DESIGN AND CONSTRUCTION PRACTICE OF SLOPES IN HONG KONG

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SUMMARY

This paper presents a general discussion on present design concepts and construction practice of slopes in Hong Kong. Stability analysis of a soil slope using a computer program and a rock slope by stereonets are illustrated. The extent and general requirements of site investigation for slopes are presented. In construction practice, surface protection methods such as chunam plastering and guniting for soil slopes and anchors for retaining rock wedge are discussed. Particular emphasis is made to Government requirements on geotechnical consultancy on design and construction supervision of geotechnical related structures.

1. INTRODUCTION

With a population of over 4.5 million in an area of about 1000 sq km, Hong Kong has one of the densest populations in theworld. The landscape features consist mainly of steep rocky hills. The high density of population and the limited availability of land make cut and fill slopes very common in Hong Kong.

In the sub-tropical climate with an annual precipitation of over 200 cm, the process of soil formation and destruction is very active. Landslides and mud flows which occur very quickly with little or no prior warning are common during the rainy season on steep natural, cut and fill slopes. Slides are more common in areas of volcanic rocks and are normally limited to upper zones of slopes, rarely extending to depths greater than 10 m (1).

The 1972 and 1976 slide disasters in Po Shan Road and Sau Mau Ping which claimed a large number of casualties necessitated the adoption of a more scientific approach to slope design and construction rather than, as previously, relying on experience along (2, 3). Since then the Government with the help of consultants has carried out comprehensive studies upon the stability of hillsides in Hong Kong.

This paper presents a general discussion from present design concepts to general construction practice of slopes in Hong Kong. Information for this paper has been drawn from a number of sources and reference is made to publications which discuss the subjects in greater detail.

Hazard Potential Classification (1)		Formed Slope Classification (2)				Angle of Natural Hillside in the Vicinity of the Site		
Category	a. Loss of life b. Economic loss	Features	Soil Cut	Soil Fill	Rock	0° to 20° Type 1	20° to 40° Type 2	>40° Type 3
						Description of Site Investigation (2)		
Low	a. None expected (no occupied premises). b. Minimal structural damage. Loss of access on minor access on minor roads, railway etc.	Slope-height angle	≯7.5m ≯50°	≯5m ≯30°	<7.5m -	1L Assessment of surrounding geology and topography for indication of stability. Visual examination of soil and rock forming the site or to be used for the embankment. Specialist Advice - Requirement (A)	2L As for type 1L. More detailed geology and topography survey. For the steeper slopes information on soil and rock joint strength parameters. Survey of hydrological features affecting the site. Specialist Advice - Requirement (B)	3L As for type 2L. Area outside confines of site to be examined for instability of soil, rock and boulders above the site. Specialist Advice - Requirement (C)
Signi-ficant	a. Few (only small occupied premises threatened) b. Appreciable structural damage. Loss of access on major roads, railways etc.	Slope-height angle	≯15m ≯60°	≯10m ≯30°	>7.5m -	1S Geology and topography survey of site and surrounding area. Soil and rock joint strength parameters for foundations and cut slopes. For embankments steeper than 1 on 3 recompacted strength parameters of fill. For cuts information on groundwater level. Specialist Advice - Requirement (B)	2S As for type 1S. Survey of hydrological features affecting the site. Specialist Advice - Requirement (B)	3S As for type 2S. Extend outside limits of site to permit analyses of slopes above and below the site. Specialist Advice - Requirement (C)
High	a. More than a few. b. Excessive. Large residential and industrial structures. Loss of access on principal roads, railways etc.	Slope-height angle	>15m >60°	>10m >30°	>15m	1H Detailed geology and topography survey of site and surrounding area. Soil and rock joint strength parameters for foundations and cut slopes. Recompacted strength parameters for fill. For cuts information on groundwater level. Specialist Advice - Requirement (C)	2H As for type 1H. Survey of hydrological features affecting the site. Extend investigation locally outside limits of site to permit analyses of slopes above and below the site. Specialist Advice - Requirement (C)	3H As for type 2H. Extend investigation more widely outside limits of site to permit analyses of stability of slopes above and below the site. Specialist Advice - Requirement (C)

Specialist Advice - Requirements (3)

(A) Services of experienced geotechnical engineer probably not necessary.

(B) Services of experienced geotechnical engineer to depend on location relative to developed or developable Land (4).

(C) Services of experienced geotechnical engineer essential. (4)

Footnotes :-

(1) Hazard potential should be assessed with reference to both present use and development potential of the area. Use highest loss category obtained under (a) and/or (b).

(2) Formed slope classification to be based upon either slope height or angle whichever gives the highest hazard category.

(3) The site should be classified according to the highest category obtained under either Clasification.

(4) At some sites the services of an Engineering Geologist may be required.

Notes:-

(i) This table is intended to provide guidance only. Each situation must be assessed on its merits to decide whether or not the recommended investigation procedures are necessary or if peculiar conditions require even more detailed examination.

(ii) Whilst the above gives an indication of the requirements for a site investigation under certain general conditions, Table 2.2 gives more précise information on how the above requirements can be met.

