

**Geotechnical Manual for Slopes
Guidance on Interpretation and Updating**

Government publications of interest to the building industry are promulgated in the list of publications in PNAP 115, among which is the Geotechnical Manual for Slopes.

2. The Geotechnical Manual for Slopes provides guidance on the standards of good practice that should be adopted for the investigation, design, construction and maintenance of slopes and site formation works in Hong Kong. The first edition of the Manual was published in draft form in November 1979 and the second edition was published in May 1984.

3. Over the years since its publication, the second edition of the Manual has become the consensus guidance document in the areas of investigation, design, construction and maintenance of slopes and site formation works. However, there have also been advances in local practice, and separate guidance documents have been prepared to supplement the Manual. These have made some parts of the Manual obsolete and more guidance is needed on the interpretation of the Manual. It is the purpose of this practice note to provide such guidance, which is given in Appendix A of this practice note.



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GUIDANCE ON INTERPRETATION OF GEOTECHNICAL MANUAL FOR SLOPES

1. This Appendix provides guidance on, and clarification of, the interpretation of some aspects of the Geotechnical Manual for Slopes (2nd Edition).
2. **TERMINOLOGY**
 - 2.1. The use of the term "risk" in the Geotechnical Manual for Slopes (Manual) to mean "consequence in the event of failure" has led to some misunderstanding. For this reason, the term "risk" shall be replaced by "consequence". This is consistent with international usage. The two types of consequence classification of slope failure given in Tables 5.2 and 5.3 of the Manual shall be referred to as "consequence-to-life" and "economic consequence" respectively.
 - 2.2. The descriptive terms "high", "low" and "negligible" are intended to reflect the likely relative severity of the failure consequence, but these have also resulted in misconceptions. To avoid possible confusion, the three categories of consequence-to-life shall be denoted as Categories 1, 2 and 3 respectively instead of "high", "low" and "negligible". For the same reason, a new system is also adopted to denote the different categories of economic consequence. The three categories of economic consequence shall be denoted as Categories "A", "B" and "C" respectively instead of "high", "low" and "negligible".
 - 2.3. A combined notation shall now be used to indicate both the consequence-to-life and the economic consequence of a feature. For example, a Category 2A feature refers to one having the second highest consequence-to-life and the highest economic consequence in the new three-tier classification system.
3. **CONSEQUENCE-TO-LIFE CATEGORIES**
 - 3.1. The recommended minimum safety factors for slopes given in Tables 5.1 and 5.4 of the Manual are related to assessed consequence-to-life categories. Because of the change in terminologies (see section 2), these Tables shall be replaced by Tables 1 and 2 in this Appendix respectively. The consequence-to-life category reflects the severity in terms of loss of life in the event of failure. Table 5.2 of the Manual, which gives typical examples of each consequence-to-life category, shall be replaced by Table 3 in this Appendix.

- 3.2. In determining the consequence-to-life category of a slope, the designer should use his own professional judgement in assessing the "severity in terms of loss of life in the event of failure" in each particular case, giving due consideration to the types of buildings and facilities that may be threatened, and how the buildings and facilities would be affected in the event of slope failure. In assessing the effects of a slope failure on buildings and facilities, account should be taken of such factors as possible mechanisms and scale of failure, site conditions, proximity of the buildings and facilities to the slope and their likely density of occupation and frequency of usage in the event of failure, travel distance of the landslide debris, resistance of the buildings and facilities to debris impact and vulnerability of occupants and users.
- 3.3. Examples (1) and (2) of Table 3 refer to situations where the buildings or facilities lie within the expected travel distance of the landslide debris, and hence the severity in terms of loss of life is high, and the consequence-to-life category is "1". No examples are given in the Table on situations where the buildings or facilities are located further away from the slopes. Following the consequence-to-life definition given in the Manual, where the buildings or facilities lie beyond the expected travel distance of the debris and the severity in terms of loss of life in the event of failure is less, the consequence-to-life category may be downgraded to "2". Where the buildings or facilities lie beyond the possible extreme limit of landslide debris, the consequence-to-life category may be taken as "3". Similar considerations apply to buildings and facilities located behind the slope crest with respect to the expected and the possible extreme limits of the area affected by the landslide.
- 3.4. In consequence-to-life classification for the purposes of slope design and stability assessment, bus shelters or similar sheltered public waiting areas shall be regarded as occupied buildings (example 1 in Table 3).

