ASSESSMENT OF LANDSLIDE RISK OF MAN-MADE SLOPES IN HONG KONG

GEO REPORT No. 177

D.O.K. Lo & W.M. Cheung

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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R.K.S. Chan
Head, Geotechnical Engineering Office
December 2005

FOREWORD

This report presents the findings of an assessment of the global landslide risks posed by man-made slope features registered in the New Catalogue of Slopes in 2000, 2004 and 2010. Specific frequency models were derived from landslide records for each type of slopes. Up-to-date slope information was extracted from various databases for the assessment of the potential landslide consequences.

This study was carried out by Dr D.O.K. Lo and Dr W.M. Cheung of the Standards and Testing Division, with much of the data collection and analyses performed by the technical staff, Mr W.M. Leung, Mr K.Y. Wong and Mr K.C. Chan. Valuable assistance was provided by the database controllers of the then Landslip Investigation Division, the Slope Safety Division and the three District Divisions. A number of colleagues, in particular Mr H.N. Wong and Mr K.K.S. Ho, provided valuable suggestions and useful comments on the study. All contributions are gratefully acknowledged.

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents

ABSTRACT

The technique of quantitative risk assessment (QRA) has been applied to evaluate landslide risk arising from sizeable man-made slopes (both old and new) registered in the New Catalogue of Slopes. The hazard includes potential landslides from man-made slopes affecting developments as well as those affecting registered squatter structures. The study quantifies the landslide risk arising from these registered man-made slopes in years 2000, 2004 and 2010, viz. before, during and after the implementation of the 10-year (2000-2010) Landslip Preventive Measures (LPM) Project. The objective of this study is to:

(a) examine the progress made in respect of the landslide risk reduction target through the 10-year LPM Project and the enhanced maintenance programme; and

(b) facilitate the formulation of future landslide prevention and mitigation programme.

This study deals with risk to life only. Other types of risk such as economic risk and social impact have not been considered. In addition, the landslide risk attributed to natural hillsides, boulders, and disturbed terrain features has not been included in this study.

The global landslide risk assessment adopted in this study includes the determination of the landslide frequency of different slope types and analysis of the corresponding potential consequences in terms of fatalities. Specific frequency models were derived from landslide records for each group of slopes (viz. old and new slopes affecting developments as well as those affecting registered squatter structures). Within each group of features, further subdivision is carried out in respect of their nature, i.e. soil cut slopes, rock cut slopes, retaining walls, and fill slopes. The failure frequency of individual slopes has been determined on the basis of slope area rather than the number of slopes. The consequence analysis gives due consideration to the characteristics of the slope features, the proximity of the affected facilities to the slope features, the size of failure and the vulnerability of the affected facilities.

The risk assessment results indicate that the existing slope safety system, in particular the 10-year LPM Project, has been effective in reducing landslide risk associated with man-made slopes in Hong Kong. Upon completion of the Project in 2010, it is estimated that the landslide risk arising from old man-made slopes will be reduced to below 25% of the level in 1977. However, given the uncertainties of the risk estimation arising from the assumptions made, a separate risk assessment should be conducted at a later stage to ascertain the risk level of old slopes in year 2010. An estimate of the risk proportion associated with different groups of slopes in 2010 has also been made.

Table of Contents
Table of Contents
Table of Contents

CONTENTS

Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents

1. INTRODUCTION

Global quantitative risk assessment (QRA) studies were carried out on old man-made slopes[1] in 1996 (DNV Technica, 1996) and in 2000 (Cheung & Shiu, 2000). In 1998, the Administration pledged that all the high-priority (referred to as "high-consequence" at that time) old man-made slopes affecting major developments, squatters and major roads would be dealt with between 2000 and 2010 via the following:

(a) upgrade 2,500 substandard government slopes and carry out safety-screening studies of 3,000 private slopes under the 10-year (2000 - 2010) LPM Project;

(b) take integrated action under government development projects to rectify substandard government slopes;

(c) clear squatter structures threatened by vulnerable government slopes under the Non-Development Clearance (NDC) Programme; and

(d) improve, as far as practicable, the stability of the remaining high-priority government slopes, which do not urgently require full-scale upgrading works[2], through the use of prescriptive measures[3] under the enhanced maintenance programme (EMP).

It was projected that by 2010, the overall landslide risk of old man-made slopes would have been reduced to below 25% of that which existed in 1977.

The 10-year LPM Project was launched in 2000. This study is a comprehensive evaluation of landslide risk of all sizeable man-made slopes (both old, i.e. pre-1977, and new, i.e. post-1977) registered in the New Catalogue of Slopes. QRA methodology has been used in the evaluation. The hazard includes potential landslides from all man-made slopes affecting developments as well as those affecting registered squatter structures[4]. The study quantifies the landslide risk arising from these registered man-made slopes in years 2000, 2004 and 2010, viz. before, during and after the implementation of the 10-year LPM Project. The objective is :

(a) to examine the progress made in respect of the landslide risk reduction target through the LPM Project and the EMP as pledged; and

(b) to facilitate the formulation of future landslide prevention and mitigation programme.

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1 'Old' man-made slopes in the present context refer to pre-1977 man-made slopes that have not been upgraded or otherwise discharged by the LPM Programme as not needing further works.

2 Upgrading works are large-scale engineering works to bring substandard slopes to the current safety standards.

3 Prescriptive measures are simple slope improvement works, using standardized and empirical engineering modules, to reduce the rate of slope deterioration and enhance slope safety (Wong et al, 1999).

4 Structures covered by the Housing Department's Squatter Control Survey conducted in 1982.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

The landslide risk results presented in this Report focus only on risk to life, which is expressed in terms of Potential Loss of Life (PLL). Other types of risk such as economic risk and social impact have not been considered. Moreover, the landslide risk attributed to natural hillsides, boulders, and disturbed terrain features has not been included in this study; this is the subject of a parallel study reported by Wong et al (2004).

2. SOURCES OF INFORMATION USED IN THE LANDSLIDE RISK ASSESSMENT

Information obtained from the following sources has been extracted for the study:

(a) Slope Information System (SIS);

(b) Landslip Preventive Measures Information System (LPMIS);

(c) Dangerous Hillside Orders and Advisory Letters Database System (DADS);

(d) District Works Information System (DWIS);

(e) Slope status review conducted by the District Divisions;

(f) GEO Landslide Database; and

(g) Report on QRA of landslides affecting squatters (Fugro, 2004).

Brief description of the information available from each source is given in Appendix A.