Fig. 1 General requirements for site investigation (Ref. 4)

This table is intended to provide guidance only

Category from table 2.1	Type 1 from table 2.1	Type 2	Type 3
Low	1.L B1 D E1	2.L B1 C1 D E1 F1* G1 C2* E2* G3	3.L A B1 C1 D E1 F1 G1 C2 E2 G3
Significant	1.S A B1 C1 D E1 F1 G1 C2 E2 G2 G3	2.S A B1 C1 D E1 F1 G1 B2 C2 E2 F2 G2 G3	3.S A B1 C1 D E1 F1 G1 B2 C2 E2 F2 G2 E3 G3
High	1.H A B1 C1 D E1 F1 G1 C2 E2 G2 E3 G3	2.H A B1 C1 D E1 F1 G1 B2 C2 E2 F2 G2 E3 G3	3.H A B1 C1 D E1 F1 G1 B2 C2 E2 F2 G2 E3 G3

A. Examination of terrestrial photographs, aerial photos and geological maps.

B. Survey of 1. topographical, geological and surface drainage features.
2. hydrological features.

C. Geological mapping of 1. surface features.
2. structures.

D. Investigation holes, such as trial pits, boreholes or drillholes, as appropriate.

E. Sampling 1. quality class 4
2. quality class 3
3. quality class 2

F. Field measurements of 1. groundwater level.
(see note i) 2. permeability.

G. Laboratory tests 1. classification tests.
(see note ii) 2. density tests for fill materials.
3. strength tests for soils and rock joints.

Notes

(i) Vane testing may be appropriate in marine silts or other fine grained soils. Installation of instruments for long term monitoring of (a) displacements where movement is suspected and (b) pore pressures, should be considered during the site investigation stage. (Chapter 10).

(ii) Chemical tests will be required if aggressive soil/water is suspected in the vicinity of steel or concrete.

* For steeper slopes only

Fig. 2 Content of site investigation
(Ref. 4)

Grade	Term	Diagnostic features
VI	Residual Soil	Rock is completely decomposed to soil with no original rock texture recognizable.
V	Completely Weathered	Rock completely decomposed by weathering in place, but texture still recognisable. In types of granitic origin, original feldspars completely decomposed to clay minerals. Cannot be recovered as cores by ordinary methods.
IV	Highly Weathered	Rock weakened so that fairly large pieces can be broken and crumbled in the hands. Sometimes recovered as core by careful diamond drilling. Stained by limonite.
III	Moderately Weathered	Considerable weathered throughout. Possessing some strength - large pieces (e.g. NX drill core) cannot be broken by hand. Often limonite-stained.
II	Slightly Weathered	Distinctly weathered throughout the rock fabric with slight limonite staining. Some decomposed feldspar in granites. Strength approaching that of fresh granite.
I	Fresh rock	Immediately beneath weathered rock, fresh rock may have some limonite-stained joints.

Fig. 3 Classification of weathered rock of igneous origin

2. SITE INVESTIGATION

Hong Kong possesses a wide variety of geological features from loose marine deposit to hard granitic rock. It is essential that an accurate knowledge of the geological and hydrogeological conditions pertaining to the slope in question be obtained and representative samples be recovered for laboratory testing prior to any form of analysis. The extent and general requirements of such investigation recommended by the Government are shown in Figures 1 and 2 (4). During investigations samples from soft materials are obtained by various sampling techniques such as conventional tube-driven samples normally 38 to 102 mm diameter, block samples, Mazier and ring samples. Hard materials are usually sampled by the conventional double tube ball-bearing swivel type core barrel, but occasionally the triple tube core barrel with orientator is used to supplement information obtained from surface joint surveys.

Geological strata usually encountered in Hong Kong are granitic or volcanic rock at various states of weathering, normally overlain by a soil mantle of residual soil and/or colluvial or alluvial deposits. The classification system normally used in Hong Kong is shown in Figure 3 (4, 5).

During boring, in-situ permeability tests are sometimes carried out at specific intervals and data so obtained are recorded for analysis normally by method specified in the USBR manual (6). When all sampling and testing are completed conventional standpipes and/or piezometers are installed in the boreholes.

Geological mapping and joint surveys of exposed rock formation are normally conducted and records are made on seepage traces as well as existing slip scars. Hydrogeological features including drainage courses and catchment areas are examined from arial photos to determine conditions affecting the stability of the slope under consideration.

3. GOVERNMENT CONTROL

As part of a landslide study, the Government has commissioned a consulting firm to catagorize existing slopes in terms of their landslide potentials and to identify potential failure areas in Hong Kong. The preliminary classification will serve as a basis for the priority to further investigation and subsequent remedial works. The Geotechnical Control Office (GCO) which consists of four divisions, namely Building Ordinance Division, Existing Slopes Division, New Works Division and Materials Division, was established in 1977 to steer and control geotechnical aspects of the civil and construction industry. Consultants are also retained by the Government to study and report on individual cases f instability.

For all proposed development whether a slope is to be constructed or to remain, the architect or engineer in charge (Authorized Person) is required by the Government to engage a geotechnical consultant . The design prepared by the geotechnical consultant must then be submitted to one of the GCO divisions for review and approval prior to carrying out any construction work. A copy of a 'Conditions' issued by the Government to a proposed development involving slopes is given in Appendix I.

4. ANALYSIS AND DESIGN

The varying conditions which can pertain to the slope materials in Hong Kong make it necessary to use effective stress concept in slope stability analysis. Theories for unsaturated soils are uneconomical or inflexible for conditions found in Hong Kong, where the degree of saturation varies to a great extent (7).

Soil testing is usually carried out using single or multi-stage consolidated drained triaxial compression test with the sample saturated under a back pressure to eliminate the effect of negative pore pressures and to simulate adverse site conditions during rainstorms. The B coefficient, defined by the ratio of changes of pore pressures (Δu) to changes of confining pressure ($\Delta\sigma_3$), should normally exceed 0.97. For slope stability analysis, the tests are usually run under low effective confining stresses to simulate in-situ site conditions. In addition, the usual physical and mechanical tests are conducted depending upon the particular site being examined.