4. **ECONOMIC CONSEQUENCE CATEGORIES**

- 4.1. Table 5.3 of the Manual, which gives typical examples of each economic consequence category, shall be replaced by Table 4 in this Appendix.
- 4.2. Although Table 1 recommends the minimum safety factors for slopes for different economic consequences, the choice of safety factors against economic loss is a decision which must be made by the owner upon the advice of the designer. In advising the owners, the designer should decide for himself the degree of economic consequence and should balance the potential economic consequence in the event of a failure against the increased construction costs required to achieve a higher factor of safety.

5. SAFETY FACTORS FOR EXISTING SLOPES

- 5.1. The minimum safety factors recommended in Table 2 may be used for the stability assessment of and design of modifications to any existing slope which is associated with new works, as long as rigorous geological and geotechnical investigations are conducted (which should include a thorough examination of slope maintenance history, groundwater records, rainfall records and any slope monitoring records) and there is sufficient knowledge of the geology, groundwater and performance history of the slope. Under these conditions, Table 2 can be used for stability assessment for known changes in imposed loadings, and for the design of remedial or preventive works, including slope flattening, improvements to surface and subsurface drainage, and the installation of support measures.
- 5.2. As Section 5.2.2 of the Manual indicates, the designer is able to adopt with confidence a lower factor of safety for an existing slope because he has the benefit of the performance history and other information that is not available for the design of a new slope. This does not imply that the standards of safety deemed to be acceptable for existing slopes are lower than those recommended for new slopes. Reference should be made to the attached note (see Annex 1 of this Appendix) on discussion of the philosophy of this approach by Malone (1985). There will often be instances, however, where particular circumstances (such as lack of adequate groundwater and rainfall records) will lead the designer to adopt, for remedial and preventive works, the standards specified for new slopes.

6. SAFETY FACTORS FOR TEMPORARY WORKS

- 6.1. Section 5.2.4 of the Manual shall be replaced by the following.
- 6.2. The safety factors required for the design of temporary works (i.e. works undertaken during construction which are not part of the permanent works) shall be the same as those for permanent new works (Table 1), but with due regard for the conditions which are likely to exist during the life of the temporary works. In some cases, for example, the consequence-to-life category during construction may be classified as "2" or "3", compared with consequence-to-life category "1" once the buildings are completed and occupied.

7. RELIABILITY OF SLOPE DESIGN

- 7.1. The reliability of slope design is discussed in Section 5.3.6 of the Manual and should be considered in deciding on the minimum safety factor to be adopted.

- 7.2. Different design solutions, e.g. open-cuttings and cuttings with structural support, have different levels of uncertainties associated with the various components of investigation, design and construction. They will have different reliability indices (hence different levels of safety) even if the assessed factor of safety is the same. In order to have a meaningful comparison of options, a higher minimum safety factor needs to be adopted for the solution with a lower reliability index than the solution with a higher index.

8. **COMPACTION OF NEW FILL SLOPES**

- 8.1. The design and construction of new fill slopes are governed by sections 5.5.1 and 9.5 of the Manual respectively. It should be noted that in some exceptional cases, such as fill forming a large platform that will not support structures, the requirement for a compacted density of 95% of maximum dry density (GEO, 1996b) can be relaxed to 90% for the interior of the platform. This may be done provided that the fill at formation level and the fill forming the peripheral slopes is compacted to 95% of maximum dry density for a vertical thickness of at least 1.5 metres and 3 metres respectively. Please note that Figure 9.1 of the Manual illustrates only one of many configurations which can be adopted. In any case, it is good engineering practice to provide adequate subsurface drainage to avoid build-up of groundwater pressure at the rear of the less permeable peripheral slopes.
- 8.2. Fill in reclamations, or behind retaining structures and in other small areas of flat land, does not generally need to meet compaction requirements for slope stability reasons. It is therefore for the designer to determine the compaction requirements based on other criteria.

9. **TREATMENT OF EXISTING FILL SLOPES**

- 9.1. Section 5.5.2 of the Manual defines the standard treatment of existing loose fill slopes by recompaction of the surface fill to a vertical depth of 3 metres. This treatment does not need to be prescribed, however, if :

- (a) a fill slope is of consequence-to-life category "3",
- (b) the fill slope is judged to be too small to pose a significant hazard, or

(Note. The size of a fill slope which may be regarded as "too small to pose a significant hazard" would depend on the distance to and the type of the facilities being affected, the topography of the ground below the slope, the liquefaction potential of the fill body, etc. Professional judgement should be exercised in individual cases in determining the size of a fill slope which could be considered as such.)

