proposed to the Federal Government of Malaysia for implementation.

In the report, 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 "Geotechnical Engineer" to the authority is mandatory.
(c) Class 3 Development (Higher Risk) : Other than submission of geotechnical report prepared by "Geotechnical Engineer", the developer shall also engage an "Accredited Checker" in the consulting team.

The classification is based on the geometry of the slopes such as height and angle. Table 1 summarises the details of the classification and as shown in Figure 1.

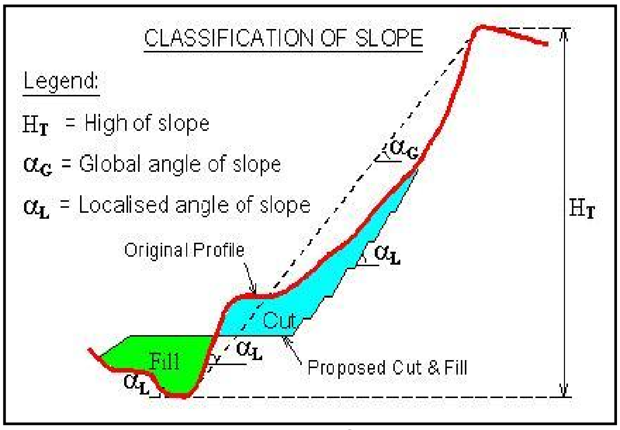


Figure 1 : Geometry of Slopes used in the Classification

It also recommended The Board of Engineers Malaysia to carry out the registration of "Geotechnical Engineer" and "Accredited Checker" to ensure only suitably competent and qualified engineers are engaged for hill-site development projects to safeguard the safety of the public.

The requirements of "Geotechnical Engineer" (GE) is similar to the one proposed by Public Works Malaysia recently. GE should satisfy the following :

(a) Registered with The Board of Engineers, Malaysia.
(b) Having a minimum of 3 years of experience in geotechnical engineering over the last 5 years, and
(c) Not less than 1 year each in the design and construction supervision of geotechnical works.

3 PLANNING OF HILL-SITE DEVELOPMET

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

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

3.1 Desk Study

Desk study includes reviewing of geological maps and memoir so that the engineers are aware and understand the geological formation of the site of the proposed development. Topographic map and aerial photographs of the site and adjacent areas should be examined to know the geomorphology features, previous and present land use, current development, construction activities, problem areas like previous slope failure, etc. The knowledge of the site histories particularly previous landslides and underground services is very important for the planning of the layouts and designs.

3.2 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 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.

3.3 Site Investigation

Site investigation (S.I.) for hill-site development should 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 field tests should be carried out with the intention to obtain the overall subsurface condition of the site like general depth of soft soil, hard stratum and most important, the depth of bedrock.

Usually the boreholes in Preliminary S.I. are spread out to cover the whole site and placed at areas of potential major cut and fill. Disturbed and undisturbed soil samples should also be collected from the boreholes to carry out laboratory testing for the necessary soil and rock parameters for preliminary geotechnical design of the slopes, foundations and retaining walls. In addition, the ground water profile should also be obtained. In sensitive and critical areas, long term monitoring of water table is also needed.

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 of 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).

3.4 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 achieve 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.

4 DESIGN OF SLOPES

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 man-made slopes, there are many factors that can contribute to slope failures :

- Incorrect or improper design, analysis or construction.
- High intensity rainfall (triggering factor)
- Lack of maintenance (triggering factor)

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

4.1 Tropical Residual Soils

In Malaysia, the warm and wet climate produces materials which are the products of insitu weathering of rocks and are commonly referred to as residual soils. The degree of weathering and the extent to which the original structure of the rock mass is destroyed varying with depth from the ground surface and is loosely termed as weathering profiles which contain material of different ‘grades’. The main characteristics of residual soils are :

- Very heterogeneous, which makes sampling and testing for representative parameters difficult.
- Usually high permeability. Therefore susceptible to rapid changes in material properties when subjected to changes of external hydraulic.

The weathering profile is an important information for slope stability analysis because it usually controls :

- The potential failure surface and mode of failure.
- The groundwater hydrology, and therefore the critical pore pressure distribution in the slope.
- The erosion characteristics of the materials.

The Geotechnical Engineering Office (GEO) (formerly Geotechnical Control Office) of Hong Kong has adopted a system for the granites in which a profile is logged according to the six rock 'material grades' given by GCO (1988). Table 1 presents the modified grades classification based on the above reference for ease of classification. For geotechnical design of the slopes, materials of Grades I to III are usually treated as 'rock' and materials of Grades IV to VI as 'soil'.