The stability of rock slopes depends to a great extent on the presence of discontinuities and therefore mapping and testing of discontinuities have always been emphasized. The Robertson shear box test on rock core, conducted at effective stress range predicted on fracture surface, is widely used.

The choice of the factor of safety in slope design is always difficult. The current factor of safety recommended by GCO is 1.4 for permanent development in residential areas and 1.2 for temporary structures. Suggestions as shown in Figure 4 have also been made on factors of safety for other site conditions (7).

Class	Cutting Type	Factor of Safety (A) Comprehensive Site Investigation*	Factor of Safety (B) Cursory Site Investigation**
1	Road cutting or cutting in remote area where probability of life at risk, due to failure, is small.	1.1	1.2
2	Road cutting on main arterial route where main line communications can be cut and risk to life is possible.	1.2	1.3
3	Areas adjacent to buildings where failure would affect stability of building e.g. car park. Risk to life significant.	1.2	1.4
4	Cuts adjacent to buildings where failure could result in collapse of building. Risk to life very great.	1.4	Not applicable

* Such a site investigation would, in addition to normal boring and drilling, include a programme of laboratory testing to determine shear strength parameters for both soils and rock failures. Joint system surveys would be carried out and likely effects of heavy rainfall on the slopes would also be considered. These effects would be included in the soils and rock stability analyses.

** Site investigation under such a classification would be limited to determine the boundaries of the various grades of material, the type of rock, and also predominant joint patterns in the case of rock stability problems. Shear strength parameters would be derived from back analysis of failures and from published figures for similar material found elsewhere in the Colony.

Fig. 4 Factors of safety for slope stability analysis (Ref. 4)

4.1 Soil Slopes

The effective shear strength parameters (c', ø') to be used in design can be measured from carefully conducted triaxial compression tests on undisturbed soil samples in the laboratory. Negative pore pressures are normally assumed to be totally eliminated by infiltration in adverse site conditions with regard to rainfall. This approach is especially conservative for protected slopes.

In practical design, the choice of the cohesion intercept, c', is complicated by the sensitiveness of the parameter to sampling and handling. A reduction of 40 to 100% of laboratory tested results or projected values from back analysis are usually adopted for design and analysis. The value of ø' is usually unaltered or slightly reduced.

The stability of slopes is also governed by the depth of the zone of saturation or wetting band that can develop in a particular storm (1, 7). The depth to which the wetting band can develop in a particular slope is dependent on the rainfall intensity and duration, the infiltration capacity of surface soil, slope topography and extent of vegetation cover. The thickness of wetting band can be determined from the limiting rate of infiltration (1), $v = k/(1-S)n$, where k is the permeability, S is the initial degree of saturation and n the soil porosity. Assuming 50% run-off, n = 40% for decomposed granite (1) and the initial (S_o) and final (S_f) degree of saturation are 0.9 and 0.6 respectively, the wetting band thickness for rainstorms having various return periods is plotted in Figure 5. The k values used are those obtained from in-situ or laboratory permeability tests.

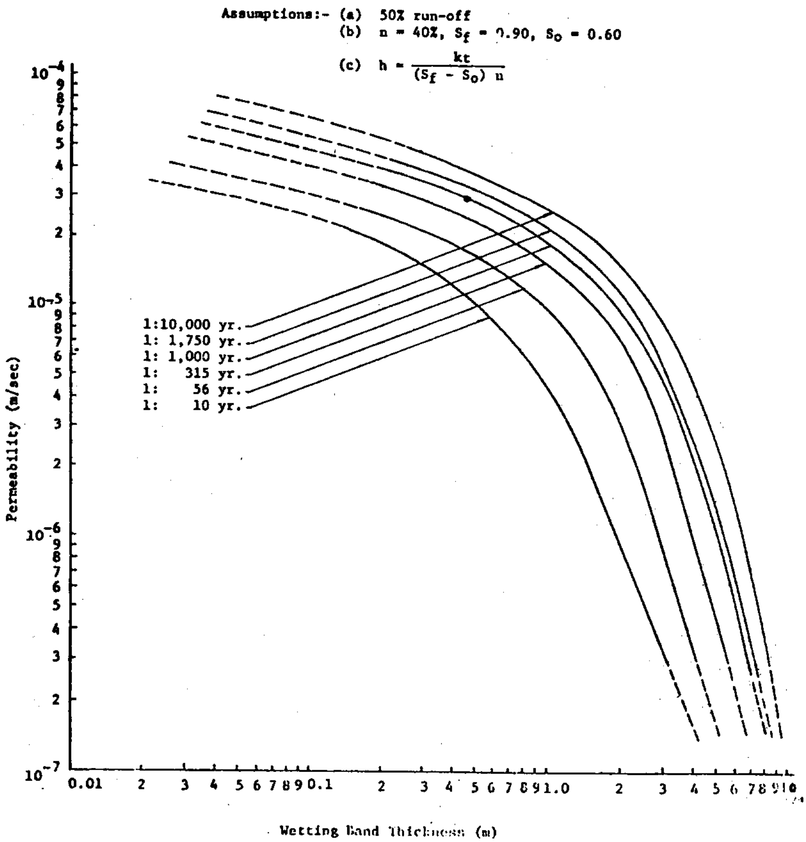


Fig. 5 Variation of wetting band thickness with permeability (Ref. 7)

Based upon the calculated wetting band thickness determined from rainstorms of different return periods together with records of groundwater level obtained by monitoring standpipes or piezometers, estimation on probable rise in phreatic surface could be made. The recommended return period by GCO is 1 in 1000 years. The depth of tension crack in unsaturated slopes and the development of hydrostatic pressure in cracks are also taken into consideration in stability analysis.