- (c) the fill slope has a cover of mature vegetation which is beneficial to the stability of the slope, and where there is a reasonable alternative engineering solution.

9.2. Reference should be made to the Report on the Slope Failures at Sau Mau Ping (Government of Hong Kong, 1977) for background on the standard treatment of existing fill slopes as recommended in the Manual.

10. **SUPERSEDED CHAPTERS/SECTIONS**

10.1. The following Chapters/Sections of the Manual are no longer applicable, having been superseded by later publications :

- (a) Chapter 1 and Section 2.3.3 are superseded by the Geological Survey Maps and Memoirs and Geoguide 3 (GCO, 1988).
- (b) Chapter 2 (except Section 2.3.3), Section 3.5 and 10.2 are superseded by Geoguide 2 (GCO, 1987).
- (c) Section 4.6 is superseded by GEO Publication No. 1/93 (GEO, 1993a).
- (d) Chapter 7 (except the parts relevant to the design of remedial or preventive works to existing gravity retaining walls as given in Section 7.3.3) is superseded by Geoguide 1 (GEO, 1993b), GCO Publication No. 1/90 (GCO, 1990) and GEO Circular No. 6/96 (GEO, 1996a).
- (e) Chapter 11 is superseded by Geoguide 5 (GEO, 1998).
- (f) References to BS 1377:1975 concerning Phase 1 tests described in Works Branch Technical Circular 6/94 are replaced by GEO Report No. 36 (GEO, 1996b).
- (g) "The Hong Kong Bibliography" referred to in the Manual is the Bibliography on Geology and Geotechnical Engineering of Hong Kong (Brand, 1984). This has been superseded by GEO Report No. 50 (GEO, 1996c).

11. **LIST OF RELATED DOCUMENTS**

- (a) Geotechnical Control Office (1984). Geotechnical Manual for Slopes. (Second Edition). Geotechnical Control Office, Hong Kong, 295 p.
- (b) Geotechnical Control Office (1987). Guide to Site Investigation (Geoguide 2). Geotechnical Control Office, Hong Kong, 359 p.
- (c) Geotechnical Control Office (1988). Guide to Rock and Soil Descriptions (Geoguide 3). Geotechnical Control Office, Hong Kong, 186 p.

- (d) Geotechnical Control Office (1990). Review of Design Methods for Excavations (GCO Publication No. 1/90). Geotechnical Control Office, Hong Kong, 192 p.
- (e) Geotechnical Engineering Office (1993a). Review of Granular and Geotextile Filters (GEO Publication No. 1/93). Geotechnical Engineering Office, Hong Kong, 131 p.
- (f) Geotechnical Engineering Office (1993b). Guide to Retaining Wall Design (Geoguide 1). (Second Edition). Geotechnical Engineering Office, Hong Kong, 258 p.
- (g) Geotechnical Engineering Office (1995b). Recommendations Arising from the Review of the Risk-to-life Categorisation System of the GCO (1984). Geotechnical Engineering Office, Hong Kong, GCC Paper No. 295.
- (h) Geotechnical Engineering Office (1996a). Guidelines for Assessment of Old Masonry Retaining Walls in Detailed Studies and for Action to be Taken on Private Walls. Geotechnical Engineering Office, Hong Kong, GEO Circular No. 6/96.
- (i) Geotechnical Engineering Office (1996b). Methods of Test for Soils in Hong Kong for Civil Engineering Purpose (Phase 1 Tests) (GEO Report No. 36). Geotechnical Engineering Office, Hong Kong, 90 p.
- (j) Geotechnical Engineering Office (1996c). Bibliography on the Geology and Geotechnical Engineering of Hong Kong to March 1996 (GEO Report No. 50). Geotechnical Engineering Office, Hong Kong, 111 p.
- (k) Geotechnical Engineering Office (1997). Control of Compaction of New Fill Slopes. Geotechnical Engineering Office, Hong Kong, GEO Circular No. 5.
- (l) Geotechnical Engineering Office (1998). Guide to Slope Maintenance (Geoguide 5). (Second Edition). Geotechnical Engineering Office, Hong Kong, 91 p.
- (m) Government of Hong Kong (1977). Report on the Slope Failures at Sau Mau Ping, August 1976. Hong Kong Government Printer, 104 p. plus 8 drgs.
- (n) Malone, A.W. (1985). Factor of Safety and Reliability of Design of Cuttings in Hong Kong (Oral Discussion). Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, San Francisco, vol. 5, pp 2647.
- (o) Works Branch (1994). Soil Testing Standard (Phase 1 Tests). Works Branch Technical Circular No. 6/94.