4.2 Analysis of Slopes

4.2.1 Information Required

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

Topography

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 cut to carry out the analysis.

Geology

The knowledge on the geology of the site will assist the engineer to predict what type of slopes failure likely to occur before embarking on the detailed analysis. The Geological conditions should also be reviewed during construction to validate the formation and to ensure surprises (if any) are taken into reassessment.

Descriptive Term	Grade	General Characteristics
Residual Soils	VI	- Original rock texture completely destroyed. - Can be crumbled by hand and finger pressure.
Completely Decomposed	V	- Rock wholly decomposed but rock texture preserved. - No rebound from N Schmidt hammer - Can be crumbled by hand and finger. - Easily indented by point of geological pick. - Slakes when immersed in water. - Completely discoloured compared with fresh rock.
Highly Decomposed	IV	- Rock weakened and can be broken by hand into pieces. - Positive N Schmidt rebound value up to 25. - Makes dull sound when struck by hammer. - Geological pick cannot be pushed into surface. - Does not slake readily in water. - Hand penetrometer strength index greater than 250kPa. - Individual grains may be plucked from surface. - Completely discoloured compared with fresh rock.
Moderately Decomposed	III	- Usually cannot be broken by hand but easily broken by geological hammer. - N Schmidt rebound value 25 to 45. - Makes dull or slight ringing sound when struck by hammer. - Rock material not friable. - Completely stained throughout.
Slightly Decomposed	II	- Not broken easily by geological hammer. - N Schmidt rebound value greater than 45. - Makes ringing sound when struck by hammer. - Strength approaches that of fresh rock. - Fresh rock colours generally retained but stained near joint surfaces.
Fresh Rock	I	- No visible signs of weathering, not discoloured. - Not broken easily by geological hammer. - Makes ringing sound when struck by hammer.

Table 1 : Material Grade Classification System (modified from GEO, 1988)

Shear Strength

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), rainwater can infiltrates with ease into it and likely that saturation conditions will be approached at shallow depths in the field during the 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).

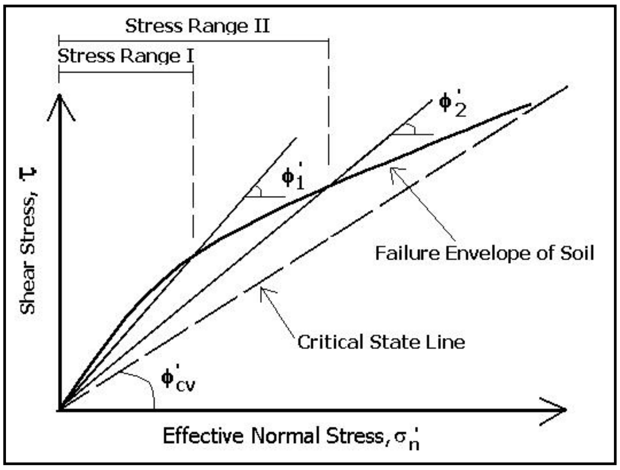


Figure 2 : Characterization of Soil Shear Strength

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 sols are curved at low effective stresses, and that the straightline projection of strengths measured at high stresses underestimates that shear strengths in the low stress range (see Figure 2). Therefore, for different stress range, different shear strength envelopes (c' and ϕ' values) should be used as shown in Figure 2.

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 testing 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.

Groundwater and Pore Water Pressure

Figure 3 shows the 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, usually dictated by the weathering profile. 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).

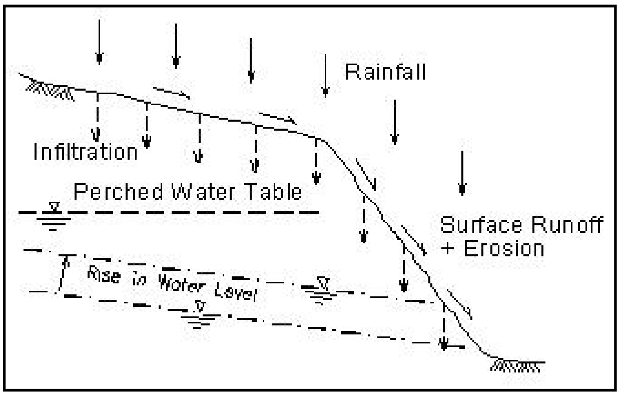


Figure 3 : Effects of rainfall on high permeable slope (from Brand, 1995)

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.

Transient perched water tables might be formed at the interface of layers of differing permeability. Therefore examination of the material profiles within a slope and the catchment above the slope must be carried out.