3. ASSUMPTIONS MADE IN THE LANDSLIDE RISK ASSESSMENT

The following assumptions have been made in the landslide risk assessment:

(a) The number of old and new slopes is estimated on the basis of the slope classification that has been established through the "Systematic Identification of Features in the Territory (SIFT)" project. In the SIFT project, registered man-made slopes are classified into five classes, viz. Classes A, B1, B2, C1 and C2. Definition of each class is given in Appendix B. Slopes assigned with SIFT Classes A, B1 or C1 correspond to old slopes, i.e. slopes formed before 30 June 1978. Slopes with SIFT Classes B2 or C2 as well as those that have been indicated by the LPMIS or DADS to be either upgraded under the LPM Programme or works having been carried out by private owners to discharge Dangerous Hillside Order (DHO) served on them correspond to new slopes.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

(b) There has been a growing popularity in the use of soil nails in upgrading cut slopes since the early 1990s. Soil nailing is recognised as a more robust and reliable scheme than cutting back in that the scheme is more resilient to local geological defects. In cases where inherent adverse geological feature or adverse hydrogeological condition is not recognised or properly dealt with, the safety margin provided by the design factor of safety in an unsupported cut will probably not be able to prevent a slope failure. On the other hand, soil nails can more effectively arrest instability due to unforeseen local adverse geological weakness and hydrogeological conditions. This is supported by the observation that soil-nailed slopes have been performing well so far and there has not been any failure of permanent soil-nailed slopes to date. In view of the difference in observed performance of soil-nailed cut slopes and other new unsupported cut slopes, the frequency of major failure of new soil cut slopes has been apportioned on the basis that new unsupported soil cut slopes are ten times more susceptible to failure than soil-nailed cut slopes. This apportionment was based on judgement giving due consideration to geotechnical principles and the landslip data. Information has been extracted from DWIS and LPMIS to estimate the number of soil-nailed cut slopes formed to date.

(c) Systematic landslide investigations in recent years have indicated that apart from the old slopes, other categories of slopes also deserve attention. These include slopes formed after 1977 but which had not been subject to geotechnical control, e.g. those formed in association with New Territories Exempted House (NTEH) before the enactment of the Building Ordinance (Application to New Territories) Cap 121 in 1987 because they were exempted from geotechnical control. Moreover, some new slopes may not have been checked by the GEO. A recent review conducted by the District Divisions indicates that the checking records of some new slopes in urban area could not be found in the GEO. While this does not imply that these slopes have not been checked by the GEO or that they were not up to standard, this could suggest that the estimated risk for new slopes might have been underestimated. The design and construction of some slope types have advanced considerably when compared to that in the 1970s and 1980s. This includes the use of more robust measures in slope stabilisation, e.g. the use of soil nailing in stabilising soil cut slopes and installation of wire meshes over rock slopes to minimise rockfall hazards.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

There are slopes formed between the late 1970s and the early 1980s, in particular soil cut slopes, which may have adopted different design standards when compared with the ones currently used. The designs of some of these features may have critically relied on the use of soil suction in providing slope stability or use of back-analysed soil strength parameters in design, the concept of which has become outdated in light of the advance in geotechnical knowledge. In view of this consideration, these slopes are collectively referred to as 'old technology' slopes. It is estimated that there are about 7,500 slopes in this category. The failure frequency of the old slopes has been adopted for this category of slopes.

(d) In the 10-year LPM Project, 2,500 substandard government features will be upgraded and safety-screening of 3,000 private features will be carried out. Over the same period, the stability of the remaining high-priority (Consequence-to-life (CTL) Category 1) government slopes will be improved through the use of prescriptive measures under the EMP. Details of the CTL Category classification system and the definitions of different types of prescriptive measures are given in Appendices C and D respectively.

(e) Old government slopes to be selected for LPM action will be those in CTL Categories 1 or 2 with Combined New Priority Classification System (CNPCS) score equal to or exceeding 8. A brief description of the CNPCS is given in Appendix E.

(f) Old private slopes to be selected for safety-screening will be those in CTL Category 1 with CNPCS score equal to or exceeding 3.

(g) For the purpose of risk assessment, it is assumed that all safety-screened old private slopes will be dealt with by year 2010. The failure frequency for new slopes has been adopted for these slopes.

(h) All old government slopes of CTL Category 1 that have not been selected for LPM action will be improved using prescriptive measures, e.g. Type 3 (structural support) or equivalent except for those small slopes with height less than 6 m and CNPCS score of less than 3 where only Types 1 & 2 works (surface protection and subsurface drainage) have been assumed.

(i) Slopes implemented with Type 3 prescriptive measures or equivalent are assumed to perform very much like the new

Table of Contents
Table of Contents
Table of Contents
Table of Contents

slopes.

(j) Based on the study by Wong & Ho (1995), it is assumed that the probability of failure of an old slope would be halved after the implementation of Types 1 or 2 prescriptive measures. Key findings of the study in respective to the use of prescriptive measures are summarised in Appendix F.

(k) All soil cut slopes selected for action in the 10-year LPM Project will be stabilised using soil nails.

(l) The consequences of failure of all old and new slopes in 2010 remain broadly similar to those in 2004.

(m) Slopes are maintained in accordance with the requirement of Geoguide 5 (GEO, 2003), and the conditions of slopes will not deteriorate with time. The same set of failure models is adopted for assessing landslide risk of slopes in 2000, 2004 and 2010.

4. METHODOLOGY

4.1 Failure Frequency Model

The failure frequency model adopted in this study is akin to that of the previous QRA on old man-made slopes (DNV Technica, 1996; Cheung & Shiu, 2000). Improvement was made to the frequency model to apportion the failure frequency based on slope area rather than the number of slopes. This improvement is reasonable as large slopes should be more susceptible to defects than small slopes.

Specific frequency models were derived from landslide records for each group of slopes (viz. old and new slopes affecting developments as well as those affecting registered squatter structures). Within each group of features, further subdivision is carried out in respect of their nature, i.e. soil cut slopes, rock cut slopes, retaining walls, and fill slopes. Landslide incident records between 1984 and 2003 were used to formulate the failure frequency models for old slopes affecting developments as well as that for old slopes affecting registered squatter structures in 2004. Similarly, records on landslide incidents between 1997 and 2003 occurred at features that are up to current safety standards were used to formulate the failure frequency models for new slopes in 2004. The failure frequencies for new soil cut slopes are apportioned based on the assumptions given in Section 3(b) to derive the failure frequencies for new unsupported cut slopes and soil-nailed cut slopes. The failure frequency models of these slopes in 2004 are then used as a basis to generate those for other years according to the surface area of individual features in that particular year. The failure frequencies for old and new slopes in 2004 are given in Appendix G.

4.2 Consequence Model

The landslide consequence model proposed by Wong et al (1997) has been adopted in

Table of Contents
Table of Contents
Table of Contents
Table of Contents

this study. In this model, consideration has been given to the consequence of a reference landslide of a prescribed size directly affecting a given type of facility located at the worst possible spot assuming occupation of the facility under average conditions. The consequence is then scaled with respect to the size of the actual failure relative to that of the reference landslide and the vulnerability of the facility given its actual location relative to the zone of the landslide. A reference landslide is defined as a 10-m wide failure with a volume of 50 m^3. The expected number of fatalities for different types of facilities has been determined from past statistics, observation and judgement. For the vulnerability of different facilities, a vulnerability factor, which is defined as the probability of loss of life, has been determined with due consideration of (i) the nature, proximity and spatial distribution of the facilities, (ii) mobility of debris and likely extent of the upslope influence zone, (iii) scale of failure, and (iv) degree of protection offered to persons by the facility.