Table 1 - Recommended Minimum Factors of Safety for New Slopes for a Ten-year Return Period Rainfall

CONSEQUENCE-TO-LIFE ECONOMIC CONSEQUENCE	Category 1	Category 2	Category 3
	Category A	1.4	1.4
Category B	1.4	1.2	1.2
Category C	1.4	1.2	>1.0
<p>Notes : (1) In addition to a minimum factor of safety of 1.4 for a ten-year return period rainfall, a slope in the consequence-to-life category 1 should have a factor of safety of at least 1.1 for the predicted worst groundwater conditions.</p> <p>(2) The factors of safety given in this Table are recommended minimum values. Higher factors of safety might be warranted in particular situations in respect of loss of life and economic loss.</p>			

Table 2 - Recommended Minimum Factors of Safety for the Stability Assessment of Existing Slopes and for Design of Remedial or Preventive Works to Slopes for a Ten-year Return Period Rainfall

Consequence-to-life	Category 1	Category 2	Category 3
Recommended Minimum Factor of Safety Against Loss of Life for a Ten-year Return Period Rainfall	1.2	1.1	>1.0
<p>Notes: (1) These factors of safety are appropriate only where rigorous geological and geotechnical studies have been carried out, where the slope has been standing for a considerable time, and where the loading conditions, the groundwater regime and the basic form of the modified slope remain substantially the same as those of the existing slope.</p> <p>(2) The factors of safety given in this Table are recommended minimum values. Higher factors of safety might be warranted in particular situations in respect of loss of life and economic loss.</p> <p>(3) 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 factor of safety of 1.0 for the worst known loading and groundwater conditions.</p> <p>(4) 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.</p>			

Table 3 - Typical Examples of Slope Failures in Each Consequence-to-life Category

EXAMPLES	CONSEQUENCE-TO-LIFE ⁺		
	Category 1*	Category 2*	Category 3*
(1) Failures affecting occupied buildings (e.g. residential, educational, commercial or industrial buildings, bus shelters [#] , railway platforms).	✓		
(2) Failures affecting buildings storing dangerous goods.	✓		
(3) Failures affecting heavily used open spaces and recreational facilities (e.g. sitting-out areas, playgrounds, car parks).		✓	
(4) Failures affecting roads with high vehicular or pedestrian traffic density.		✓	
(5) Failures affecting public waiting areas (e.g. bus stops [#] , petrol stations).		✓	
(6) Failures affecting country parks and lightly used open-air recreation areas.			✓
(7) Failures affecting roads with low traffic density.			✓
(8) Failures affecting storage compounds (non-dangerous goods).			✓

× Item added in 1995 to clarify the intention of the consequence categories.

+ Prior to March 1996, "Consequence-to-life" was referred to as "Risk-to-life".

* Prior to March 1996, "Category 1", "Category 2" and "Category 3" were referred to as "High", "Low" and "Negligible" respectively.

In the context of this Table, bus shelters are those with a cover that shelters people waiting there from direct sunlight or rainfall, while bus stops are those without such a cover.

Table 4 - Typical Examples of Slope Failures in Each Economic Consequence Category

EXAMPLES	ECONOMIC CONSEQUENCE ⁺		
	Category A*	Category B*	Category C*
(1) Failures affecting buildings, which could cause excessive structural damage.	✓		
(2) Failures affecting essential services [#] which could cause loss of that service for an extended period.	✓		
(3) Failures affecting rural or urban trunk roads or roads of strategic importance.	✓		
(4) Failures affecting essential services [#] which could cause loss of that service for a short period.		✓	
(5) Failures affecting rural (A) or primary distributor roads which are not sole accesses.		✓	
(6) Failures affecting open-air car parks.			✓
(7) Failures affecting rural (B), feeder, district distributor and local distributor roads which are not sole accesses.			✓
(8) Failures affecting country parks.			✓

+ Prior to March 1996, "Economic Consequence" was referred to as "Economic Risk".

* Prior to March 1996, "Category A", "Category B" and "Category C" were referred to as "High", "Low" and "Negligible" respectively.

Essential services are those that serve a district and are with no or very inferior alternatives. Examples are mass transit facilities and trunk utility services.