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 the 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.

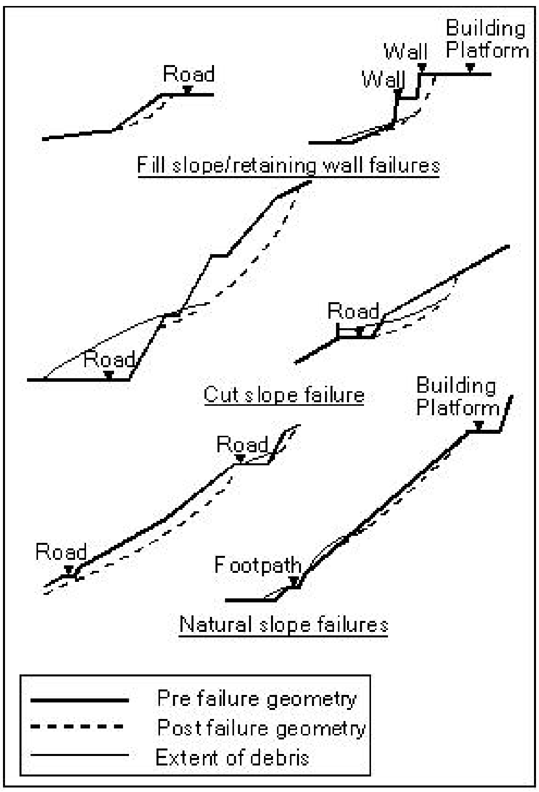


Figure 4 : Typical Slope Failures in Residual Soils (modified from GCO, 1991)

4.2.2 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. Figure 4 shows some of the typical slope failures in residual soils.

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. For the check on non-circular and wedge failure mode, methods such as Janbu (1972) or Morgenstern & Price (1965) are recommended. In practice, it is advisable to check for both circular and non-circular failure modes in designs.

4.3 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)

Examples on "Risk-to-Life"	
(1) Failure affecting country parks and lightly used open-air recreation areas. (2) Failures affecting roads with low traffic density. (3) Failures affecting storage compounds (non-dangerous goods).	Negligible
(4) Failures affecting densely used open spaces and recreational facilities (e.g. sitting-out areas, playgrounds, car parks). (5) Failures affecting roads with high vehicular or pedestrian traffic density. (6) Failures affecting public waiting areas (e.g. railway platforms, bus stops, petrol stations).	Low
(7) Failures affecting occupied buildings (e.g. residential, educational, commercial, industrial). (8) Failures affecting buildings storing dangerous goods.	High

Table 2 : Examples on "Risk-to-Life" (after GCO, 1991)

Examples on "Economic Risk"	
(1) Failure affecting country parks. (2) Failures affecting rural (B), feeder, district distributor and local distributor roads which are not sole accesses. (3) Failures affecting open-air car parks.	Negligible
(4) Failures affecting rural (A) or primary distributor roads which are not sole accesses. (5) Failures affecting essential services which \could cause loss of that service for a temporary period (e.g. power, water and gas mains). (6) Failures affecting rural or urban trunk roads or roads of strategic importance.	Low
(7) Failures affecting essential services, which could cause loss of that service for an extended period. (9) Failures affecting buildings, which could cause excessive structural damage.	High

Table 3 : Examples on "Economic Risk" (after GCO, 1991)

There are three level of risk in each factor (negligible, low and high). Tables 2 and 3 show the typical examples of the two factors above. 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 are listed in Table 4 for different level of risk (as illustrated in Table 2 and 3). In addition, slopes of high risk-to-life category should have FOS of 1.1 for the predicted worst groundwater conditions.

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 5 may be used. Otherwise or substantial modification to the existing slopes is required, the recommended FOS in Table 4 shall be adopted.

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 4 : 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 5 : Modified Recommended FOS for Existing Slopes (modified from GCO, 1991)

It is very important to be aware that not all natural slopes are safe. It is very common for natural slopes to fail during monsoon even there is no activity like clearing of trees or development around it. Therefore evaluation of the stability of the natural slopes in or adjacent to the site should also be carried out. Usually it is not advisable to disturb the natural slopes and vegetation just to achieve marginal improvement in stability unless the slope is unsafe. However, it is important not to locate buildings at areas that could be affected by landslide. Natural slopes need not achieve the FOS listed in Table 4 provided that (GCO, 1991):

- the slope is undisturbed (e.g. has not been and will not be cut, stripped of vegetation, subjected to increase loading or subjected to increase infiltration by alteration of the natural drainage regime), and
- a careful examination to determine there is no evidence of instability or severe surface erosion.