Details of the consequence model including the expected number of fatalities of a reference landslide, distribution of landslide debris volume, the values of vulnerability factor for different types of facilities, and the distribution of width of landslides are tabled in Appendix H.

4.3 Estimation of Landslide Risk

The global landslide risk for man-made slopes is determined by the summation of the products of failure frequency and the respective consequences for all classes of slope features. A worked example demonstrating the method for calculating the landslide risk for an old soil cut slope is given in Appendix I.

5. ANALYSIS AND RESULTS

5.1 Landslide Risk in 2004

Landslide risk assessment was carried out for about 55,500 man-made slopes, which have sufficient data for analysis. Out of them, there are about 30,900 old and 21,000 new man-made slopes affecting developments, and 3,600 old slopes affecting registered squatter structures. The results of the assessment are as follow:

(a) The landslide risk in terms of potential loss of life (PLL in a year) attributed to old slopes affecting developments is 5.9 (70% from CTL Category 1 slopes, 29% from CTL Category 2 slopes and 1% from CLT Category 3 slopes).

(b) The landslide risk (PLL in a year) attributed to old slopes affecting registered squatter structures is 1.1.

(c) The landslide risk (PLL in a year) attributed to new slopes affecting developments is 2.7 (74% from slopes treated by 'old technology' and 26% from slopes treated by robust measures).

The total landslide risk (PLL in a year) attributed to all categories of slopes is 9.7 (i.e.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

5.9 + 1.1 + 2.7).

5.2 Landslide Risk in 2000

Between 2000 and 2004, about 1,400 old slopes have been either upgraded under LPM Project or through development projects, or have their stability enhanced through EMP. As such, it was estimated that, in 2000, there were about 32,300 old slopes affecting developments and 19,600 new slopes. The results of the assessment are as follows:

(a) The landslide risk (PLL in a year) attributed to the old slopes affecting developments is 7.9 (72% from CTL Category 1 slopes, 27% from CTL Category 2 slopes and 1% from CLT Category 3 slopes).

(b) The landslide risk (PLL in a year) attributed to old slopes affecting squatter structures is 1.1 (presuming that the conditions and settings of these old slopes remain broadly similar to that in 2004, the associated landslide risk would have been the same as that in 2004).

(c) The landslide risk (PLL in a year) attributed to new slopes affecting developments is 2.5 (80% from slopes treated by 'old technology' and 20% from slopes treated by robust measures).

The total landslide risk (PLL in a year) attributed to all categories of slopes is 11.5 (i.e. 7.9 + 1.1 + 2.5).

5.3 Landslide Risk in 2010

Upon completion of the 10-year LPM Project and the EMP in 2010, it is anticipated that the number of old slopes will reduce to about 24,300 (among which about 2,000 CTL Category 1 government slopes would have been treated by Type 1 or 2 prescriptive measures through EMP), and the number of new slopes will increase to 27,600 (among which about 5,500 slopes would have been treated by the LPM Project and about 2,500 government slopes would have been treated by Type 3 prescriptive measures or equivalent through the EMP. The results of the assessment are as follows:

(a) The landslide risk (PLL in a year) attributed to old slopes affecting developments will be about 1.7 (6% from CTL Category 1 slopes, 88% from CTL Category 2 slopes and 6% from CLT Category 3 slopes).

(b) The landslide risk (PLL in a year) attributed to old slopes affecting squatter structures will be 1.1 (presuming that the conditions and settings of these old slopes remain broadly similar to that in 2004, the associated landslide risk will

Table of Contents
Table of Contents
Table of Contents
Table of Contents

remain the same as that in 2004).

(c) The landslide risk (PLL in a year) attributed to new slopes affecting developments will be about 2.8 (71% from slopes treated by ‘old technology’ and 29% from slopes treated by robust measures).

The total landslide risk (PLL in a year) attributed to all categories of slopes will be 5.6 (i.e. 1.7 + 1.1 + 2.8).

5.4. Discussion

As indicated by the risk profiles, it is estimated that the landslide risk (PLL in a year) arising from old slopes affecting developments would be reduced from about 7.9 in year 2000 (see Section 5.2) to about 1.7 in year 2010 (see Section 5.3) through the 10-year LPM Project and the EMP using Type 3 prescriptive measures or the equivalent. Among the risk reduction (PLL in a year) of 6.2 (i.e. 7.9 - 1.7), 5.3 is contributed by the 10-year LPM Project and the remaining 0.9 is contributed by the EMP using Type 3 prescriptive measures or the equivalent. Furthermore, out of the risk reduction of 5.3 attributed to the 10-year LPM Project, 3.5 is contributed by the upgrading of 2,500 substandard government slopes and the remaining 1.8 is contributed by the safety-screened 3,000 private slopes and the carrying out of the required upgrading works by private slope owners. It is anticipated that the Slope Safety Pledge made in respect of landslide risk reduction can be met through the 10-year LPM Project alone.

The risk assessment in this study involves a number of uncertainties. Although many of these uncertainties cannot be measured or quantified, they should be borne in mind when interpreting the estimated risk levels. The following are a list of uncertainties:

(a) The number of old and new slopes is primarily estimated on the basis of SIFT classification, and the information from LPMIS and DADS. The results of the study depend on the accuracy of the information provided by these sources. Similarly, the estimation of the number of “old technology” slopes is constrained by the accuracy of the data sources.

(b) Due to the lack of historical failure data of soil-nailed slopes, the respective failure frequency model has to be established by judgement. This uncertainty also applies to the failure frequency model for those slopes treated by Types 1 or 2 prescriptive measures.

(c) Although the failure frequency model has been improved to reflect the fact that the likelihood of failure is related to slope surface area, the assumption that the failure probability is linearly proportional to slope surface area may introduce uncertainty in the risk assessment.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

(d) The estimated risk level in 2010 depends on the progress of the 10-year LPM Project and the EMP in the coming years including the discharge of Dangerous Hillside Orders served on private slopes.

Assessment of landslide risk of natural hillside (Wong et al, 2004) indicates that the order of the overall risks associated with natural hillside will be comparable to that with man-made slopes by 2010. In other words, man-made slopes will contribute about half of the overall landslide risk. The risk proportion associated with different groups of man-made slopes in 2010, rounded to the nearest 5%, is given in Table 1.