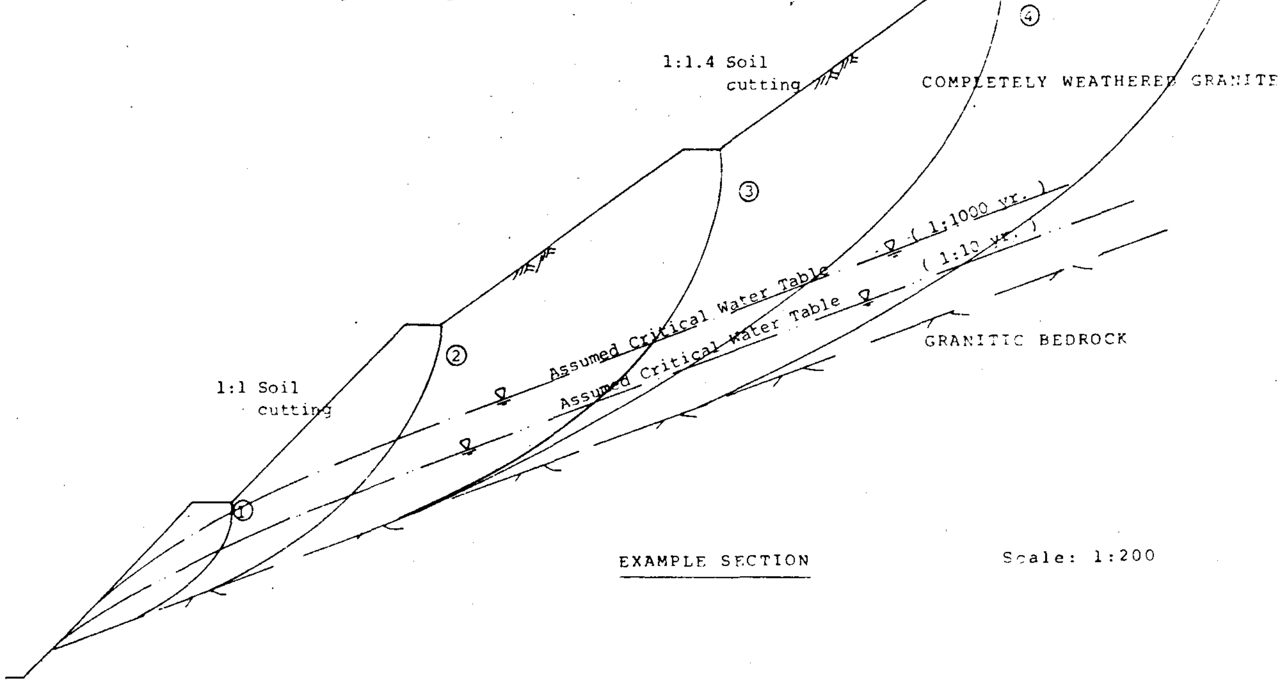
Studies of existing failure surfaces in Hong Kong indicate that much of these failure surfaces are controlled by weathering profiles or relict joints and are planar or non-circular over a considerable portion of the surface. For this reason, methods of analysis assuming circular failure surfaces are considered not suitable for slopes in Hong Kong. Alternative methods assuming generalised slip surfaces are those proposed by Janbu (8) and Morgenstern and Price (9). Details of these methods have been described elsewhere. The type of static conditions satisfied, the assumptions made and the expression of the factor of safety are given in Figure 6. The Janbu Routine method which is suitable for hand calculation, and the more rigorous Morgenstern-Price Method are commonly employed in analysis. Design charts (10) are also used in designing simple and/or temporary slope. An example of a slope stability analysis is illustrated in Figure 7 and a computer program for stability analysis using Janbu Routine Method is included in Appendix II.

Fig. 6 Methods of Generalised Slope Stability Analysis

METHOD	STATICS EXPLICITY SATISFIED	ASSUMPTION TO MAKE PROBLEM DETERMINATE	FACTOR OF SAFETY EQUATIONS
Janbu's Simplified Method	F = 0 horizontal direction for overall slope. F = 0 vertical direction for each slice.	Uses a correction factor, f_o to account for the effects of the shear side forces. Is dependent on c', ϕ' and the shape of the failure surface.	$F = f_o \cdot \dfrac{\Sigma(c' \cdot l + [\frac{W}{\cos\alpha} - u \cdot l] \cdot \tan\phi')/m_\alpha}{(A_L - A_R) + \Sigma W \cdot \tan\alpha}$
Janbu's Rigorous Method	F = 0 horizontal direction for overall slope. F = 0 vertical direction for each slice F = 0 horizontal direction for each slice. M = 0 about the center of the base of each slice.	Assumes that a "line of thrust" defines the direction of the side forces.	$F = \dfrac{\Sigma(c' \cdot l + [\frac{W}{\cos\alpha} + \frac{(X_L - X_R)}{\cos\alpha} - u \cdot l] \cdot \tan\phi')/m_\alpha}{(A_L - A_R) + \Sigma[W + (X_L - X_R)] \tan\alpha}$ where $X_R = E_R \cdot \tan\alpha_t$ α_t = angle of the line of thrust
Morgenstern-Price Method	F = 0 horizontal direction for overall slope. M = 0 about center of rotation for overall slope. F = vertical direction for each slice. F = 0 horizontal direction for each slice. m = 0 about the center of the base of each slice.	Assumes a side force function (f(x)) to specify the direction of the resultant of the normal and shear side forces. eg. i) Sine function ii) Clipped Sine function iii) Trapezoidal function iv) Any specified function	$F_M = \dfrac{\Sigma(c' \cdot l \cdot R \cdot \cos\alpha + [W \cdot R + (X_L - X_R) - u \cdot l] R \cdot \cos\alpha \cdot \tan\phi')/m_\alpha}{A_L \cdot a_L - A_R \cdot a_R + \Sigma W \cdot x - \Sigma P \cdot f}$ $F_F = \dfrac{\Sigma(c' \cdot l + [\frac{W}{\cos\alpha} + \frac{(X_L - X_R)}{\cos\alpha} - u \cdot l] \tan\phi')/m_\alpha}{(A_L - A_R) + \Sigma W + (X_L - X_R) \cdot \tan\alpha}$ where $X_R = E_R \cdot \lambda \cdot f(x)$