ANNEX 1

FACTOR OF SAFETY AND RELIABILITY OF DESIGN OF CUTTINGS IN HONG KONG (ORAL DISCUSSION) BY MALONE (1985)

This contribution is about the stability factors of safety which are used in Hong Kong in the design calculations for cuttings in the weathered mantle of slopes.

Most landslides in cuttings occur during intense rainstorms, hence groundwater conditions assumed in stability calculations correspond to an extreme rainfall condition. Lower factors of safety are used when rarer rainfall conditions are assumed. Factor of safety is also tied to consequences of failure, the following minimum values being stipulated in the Geotechnical Manual for Slopes for the 10-year return period rainfall case (Geotechnical Control Office, 1984):

1.4	high risk to life
1.2	low risk to life
> 1.0	negligible risk to life

It is understood that the value 1.4 was chosen as this value is often used for the slopes of large earthfill dams.

The Geotechnical Manual for Slopes also makes some recommendations on the stability calculation model to be employed and the method of measurement of the input parameters for the calculation. However, this falls short of the complete specification that would be needed to guarantee a consistent standard of safety between cases with equal calculated values of factor of safety. Alternatively, standard of safety can be expressed as probability of failure, and this can, in principle, be calculated by regarding the parameters as random variables. In considering the application of probabilistic approaches to cutting design in Hong Kong conditions, it is helpful to examine the three principal sources of uncertainty in the design calculation: the selection of trial slip surfaces, groundwater conditions and shear strength.

Selection of Trial Slip Surfaces

Under Humid Subtropical climatic conditions igneous rock masses adjacent to the surface of slopes can weather to give a complex pattern of fresh corestones and matrix material in various states of decomposition. The simplification of such geological complexity into a 2-D layered model, one surface of which represents a sloping "rockhead", often results in trial slip surfaces being positioned unrealistically.

Selection of Groundwater Conditions

The phreatic surface corresponding to a design rainstorm is usually modelled at a fixed head above this imaginary sloping "rockhead" surface, or above the dry season phreatic surface if higher, without benefit of piezometric observations of storm response.

In reality a more complex hydrogeological system exists, better modelled as 2 or more interacting inclined aquifers (Geotechnical Control Office, 1982). Local

geological effects like flow in natural pipes in steep slopes, or partial occlusion by dykes, can be important, as can local leakage from water services in steeply sloping urban areas. Hence design data ought to be obtained by extrapolation of measured seasonal and storm piezometric response within the aquifer of interest at the site of the proposed cutting.

Selection of Shear Strength Parameters

The mass shear strength will depend on the disposition of core-stones, but it is conventional to rely in design on laboratory measurements of matrix shear strength. The shear strength of decomposed granite in particular will vary markedly with the state of decomposition, which ought therefore to be quantitatively defined, but rarely is. The consolidated undrained compression test with pore water pressure measurement is conventional, but this does not reproduce the stress path followed in an element of soil adjacent to a slip plane as failure is approached.

Existing Slopes and More Reliable Design

It is in the analysis of existing slopes that practice in Hong Kong has come under most scrutiny, because preventive works are often very costly and very inconvenient. It has been generally agreed that lower factors of safety may be adopted for existing slopes, whilst maintaining the same adequately low probability of failure. This can be achieved at the cost of greater reliability, as is well illustrated by the case history presented by Lambe in the First Terzaghi Oration (Lambe, 1985 fig. 21). The opportunity to adopt lower factors of safety in Hong Kong has recently been introduced for the analysis of existing cuttings which have withstood extreme rainstorms, in cases where values of the parameters in the calculation model are known more reliably. Thus, for assessment of the stability of existing slopes, seasonal and storm piezometric response can be measured in the prototype, and storm seepage and runoff observed. The actual geology can be determined in inspection trenches. Foundations of adjacent structures can be examined, input geometry can be based on topographic survey and soil densities can be measured in situ.

For design calculations which utilize this more reliable data a minimum factor of safety of 1.2 is stipulated in the Geotechnical Manual for Slopes for the high risk to life case.

References

Geotechnical Control Office (1982). Mid-levels Study: Report on Geology, Hydrology and Soil Properties. Geotechnical Control Office, Hong Kong, 265 p. plus 54 drgs.

Geotechnical Control Office (1984). Geotechnical Manual for Slopes (second edition). Geotechnical Control Office, Hong Kong, 295 p.

Lambe, T.W. (1985). The First Terzaghi Oration: Amuay landslides. Proceedings of the 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Golden Jubilee Volume, pp 137-158.

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