6. COST-BENEFIT ANALYSIS

A cost-benefit analysis for slope upgrading works beyond 2010 has been carried out. The risk distribution among individual slopes is not uniform. Summary of the risk distribution is shown in Appendix J. With reference to the risk distribution, the top 1,500 slopes with the highest proportion of risk (mainly new slopes treated by 'old technology' affecting developments, old slopes affecting developments (CTL Category 2), and old slopes affecting registered squatter structures) constitute about 30% of the total risk arising from man-made slopes. By assessing the cost of upgrading these slopes and the corresponding reduction in landslide risk, the result of the analysis indicates that it will cost about $18 M to $22 M to save a life. Details of the analysis are given in Appendix J.

7. CONCLUSIONS

The existing slope safety system, in particular the 10-year LPM Project, has been effective in reducing landslide risk associated with man-made slopes in Hong Kong. Upon completion of the Project in 2010, it is estimated that the landslide risk arising from the untreated old slopes will be reduced to below 25% of the level in 1977. However, given the uncertainties of the risk estimation arising from the assumptions made, a separate risk assessment should be conducted at a later stage to ascertain the risk level of old slopes in year 2010.

An estimate of the risk proportion associated with different groups of slopes in 2010 has also been made.

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF TABLES

Table of Contents
Table of Contents
Table of Contents

Table 1 - Risk Profile for All Man-made Slopes in 2010

Slope Category		Proportion of Total Risk (%)
New slopes treated by 'old technology' affecting developments		20
New slopes treated by robust measures affecting developments		5
Old slopes affecting developments	CTL Category 1	< 1
	CTL Category 2	15
	CTL Category 3	< 1
Old slopes affecting registered squatter structures		10
Note: Natural hillsides (including natural terrain catchments, boulder fall hazards and disturbed terrain features) contribute the remaining of the total landslide risk.		

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX A

BRIEF DESCRIPTION OF INFORMATION SOURCES

A.1 GENERAL

Information from various sources as tabulated in the following sections has been available for the landslide risk assessment.

A.2 SLOPE INFORMATION SYSTEM (SIS)

Information	Field Name
Feature number	FEATURE
Location	LOCATION
Northing (m)	NORTH
Easting (m)	EAST
Toe elevation of slope (mPD)	TOE_ELV
Consequence category	CONSEQ_CAT
Distance between toe facility and slope toe	TOE_DIST
Type of toe facility	TOE_TYPE
Distance between crest facility and slope crest	CREST_DIST
Type of crest facility	CREST_TYPE
SIFT class	SIFT_CLASS
Combined New Priority Classification System score	CNPCS
Maintenance responsibility	MR
Slope material	SF_MAT
Slope geology	SF_GEOLOGY
Slope height (m)	SF_HEIGHT
Slope length (m)	SF_LENGTH
Slope angle (degree)	SF_ANGLE
No. of slope berm	SF_BERM
Berm width (m)	SF_BERMW
Wall material type	WF_TYPE
Wall height (m)	WF_HEIGHT
Wall length (m)	WF_LENGTH
Wall angle (degree)	WF_ANGLE

Table of Contents
Table of Contents
Table of Contents
Table of Contents

A.3 LANDSLIP PREVENTIVE MEASURES INFORMATION SYSTEM (LPMIS)

Information	Field Name
Feature number	SLOPE_NUM
Easting (m)	EASTING
Northing (m)	NORTHING
Location	LOCATION
Consultancy agreement no.	AGREEMENT
Study type	STUDY_TYPE
Report no.	REPORT_NO
Date of study completion	END_STUDY
Status of submission (report submitted or not)	STATUS_STD
Recommendation	RECOM
Contract no.	CONTRACT
Status of works	STATUS_WKS
Date of commencement of works	START_WORK
Date of completion of works	END_WORKS
Drawing no.	DWG_NO
Memo no.	MM_NO
Type of works	TYPE_WORK

Table of Contents
Table of Contents
Table of Contents
Table of Contents

A.4 DANGEROUS HILLSIDE ORDERS AND ADVISORY LETTERS DATABASE SYSTEM (DADS), DISTRICT WORKS INFORMATION SYSTEM (DWIS), AND SLOPE STATUS REVIEW

Information	Field Name
Feature number	FEATURE
Dangerous Hillside Order (DHO) no.	DH_ORDER
Feature location	LOCATION
Date of issue of DHO	DATE_OF_ISSUE
GEO case reference no.	CASE_REFERENCE
Status of order (e.g. complied, in force, etc)	STATUS_OF_ORDER
Status of works (e.g. completed, not commenced, etc)	STATUS_OF_WORKS
File identity no.	FILE_ID
Location	TITLE
Engineer's name	FK_GE
Last update date	LASTUPDATEDATE
Section reference	FK_RIS
Section name	FK_SECTION
Description (e.g. comments, advice)	DESCRIPTION
Checking status	FK_CHECKING_STATUS
Responsible government department	FK_GOVT_PARTY

Table of Contents
Table of Contents
Table of Contents
Table of Contents

A.5 GEO LANDSLIDE DATABASE

Information	Item no.
Incident no.	1
Feature no.	2
Location	3
Easting (m)	4
Northing (m)	5
Map scale	6
Date of report	7
Time of report	8
Date of inspection	9
Date of failure	10
Failure type	11
Feature type	12
Material and mass	13
Volume (m^3)	14
Feature condition	15
Contributing causes of failure	16
Consequence of failure	17
Immediate advice given	18
Further action	19
Landslip card	20
District action required	21
GEO comments	22

Table of Contents
Table of Contents
Table of Contents
Table of Contents

A.6 REPORT ON QRA OF LANDSLIDE AFFECTING SQUATTERS (FUGRO, 2004)

Fugro (Hong Kong) Limited (2004) reported a QRA of landslides affecting squatter dwellings in Hong Kong. As part of the assignment, information on man-made slopes and squatter dwellings was collected. Table A1 shows the system adopted by Fugro (Hong Kong) Limited for classification of slope features according to the maintenance responsibility of the slopes and the land status of affected squatter dwellings.

For landslide risk assessment, Fugro (Hong Kong) Limited has developed a fairly sophisticated landslide consequence model such that the distribution of individual risk to the most vulnerable person posed by different category of slopes affecting squatter dwellings can be determined. In comparison, the landslide consequence model developed by Wong et al (1997) is a generalized model, which is applicable to all categories of slopes. In the present study, the risk due to slope features of government and mixed maintenance responsibility has been recalculated using the consequence model of Wong et al (1997) for consistency.

A.6.1 REFERENCES

Fugro (Hong Kong) Limited. (2004). Quantitative Risk Assessment of Landslides Affecting Squatters - Report for Final Study. Report prepared for the Geotechnical Engineering Office, Hong Kong.