SLIP SURFACE	1	2	3	4	5	
FACTOR OF SAFETY (1:1000 yr.)	1.46	1.21	1.37	1.32	1.37	> 1.13 (O.K.)
FACTOR OF SAFETY (1:10 yr.)	1.77	1.46	1.50	1.41	1.48	> 1.40 (O.K.)

Note: All soil cut slopes to be covered with 75 mm thick chunam plaster;
50 mm dia. weepholes be provided at 1.2 m c/c.



EXAMPLE SECTION

Scale: 1:200

Project

SLOPE STABILITY ANALYSIS

Fig. 7

4.2 Rock Slopes

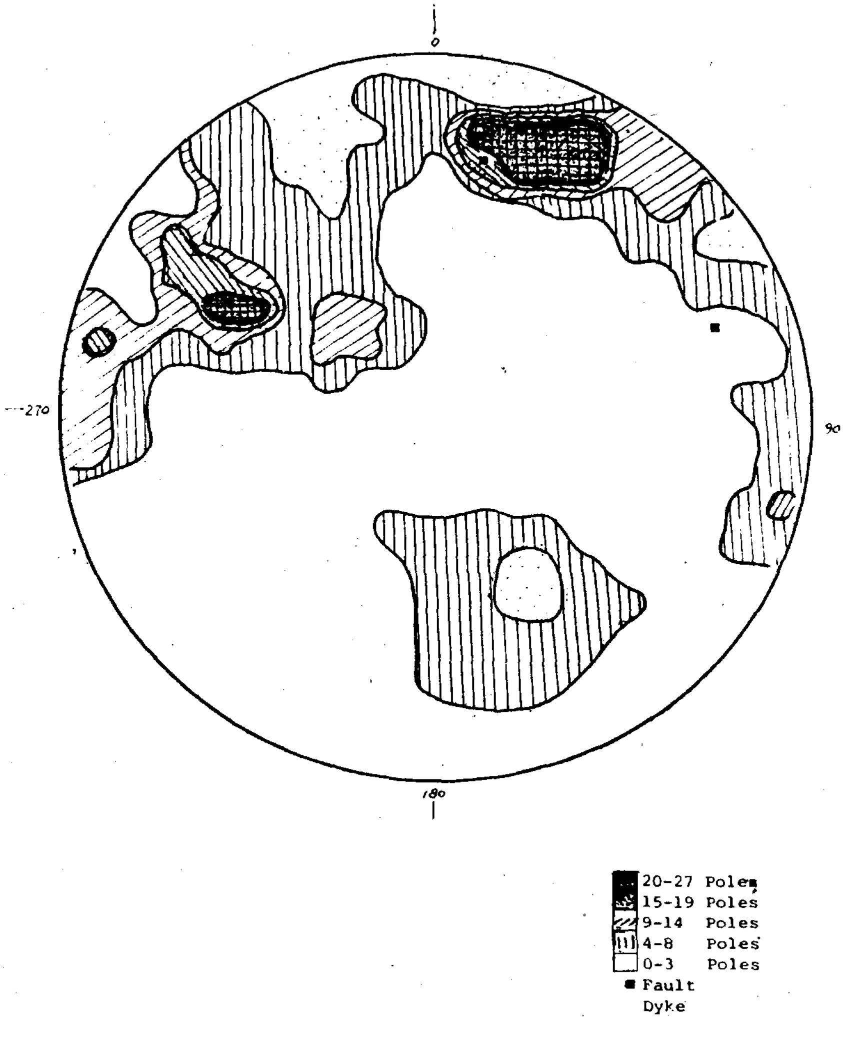
The stability of a rock slope is dependent, to a large extent, on the presence of relict joints in the rock formation and the weathering profiles. For this reason joints exhibited on a rock face must be examined.

Stereonets drawn by spherical projections from surface joint surveys provide a convenient means for the presentation of statistical geological data. Details of the method and its application have been described elsewhere (10) and will not be discussed in the context of this paper. Data obtained from orientated boreholes are sometimes used to supplement the results from stereonet to identify zones of potential instability. Isolated relict joints which may be overlooked by statistical joint survey but whose presence alone may cause severe instability are also identified.

Friction angles of 31^{o} to 39^{o} are normally used for granitic joints of different grades of weathering while that for volcanic joints is about 30^{o} (11). Special precaution is given to the presence of clay-filled joints which show much strength loss. The cohesion parameter could be studied by back analysing previous slope failures, assuming a dry slope and upper bound value for ϕ to give a conservative result. The cohesion value normally used is 30 kPa for granitic joints and 40 kPa for volcanic joints (11). A typical analysis on the stability of rock slope is given in Figures 8 and 9.