4.4 Design of Cut Slopes

Usually in Malaysia, the vertical interval of slopes between intermediate berms is about 5m. GCO (1991) recommended that the vertical interval of slopes should not be more than 7.5m. 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 4.

4.5 Design of Fill Slopes

Similar to cut slopes, berms of 1.5m wide at 5m 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 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. Sufficient numbers of discharge drains should be place to collect the water in the filter layer and discharge it outside the limits of the fill and away from the slopes.

4.6 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 the rainy season. 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 two 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. Figure 5 shows the typical details of the cast-in-situ berm drain. 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 the 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. Figure 6 shows a typical detail of step channel. 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.

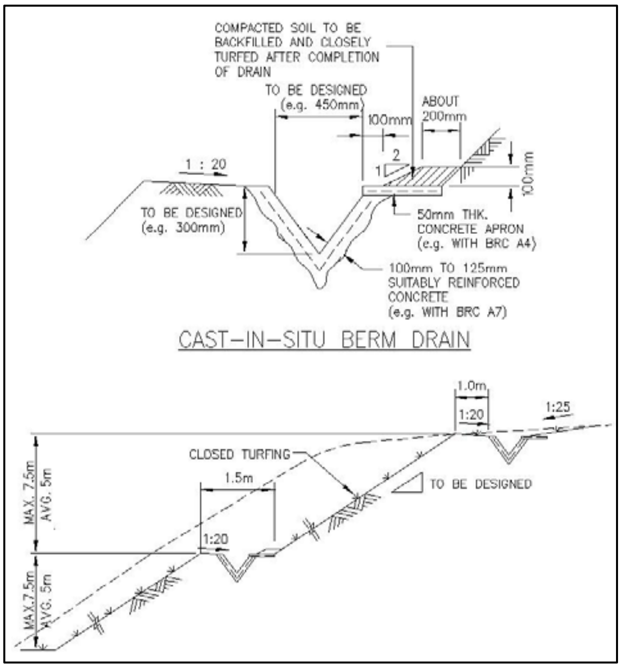
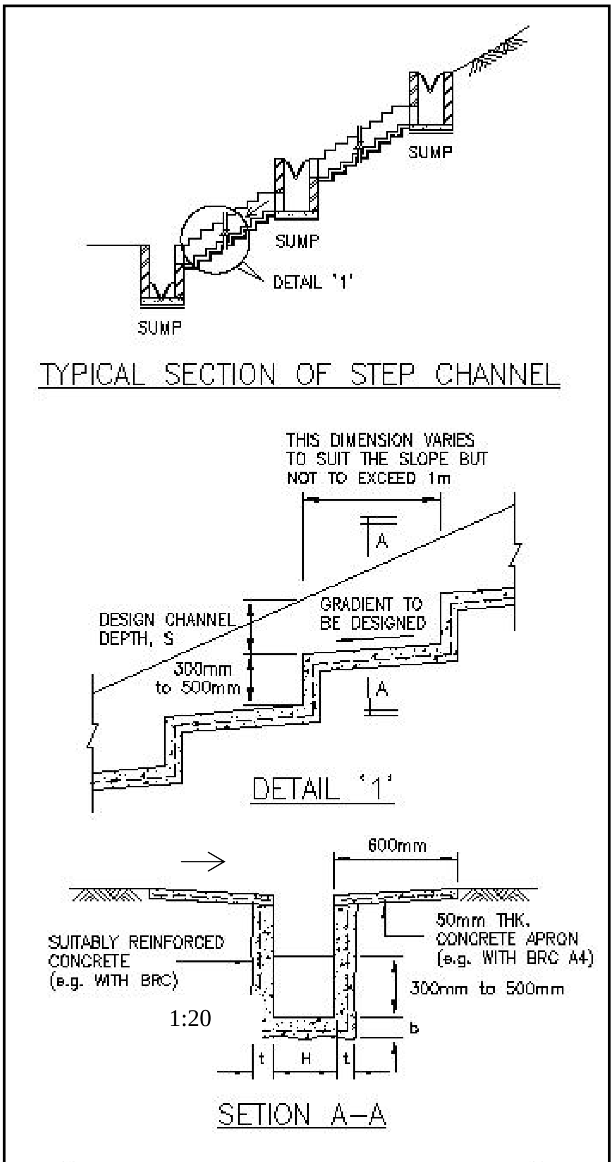


Figure 5 : Typical Details of Cast-In-Situ Berm Drain

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) with proper drainage weepholes.