Wong, H.N., Ho, K.K.S. and Chan, Y.C. (1997). Assessment of consequence of landslides. Proceedings of the Landslide Risk Workshop, IUGS Working Group on Landslides, Honolulu, pp. 111-149.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table A1 - Classification of Slope Features According to Maintenance Responsibility of the Slope Features and Land Status of the Affected Dwellings

Maintenance Responsibility (MR) of Slope Features	Land Status of Affected Squatter Dwellings		Private Slope Features (1)	Licence Slope Feature (2)	Government & Mixed MR Slope Features (3)
Slope Features with Government MR	1.	Government Land (solely)			✓
	2.	Licensed Land (solely) (i.e. land covered by a short term licence/permit)		✓	
	3.	Private Land (solely)			✓
	4.	Govt. + Licensed Lands (mixed)		✓	
	5.	Govt. + Private Lands (mixed)			✓
	6.	Govt. + Licensed + Private Lands (mixed)		✓	
	7.	Licensed + Private Lands (mixed)		✓	
Slope Features with Mixed Government and Private MR	8.	Government Land (solely)			✓
	9.	Licensed Land (solely) (i.e. land covered by a short term licence/permit)		✓	
	10.	Private Land (solely)			✓
	11.	Govt. + Licensed Lands (mixed)		✓	
	12.	Govt. + Private Lands (mixed)			✓
	13.	Govt. + Licensed + Private Lands (mixed)		✓	
	14.	Licensed + Private Lands (mixed)		✓	
Slope with Private MR	15.	Any Land Status	✓		

Notes:
(1) Private slope features are those slope features for which the MR lies with private parties.
(2) Licence slope features are those slope features which affect squatter dwellings on licensed/permit lands, including any mixed dwellings with part status of licence, but excluding those dwellings affected by slope features with private MR.
(3) Government or mixed MR slope features are those slope features which are not private nor licence features.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents

Table of Contents

APPENDIX B

DEFINITION OF SIFT CLASSES

Table of Contents

Table of Contents

Table B1 - SIFT Classification of Slope Features

Class	Classification Criteria
A	Fill feature considered to have similar circumstances to the Baguio Villas landslide site
B1	Fill feature assumed not to have been checked by GEO (formed pre-1978 or illegally tipped fill)
B2	Fill feature assumed to have been checked by GEO (formed post-1978) or Housing Department, or studied to Stage 2 or equivalent
C1	Cut feature formed pre-1978 or illegally formed
C2	Cut feature formed post-1978
Note: SIFT is the acronym of Systematic Identification of Features in the Territory	

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX C

CONSEQUENCE-TO-LIFE CLASSIFICATION SYSTEM

C.1 GENERAL

The consequence-to-life (CTL) category reflects the severity in terms of loss of life in the event of failure. Typical examples of each CTL category are given in WBTC No. 13/99 (Works Bureau, 1999) and are reproduced in Table C1.

In determining the consequence-to-life category of a slope, one 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 landslip debris, resistance of the buildings and facilities to debris impact and vulnerability of occupants and users. Detailed guidelines are given in GEO Technical Guidance Note No. 15 (GEO, 2004).

C.2 PROXIMITY OF FACILITIES AT SLOPE TOE AND TRAVEL DISTANCE OF LANDSLIDE DEBRIS

An assessment of whether a facility would be within or beyond the travel distance of landslide debris, and hence downgrading or upgrading of the CTL category, can be made by comparing the shadow angle of the slope feature with respect to the facility with the travel angle of debris (see Figure C1). The shadow angle of the slope feature is the angle between the horizontal and a line drawn from the nearest point of the facility affected to the point (generally the crest of the slope feature) on the slope feature that gives a clear line of sight and maximum obliquity. The travel angle of debris is the angle between the horizontal and a line joining the crest of the landslide scarp to the distal end of the debris. A reasonable estimate of the potential debris travel distance can be made by projecting the travel angle from a point (normally the crest of the slope feature) on the slope feature that can give a clear line of sight to the toe facility and yields the farthest debris travel distance, instead of projecting from the crest of an assumed failure scarp. The travel angle concept provides a reasonable prediction of debris travel distance for man-made slope features where the downslope gradient is fairly flat.

Figure C1 shows the relationship between the travel angle and volume of landslide debris for some slope failures in Hong Kong. The travel angle of debris varies with the nature of the slope-forming material, and the mechanism and scale of failure. The data in Figure C1 include landslides in soil cut slopes, rock cut slopes, fill slopes and retaining walls. By reference to Figure C1, a suitably conservative estimate of the expected and possible extreme travel distance of the landslide debris can be made as follows:

Type of Feature	Travel Angle for Estimation of the Expected Travel Distance of Landslide Debris	
	Debris Volume ≤ 300 m^3	Debris Volume > 300 m^3
Cut Slopes and Retaining Walls	35°	25°
Fill Slopes	25°	15°

Table of Contents Table of Contents Table of Contents Table of Contents

Type of Feature	Travel Angle for Estimation of the Possible Extreme Travel Distance of Landslide Debris	
	Debris Volume ≤ 300 m^3	Debris Volume > 300m^3
Cut Slopes and Retaining Walls	30°	20°
Fill Slopes	20°	10°

The scale of failure depends on, among other things, the height of the slope feature. Past failure records (see Figure C2) indicate that those with volume of more than 300 m^3 mostly occurred in slope features with height greater than 10 m.

For high slope features (e.g. slope features higher than 15 m), users and occupants of facilities which lie outside the expected travel distance of debris could still be vulnerable to casualty from potential large-scale failures. When dealing with high slope features, extreme care should be exercised in assessing the consequence of failure before it is decided to downgrade the CTL category of the slope feature.

For gentle cut slopes whose gradient is less than the above recommended travel angles, the consideration of the expected travel distance of debris by means of travel angle alone may not be adequate in assessing their CTL category for cases where the feature can give rise to large failures and the toe facility lies very close to the feature. Under such circumstances, it is prudent to consider the presence of an adequate buffer space at the toe to accommodate debris before the CTL category can be downgraded (e.g. a 3 m wide buffer zone in front of a 10 m high cut slope is generally considered adequate).

In some cases, the height of a feature may vary along its length and the location of the affected facility may not coincide with the maximum feature height. Under such circumstances, the assessment of the CTL category for the feature should take account of the likely failure scenarios, site conditions and characteristics of that part of slope where debris from it could reach the facility. Where several facilities exist, the potential consequence of failure in relation to each facility should be assessed to determine which facility could give rise to the most severe consequence.

C.3 PROXIMITY OF FACILITIES AT THE FEATURE CREST AND EXTENT OF FAILURE

The back scarp of a failure may extend beyond the crest of the slope feature thereby affecting the crest facility. Figure C3 shows the relationship between the crest influence zone (see Figure C1 for definition) and landslide volume. The extent of the crest influence zone has been normalised with respect to the slope height. The accuracy of the information of the crest influence zone may have been hampered in some cases where the original feature profile prior to failure was not reliably known at the time of landslip inspection. Nevertheless, it is adequately conservative to assume that the expected crest influence zone is not larger than 0.4 times the slope height. For the extreme limit of the crest influence zone, it can be taken as the slope height.