Project Equal area stereogram Fig. 8

Station 1+17 to 2+35
Slope : Dip direction 153°
Dip angle 70°
Friction angle : 35° (Assumed)
346 poles



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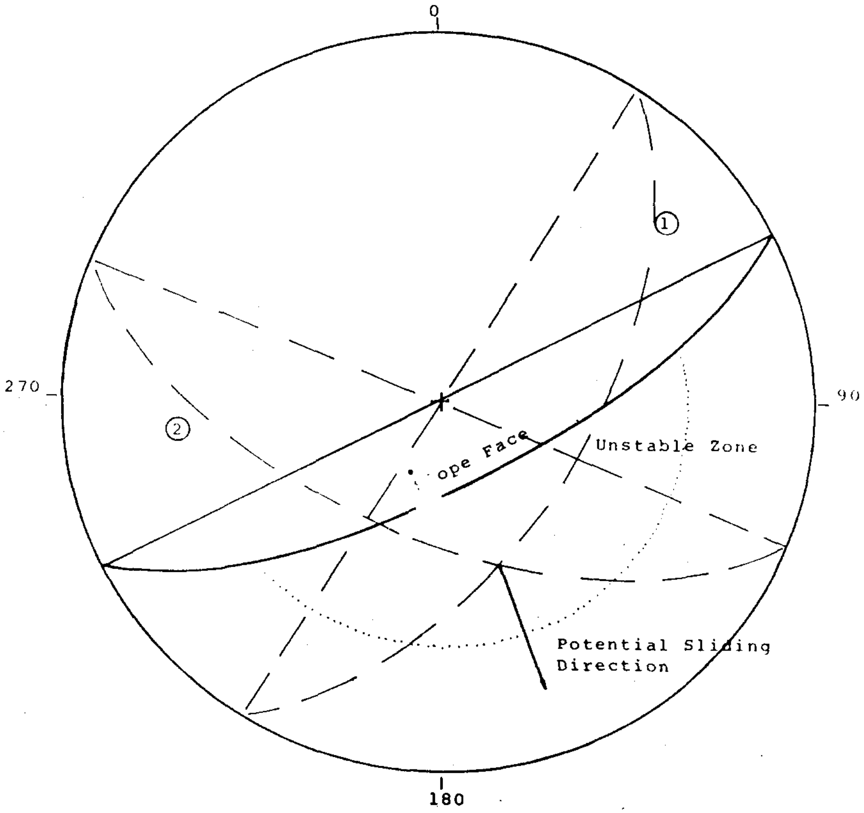
Project

Fig. 9

Stereoplot of Geological Data at Station 1+25

Slope face: $152^o/70^o$ (Slope angle)
Joint plane: 1. $122^o/58^o$ (Dip angle)
2. $203^o/60^o$ (Dip angle)
Friction angle: 35^o (assumed)



5. CONSTRUCTION PRACTICE

Theoretical aspects of the analysis and design of slopes in Hong Kong have been dealt with in the previous sections. The actual construction process and its supervision may have significant effects on the final stability which may be difficult to estimate. This section will briefly consider general slope construction practice normally used in Hong Kong and the level of supervision carried out by geotechnical engineers.

5.1 Level of Supervision

For government projects involving slopes, a consultant is always appointed by the government for the total overseeing of the geotechnical aspects of the project. The consultant will act as government's representative in the design and supervision of the project. Consultants are also retained, in some cases, by the government to act on its behalf for the general checking of privately developed slopes in some areas. For private developments, guidelines have been issued on the requirement of geotechnical expertise in design as well as supervision. The level of supervision ranges from full time geotechnical engineer on site with monthly reports to the Government to periodical geotechnical inspections. Figures 1 and 2 listed the requirements on supervision and, in Appendix I, the requirement on geotechnical consultancy as one of the approval conditions of a proposed development are given. It is hoped that under such a network of cross checking that construction on slopes could be done under constant and proper supervision.

5.2 Soil Slopes

Cut slopes in soils are usually made at 30 to 60 degrees to the horizontal depending on the expected duration of the slope. Fill slopes are normally formed at angles ranging from 25 to 45 degrees. Flights of slopes are usually 7.5 m high with berms 1.5 m wide. General types of slope protection methods include stone pitching, chunam plastering, guniting and hydroseeding. Chunam plaster is a common form of surface protection for soil slopes in Hong Kong. Chunam is a cement-soil mixture consisting of 1 part of cement, 3 parts of hydrated lime and 20 parts of non-organic soil by weight. The materials are well-mixed, sprinkled with water and applied by hand. Chunam surfacing is inexpensive compared to other forms of slope protective works but should only be considered as a temporary measure. The cost of regular maintenance may offset the initial low cost of construction and for this reason the use of gunite has become increasingly popular. More elaborate method of surface protection consists of casting diamond shaped interlocking grids filled with a thin layer of no-fines concrete onto which top soil and turf are placed.

Retaining structures associated with slopes generally used are conventional reinforced concrete and gravity walls. Occasionally cantilevered or anchored caisson walls and stabilizing piles (or caissons) are also used for supporting very high slopes.

The installation of a properly designed and adequate drainage system to intercept surface run-off and infiltration is also of prime importance. Concrete surface drainage channels are always provided along the top and toe, and along the berms to divert surface run-off to catch pits. To lower the groundwater level and to reduce infiltration to critical slope surfaces, drainage systems such as inclined drainpipes, drainage blankets and galleries with sandwich filter materials are often constructed.

As required by the Government, the construction of fill slope is strictly controlled by geotechnical engineers. The weathered granitic rock which consists of 20 to 40% by weight of fines are normally used as fill material. The fill is placed in layers 200 to 300 mm in thickness and compacted to at least 95% of the maximum dry density determined by the standard proctor test.

To compact the sandy fill material near the surface of the slope to the required degree of compaction, the slope is normally slightly over-built and, after compaction, trimmed to the required profile. Vibrating rollers are commonly used for compaction. Field density tests are usually carried out by sand replacement and occasionally liquid-filled balloon type densometers are also used.