TYPICAL DIMENSIONS OF STEP CHANNEL			
NOMINAL SIZE OF CHANNEL H (mm)	THICKNESS t (mm)	THICKNESS b (mm)	SPLASH ALLOWANCE S (mm)
225 TO 300	100	100	200
375 TO 675	100	150	350
750 TO 900	125	200	400

Figure 6 : Typical Details of Step Channel

5 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. 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 so 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 placed in layers not exceeding 300mm thick 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 a good practice to construct first the interceptor drains or berm drains with proper permanent or temporary outlet and suitable dissipators to ensure discharge velocity is less than 1.5m/sec 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 than14 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.

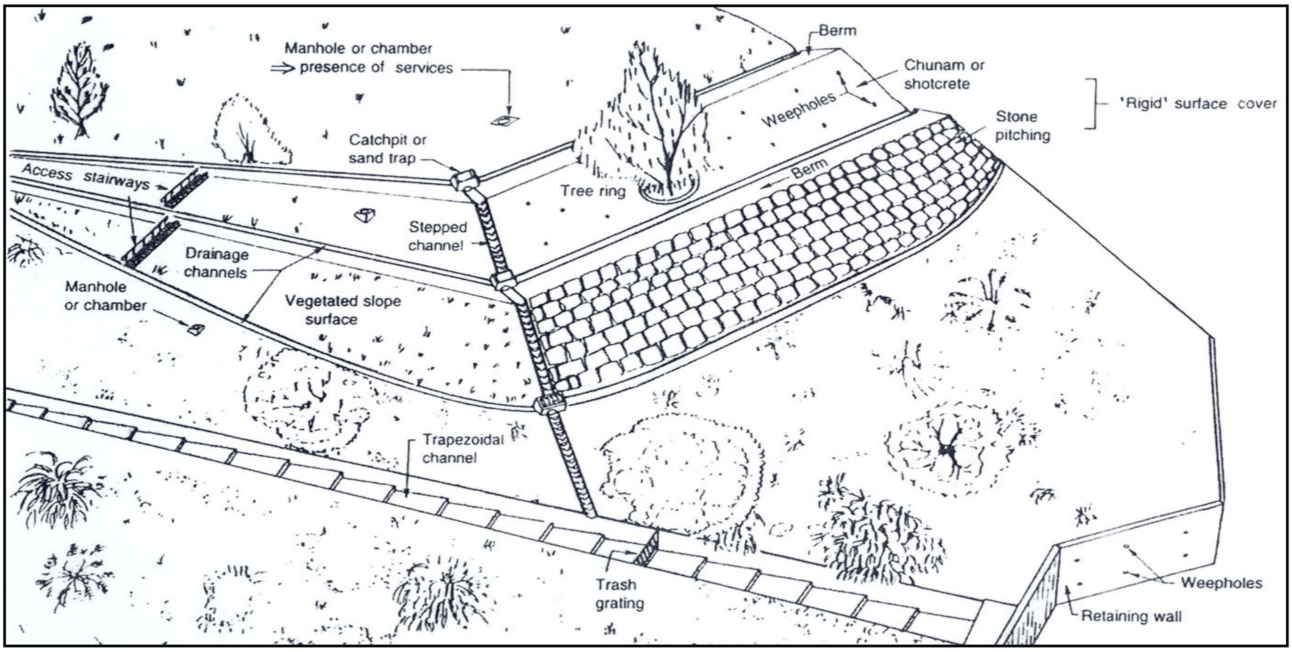


Figure 7 : Typical Features of Slope and Retaining wall that Require Maintenance (from GEO, 1995)

6 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.

Figure 7 shows the typical features of slope and retaining wall that require maintenance. The basic maintenance works as of Category A Routine Maintenance Inspections stated above include :

(a) Clearance of accumulated debris or soils from drainage channels.
(b) Repair of cracked or damaged drainage channels or pavement
(c) Repair of cracked or damaged rigid slope surface protection.
(d) Clear and unblock weepholes and outlet drain pipes.
(e) Removal of any vegetation that can cause severe cracking of drainage channels.
(f) Re-turfing on bare soil slope surface.
(g) Removal of loose rock debris and undesirable vegetation from rock slopes or around boulders.
(h) Check for leakage of buried water-carrying services (e.g. water supply, sewerage pipes).
(i) Detect tell-tale signs like creeping of slope, tension cracks, or cracking of the buildings near the slopes (Gue, 1999).

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 widening 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.

7 CONCLUSION

Geotechnical input by the engineer 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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