In assessing the effects of landslides on building located at the crest, the nature of the

Table of Contents
Table of Contents
Table of Contents
Table of Contents

building's foundation should also be taken into account. For example, the degree of damage to a building founded on piles is expected to be small if its foundation does not rely on the slope feature for stability. In such a case, the CTL category may still be downgraded even if the building lies within the expected crest influence zone of the landslide.

C.4 SCALE OF FAILURE

Landslides from small soil cut slopes, fill slopes and retaining walls are generally of small failure volume and are unlikely to cause severe damage to substantial structures. Hence, when a slope feature is small and in the judgement of the inspecting engineer, the toe facilities are structures that have sufficient structural strength to withstand debris impact without collapse, and that casualties due to intrusion of debris through openings such as windows or doors are unlikely, the CTL category of the feature may be downgraded by one category following the guidance in Works Bureau (1999). Figure C2 shows that the failure volume of landslides on slope features with a height of 4 m or less have all been less than 50 m^3. Based on these data, a reasonably conservative assumption of a small slope feature is one that is not higher than 4 m.

A small piece of falling rock could cause severe injury or fatalities. As such, the above principle is not applicable to rock slopes and soil cut slopes with potential boulder fall or fall of rock blocks.

In the event where steep natural terrain locates above the feature crest, due consideration should be given to the potential for large failures in the assessment of the CTL category. Each case should be judged on its own merits.

C.5 REFERENCES

GEO (2004). Guidelines for Classification of Consequence-to-Life Category for Slope Features (GEO Technical Guidance Note No. 15). Geotechnical Engineering Office, Hong Kong.

Works Bureau (1999). Geotechnical Manual for Slopes Guidance on Interpretation and Updating (Works Bureau Technical Circular No. 13/99). Works Bureau, Hong Kong.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table C1 - Typical Examples of Facilities Affected by Landslides in Each Consequence-to-Life Category

Group	Facilities	Consequence-to-life Category[1]
1	(a) Heavily Used Buildings - residential building, commercial office, store and shop, hotel, factory, school, power station, ambulance depot, market, hospital, polyclinic, clinic, welfare centre	1
	(b) Others - bus shelter, railway platform and other sheltered public waiting area - cottage, licensed and squatter area - dangerous goods storage site (e.g. petrol stations) - road with very heavy vehicular or pedestrian traffic density	
2	(a) Lightly Used Buildings - indoor car park, building within barracks, abattoir incinerator, indoor games' sport hall, sewage treatment plant, refuse transfer station, church, temple, monastery, civic centre, manned substation	
	(b) Others - road with heavy vehicular or pedestrian traffic density - major infrastructure facility (e.g. railway, tramway, flyover, subway, tunnel portal, service reservoir) - construction site (if future use not certain)	2
3	- heavily used open space and public waiting area (e.g. heavily used playground, open car park, heavily used sitting out area, horticulture garden) - road with moderate vehicular or pedestrian traffic density	
4	- lightly-used open-air recreation area (e.g. district open space, lightly used playground, cemetery, columbarium - non-dangerous goods storage site - road with low vehicular or pedestrian traffic density	3
5	- remote area (e.g. country park, undeveloped green belt, abandoned quarry) - road with very low vehicular or pedestrian traffic density	

Note: (1) The consequence-to-life category refers to situation where the facilities are located within the expected travel distance of landslide debris. Any indirect consequences should also be taken into consideration, e.g. debris falling into a catchwater can travel long distance and affect other facilities.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

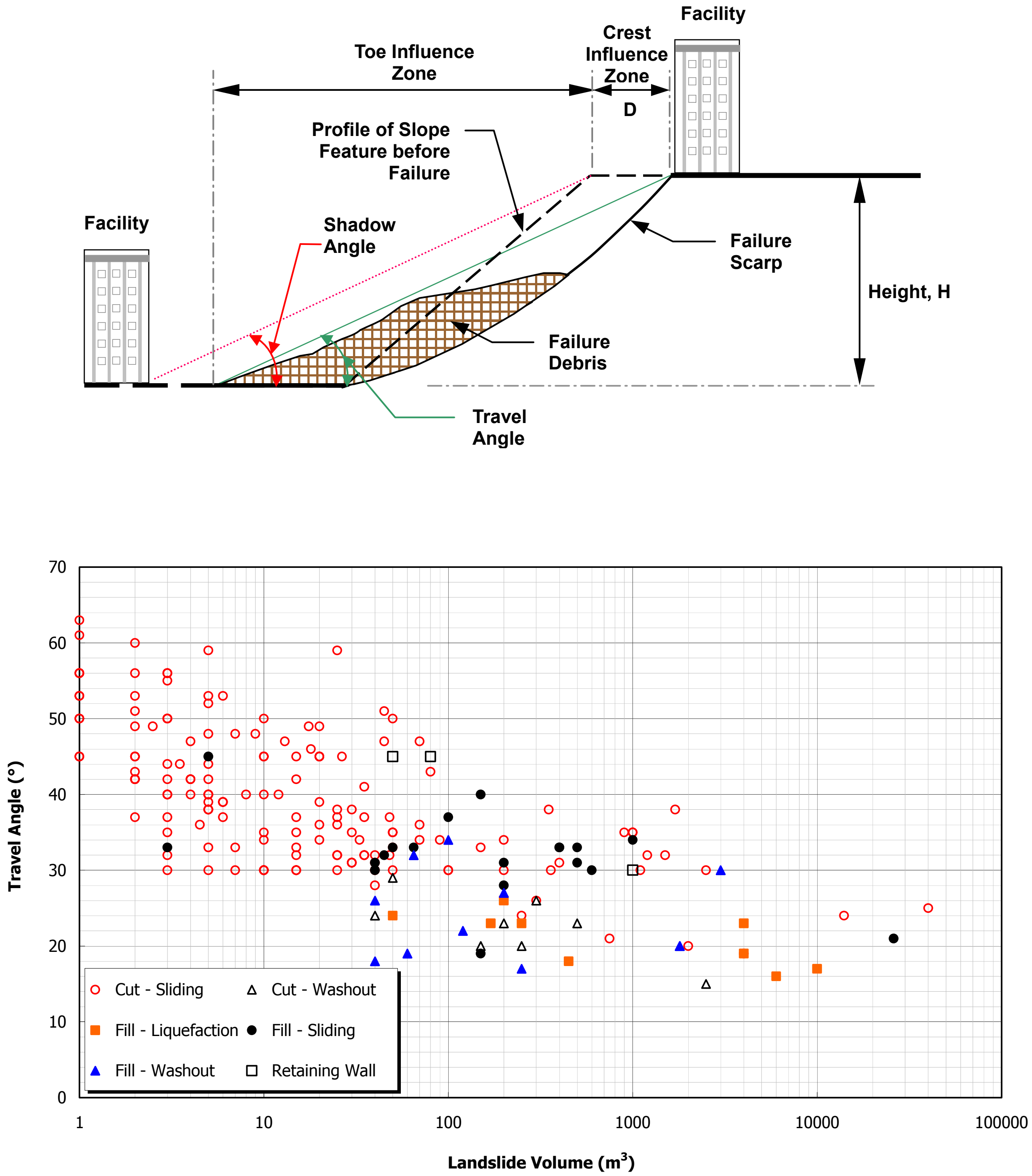
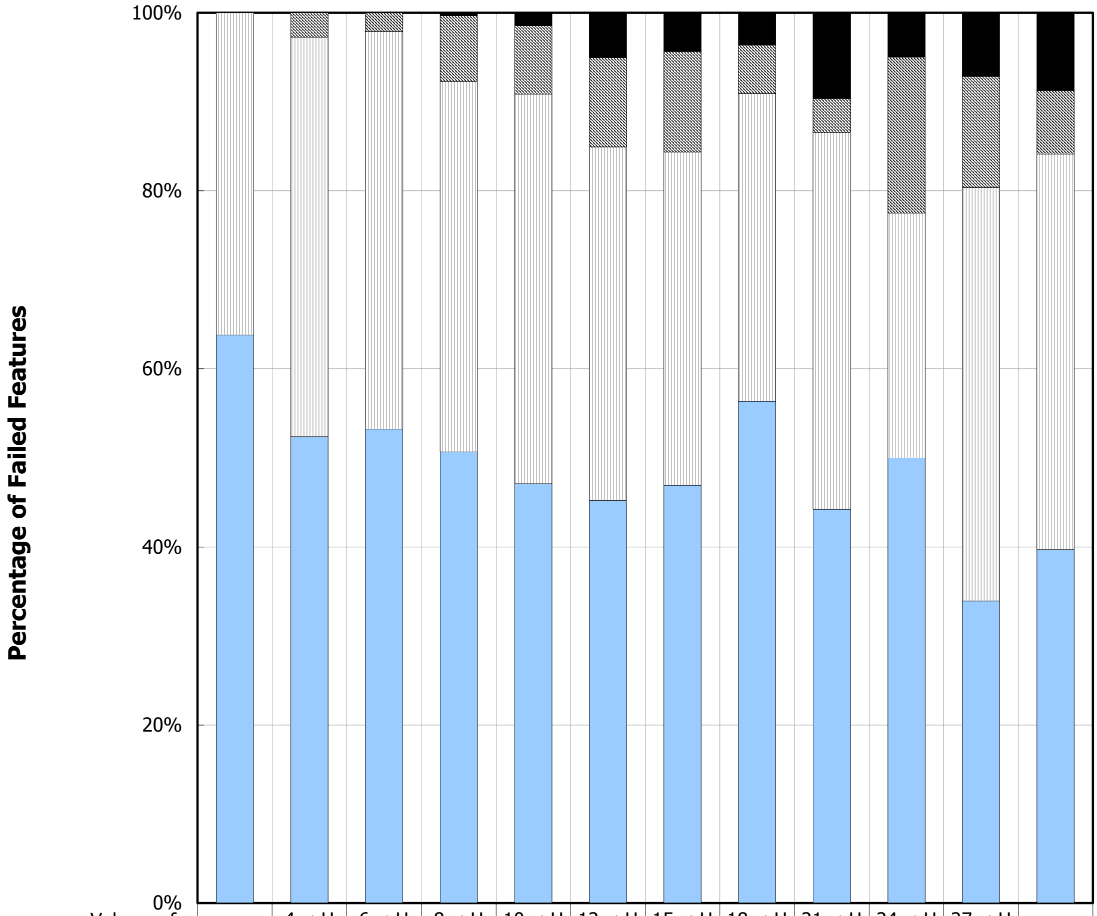