Surface of fill slope is normally turfed. The infiltration is normally intercepted and diverted to outlets through filter layers placed between the original ground and fill.

5.3 Rock Slope

Rock cuts are usually made at 60 to 75 degrees to the horizontal with 1 m wide benches at every 15 m of height. Excavation is normally carried out by blasting in unrestricted areas and by pneumatic drills in restricted area. Permission to blast, if given by the geotechnical engineer, has also to be granted by the Mines Department to satisfy their safety requirements such as erecting wire nets to protect the surroundings from flying rocks.

Overblasting during the excavation of slopes is one of the main factors causing rock falls in Hong Kong. The dominanting effect of overblasting is the reduction of strength in joints, thus causing instability of the finished slope face. The common practice is to carry out normal blasting, usually by a square pattern, to a distance of about 3 m from the final surface. Smooth blasting or pre-split blasting is then used to produce a smooth and undamaged rock face. The blasting operation has to be engineered by qualified personnel and supervised by representative from the Mines Department.

The indiscriminate use of a standard profile such as cutting of benches to daylight potentially unstable sheeting joint planes may reduce the stability of the slope. Close supervision is therefore required to modify design on site. Joint system surveys and additional analysis are also made on the as-constructed slope to verify the stability conditions.

Drainage system and surface protection where applicable are similar to that for soil slopes. Remedial measures applicable to rock slopes include trimming, erecting concrete pillars and buttresses to retain toppling rocks, and various steel retaining devices such as dowel bars, rock bolts and anchors to resist sliding rock masses. The use of anchors and bolts as permanent structures must satisfy the requirement against corrosion, creep and long term monitoring which may last for the entire life of the building structure. For highly fractured rock faces, gunite reinforced with wire mesh is also commonly used.

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APPENDIX I

SPECIAL CONDITIONS FOR PROPOSED DEVELOPMENT (SOIL AND ROCK INVESTIGATION)

(a) Upon development or redevelopment of the lot or any part thereof the purchaser shall :-

(i) at his own expense carry out and complete to the satisfaction of the Director of Public Works such foundation and formation works on the lot as the said Director shall require in his absolute discretion, and shall not commence any building work on the lot before completion of such foundation and formation works, and

(ii) before commencement of any foundation and formation works on the lot at his own expense appoint an Engineer or Consultant specialising in the practice of soil and rock engineering (hereinafter referred to as "the said consultant") who shall be subject to the approval of the Director of Public Works. The said consultant will undertake a full soil and rock investigation to justify the feasibility of any related proposal submitted.

(b) No development work, including foundation and formation works, on the lot shall be carried out except under the direct supervision of the said consultant throughout the entire period of development. The said consultant shall be required to :-

(i) assist the authorized person (as defined in the Buildings Ordinance) in charge of the development of the lot (hereinafter referred to as "the said authorized person") in preparing the detailed geotechnical design and calculations for the foundation and formation works to be carried out on the lot;

(ii) undertake such specific field and laboratory tests as the Director of Public Works shall consider necessary or require to qualify the assumptions made in the slope stability and foundation investigation carried out on the lot by the said

(iii) ensure by supervision that all the requirements and conditions which may be imposed by the Director of Public Works relating to the foundation and formation works on the lot are complied with to the satisfaction of the said Director; and

(iv) assist the said authorized person in preparing an associated works programme, and submit a monthly report to the said authorized person and the Director of Public Works reviewing all matters arising from the foundation and formation works on the lot so that accurate details of the same will be available at all times and particularly when called for by the said Director. Such monthly report shall record, contain and outline :-

(1) the number and duration of site visits made by the said consultant;

(2) all data obtained from tests;

(3) records of strata encountered and notes to indicate whether these corroborate or contradict the findings of the feasibility reports prepared by the said consultant, the need for re-design, if required, being made clear;

(4) performance on past programme;

(5) a revision of programme; and

(6) any other relevant matters and information which the said consultant may require to call to the attention of the said Director.

Appendix II

User Instructions

1 SLOPE STABILITY ANALYSIS : JANBU ROUTINE METHOD 2

START | N | W tan α | F_1 | F_2

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	LOAD PROGRAM				0·00
2	INITIALIZE			A	0·00
3	KEY IN DATA : SOIL DENSITY	γ_s		↑	
	FRICTION ANGLE	$\tan \phi'$		↑	
	WATER DENSITY	γ_w		↑	
	COHESION	c'	f	A	γ_s
4	KEY IN SLICE CHARACTERISTICS : WATER HEIGHT	h_w		↑	
	SLICE WIDTH	Δx		↑	
	SLICE HEIGHT	h_m		B	N
5	KEY IN SLICE CHARACTERISTICS : SLICE ANGLE	α		C	$W \tan \alpha$
6	REPEAT STEPS 4 & 5 FOR EACH SLICE.				
7	KEY IN DATA : CORRECTION FACTOR	f_0		↑	
	HORIZONTAL FORCE	Q		D	F_1
8	KEY IN DATA : ASSESSED FACTOR OF SAFETY (OPTIONAL)	F_1		↑	
9	START ITERATION			E	F_2

NOTES: 1 DATA INPUT IN CONSISTENT UNITS.
2 INTERMEDIATE DISPLAYS ARE ITERATED FACTORS OF SAFETY,
3 PROGRAM TERMINATES EXECUTION WHEN $F_1 \sim F_2 \leq 0.005$, THE NO. OF SLICES FOLLOWED BY THE FINAL FACTOR OF SAFETY ARE DISPLAYED
4 MAXIMUM NO. OF SLICES IS 15
5 LIMITATIONS TO INPUT : $N < 10^4$
α : TO 1 DECIMAL PLACE