Figure C1 - Relationship between Travel Angle and Landslide Volume for Selected Slope Failures in Hong Kong

Table of Contents
Table of Contents
Table of Contents
Table of Contents



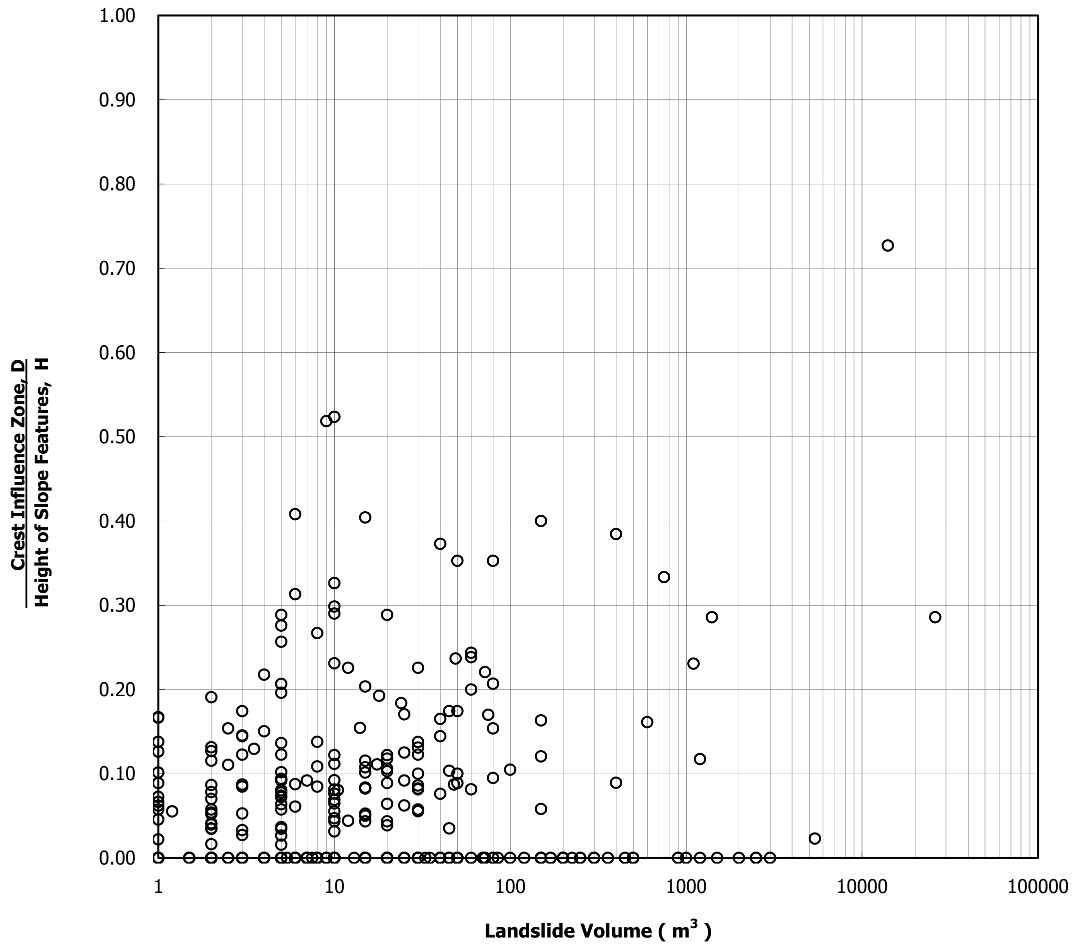
Volume of Debris, V (m³)	H≦4	4 < H ≦6	6 < H ≦8	8 < H ≦10	10 < H ≦12	12 < H ≦15	15 < H ≦18	18 < H ≦21	21 < H ≦24	24 < H ≦27	27 < H ≦30	H > 30
■ V > 300	0	0	0	1	3	10	5	4	5	2	4	11
▧ 50 < V ≦300	0	15	9	22	16	20	13	6	2	7	7	9
▥ 5 < V ≦50	106	245	192	124	91	79	43	38	22	11	26	56
□ V ≦5	187	286	229	151	98	90	54	62	23	20	19	50
SubTotal	293	546	430	298	208	199	115	110	52	40	56	126