JANBU ROUTINE METHOD (HP-67)

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	f LBL A	31 25 11	
	f CL REG	31 43	
	f P⇄S	31 42	
	f CL REG	31 43	
	f P⇄S	31 42	
	1	01	
	0	00	
	h ST I	35 33	
	CLX	44	CLEAR ALL REGISTERS
010	h RTN	35 22	SET I REGISTRAR TO 10
	g LBL A	32 25 11	
	STO 4	33 04	
	h R↓	35 53	
	STO 3	33 03	
	h R↓	35 53	
	f TAN	31 64	
	STO 2	33 02	
	h R↓	35 53	
	STO 1	33 01	STORE IN SOIL DATA
020	h RTN	35 22	
	f LBL B	31 25 12	
	RCL 1	34 01	
	×	71	
	STO 6	33 06	
	h R↑	35 54	
	RCL 3	34 03	
	×	71	
	−	51	
	RCL 2	34 02	
030	×	71	
	RCL 4	34 04	
	+	61	
	×	71	
	h R↓	35 53	
	STO ×6	33 71 06	
	h R↑	35 54	
	STO 0	33 00	CALCULATE N
	h RTN	35 22	
	f LBL C	31 25 13	
040	STO 9	33 09	
	f GSB 1	31 22 01	
	RCL 0	34 00	
	RCL 9	34 09	
	ENTER	41	
	f TAN	31 64	
	STO ×6	33 71 06	
	h R↓	35 53	
	f COS	31 63	
	g x²	32 54	
050	h R↑	35 54	
	RCL 2	34 02	
	×	71	
	1	01	
	+	61	
	×	71	
	÷	81	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	STO + 7	33 61 07	
	RCL 6	34 06	
	STO + 8	33 61 08	CALCULATE W and STORE N & α IN MEMORY
060	h RTN	35 22	
	f LBL 1	31 25 01	
	ENTER	41	
	RCL 0	34 00	
	EEX	43	
	4	04	
	÷	81	
	h x⇄y	35 52	
	EEX	43	
	1	01	
070	×	71	
	+	61	
	STO (i)	33 24	
	f ISZ	31 34	SUBROUTINE FOR
	h RTN	35 22	STORING N & α IN I MEMORY
	f LBL D	31 25 14	
	RCL 8	34 08	
	+	61	
	h x⇄y	35 52	
	÷	81	
080	STO 8	33 08	
	RCL 7	34 07	
	h x⇄y	35 52	
	÷	81	CALCULATE F₁
	h RTN	35 22	
	f LBL E	31 25 15	
	STO 1	33 01	
	1	01	
	0	00	
	f LBL 3	31 25 03	
090	h ST I	35 33	
	RCL (i)	34 24	
	f GSB 4	31 22 04	
	STO 0	33 00	
	RCL 1	34 01	
	ENTER	41	
	h R↓	35 53	
	h R↓	35 53	
	f TAN	31 64	
	h R↑	35 54	
100	STO 1	33 01	
	÷	81	
	RCL 2	34 02	
	×	71	
	1	01	
	+	61	
	RCL 0	34 00	
	f yˣ	31 63	
	g x²	32 54	
	×	71	
110	÷	81	
	STO + 5	33 61 05	
	f ISZ	31 34	

REGISTERS (ALL USED)

0	1	2	3	4	5	6	7	8	9
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Listing

STEP	KEY ENTRY	KEY CODE	COMMENTS
	RCL (i)	34 24	
	f x=0	31 51	
	GTO 5	22 05	
	h RCL I	35 34	
	GTO 3	22 03	
	f LBL 5	31 25 05	
	RCL 5	34 05	
120	RCL 8	34 08	
	÷	81	
	0	00	
	STO 5	33 05	
	h R↓	35 53	
	STO 3	33 03	
	f -x-	31 84	
	RCL 1	34 01	
	−	51	
	h ABS	35 64	
130	.	83	
	0	00	
	0	00	
	5	05	
	g x≤y	32 71	
	GTO 8	22 08	
	h RC I	35 34	
	1	01	
	0	00	
	−	51	
140	h PAUSE	35 72	
	RCL 3	34 03	ITERATION FOR FINAL T
	h R/S	35 22	
	f LBL 8	31 25 08	
	RCL 3	34 03	
	GTO E	22 15	
	h R/S	35 22	
	f LBL 4	31 25 04	
	ENTER	41	
	ENTER	41	
150	f x<0	31 71	
	GTO 7	22 07	
	g FRAC	32 83	
	EEX	43	
	4	04	
	×	71	
	h x≶y	35 52	
	f INT	31 83	
	EEX	43	
	1	01	
160	÷	81	SUBROUTINE TO CONVERT
	h R/S	35 22	N αα WHEN α IS POSITIVE
	f LBL 7	31 25 07	
	ENTER	41	
	g FRAC	32 83	
	1	01	
	+	61	
	EEX	43	
	4	04	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	×	71	
170	h x≶y	35 52	
	f INT	31 83	
	1	01	
	−	51	
	EEX	43	
	1	01	
	÷	71	SUBROUTINE TO CONVERT
177	h R/S	35 22	N αα WHEN α IS NEGATIVE
180			
190			
200			
210			
220			

LABELS

A ✓	B ✓	C ✓	D ✓	E ✓
a ✓	b	c	d	e
0	1 ✓	2	3 ✓	4 ✓
5 ✓	6	7 ✓	8 ✓	9

FLAGS

0	
1	
2	
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☐	DEG	☐	FIX	☐
1	☐	☐	GRAD	☐	SCI	☐
2	☐	☐	RAD	☐	ENG	☐
3	☐	☐			n ____	