Height of Failed Features, H (m)

Note: Based on landslide incidents at registered slopes (soil and rock cut slopes, fill slopes and retaining walls) reported to GEO between 1984 and 2002.

Figure C2 - Relationship between the Height of Slope Features and Scale of Failures

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes: (1) Based on notable landslides between 1992 and 2002 and landslide incidents reported to the GEO between 1999 and 2002.
(2) Refer to Figure C1 for definitions of D and H.

Figure C3 - Relationship between the Normalised Extent of Crest Influence Zone (D/H) and Landslide Volume

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents

Table of Contents

APPENDIX D

TYPES OF PRESCRIPTIVE MEASURES

Table of Contents

Table of Contents

D.1 DEFINITION AND TYPES OF PRESCRIPTIVE MEASURES

Prescriptive measures are pre-determined, experience-based and suitably conservative modules of works prescribed to a slope or retaining wall to improve its stability or reduce the risk of failure, without detailed ground investigations and design analyses (Wong et al, 1999). Some examples are illustrated in Figure D1. These generally involve conventional and conservative details in design, and attention to specification and control of materials, workmanship, protection and maintenance procedures.

Prescriptive measures for soil cut slopes may broadly be classified into the following three types according to the design objectives (Table D1):

(a) Type 1 - surface protection, local trimming and drainage,

(b) Type 2 - subsurface drainage, and

(c) Type 3 - structural support.

Some examples of the various types of prescriptive measures for soil cut slopes are given in Figures D2 to D8. Examples of prescriptive measures for retaining walls and rock cut slopes are given in Wong et al (1999) and GEO (2004) respectively.

D.2 REFERENCES

GEO (2004). Guidelines on the Use of Prescriptive Measures for Rock Cut Slopes (GEO Technical Guidance Note No. 13). Geotechnical Engineering Office, Hong Kong.

Wong, H.N., Pang, L.S., Wong, A.C.W., Pun, W.K. and Yu, Y.F. (1999). Application of Prescriptive Measures to Slopes and Retaining Walls (GEO Report No. 56). (Second edition). Geotechnical Engineering Office, Hong Kong, 73 p.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table D1 - Prescriptive Measures for Soil Cut Slopes

Type	Prescriptive Measures	Primary Design Objectives	Item No. and Description of Works
1	Surface protection and local trimming	- Improve surface protection - Improve local stability	1.1.1 Cover slope face with shotcrete
			1.1.2 Locally trim and remove loose materials
			1.1.3 Fill local areas with no-fines concrete: (a) at upper part of slope (b) at lower part of slope or on berm
			1.1.4 Cover upslope area with shotcrete
	Surface drainage	- Improve surface drainage	1.2.1 Provide surface drainage channels
			1.2.2 Provide slope crest channel with upstand
2	Subsurface drainage	- Improve subsurface drainage - Provide contingency subsurface drainage measures	2.1 Provide drainage behind impermeable slope surface cover: (a) with no-fines concrete toe (b) with relief drains
			2.2 Cover slope face with no-fines concrete: (a) at upper part of slope (b) at lower part of slope or on berm
			2.3 Provide raking drains: (a) at upper part of slope (b) at lower part of slope (c) at specific seepage or potential seepage areas
			2.4 Provide counterfort drains at upper part of slope
			2.5 Provide toe drain
3	Structural support	- Provide support to improve overall slope stability	3.1 Provide soil nails

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table D2 - Standard Soil Nail Layout (Based on Wong et al, 1999)

Standard Soil Nail Layout	H_e (m)	ϕ_r (mm)	ϕ_h (mm)	A			B			C		
				N	L(m)	S_h(m)	N	L(m)	S_h(m)	N	L(m)	S_h(m)
(a)	3.0	25	100	2	3.5	1.5	2	3.5	1.5	2	3.5	1.5
(b)	4.0	25	100	2	4.5	1.5	2	4.5	1.5	2	4.5	1.5
(c)	5.0	25	100	3	6.0	1.5	3	6.0	1.5	3	6.0	2.0
(d)	7.5	25	100	4	9.0	1.5	3	8.5	1.5	3	7.5	1.5
(e)	10.0	25	100	6	10.0	1.5	4	9.5	1.5	4	8.5	1.5
(f)	12.5	32	100	6	11.0	1.5	5	10.0	1.5	5	10.0	2.0
(g)	15.0	32	100	7	12.0	1.5	6	11.0	1.5	6	11.0	2.0
(h)	17.5	32	100	8	13.0	1.5	8	11.5	2.0	7	11.5	2.0
(i)	20.0	32	100	10	13.5	2.0	9	12.0	2.0	8	12.0	2.0
(j)	22.5	32	100	11	14.0	2.0	9	12.0	2.0	8	12.0	2.0
(k)	25.0	32	100	12	14.5	2.0	10	12.0	2.0	8	12.0	2.0

Notes:

(1) H_e is the maximum effective slope height, ϕ_r the nail diameter, ϕ_h the hole diameter S_h the horizontal spacing of nails, and N & L the number of rows and length of the soil nails respectively.

(2) For H_e between any of the two consecutive values, the soil nail layout corresponding to the higher H_e value should be adopted.

(3) Soil nails should be evenly spaced over the slope face.

(4) N is the number of soil nails per vertical column required at the critical section, i.e. the section with the maximum effective height, H_e. At other parts of the slope, soil nails should be provided at vertical and horizontal spacings similar to that at the critical section. Alternatively, different soil nail layouts according to the maximum H_e of that part of the slope may be adopted.

(5) 'A', 'B' and 'C' refer to a large factor of safety increase ($0.3 < \Delta FOS \leq 0.5$), a medium factor of safety increase ($0.1 < \Delta FOS \leq 0.3$) and a small factor of safety increase ($0 < \Delta FOS \leq 0.1$) respectively.

(6) If in the process of drilling rock is encountered such that part of the soil nails will be installed in rock (e.g. installation through a PW50/90 zone or better, see Geoguide 3), the designer may exercise professional judgement to reduce the nail length L. In the absence of site-specific ground investigation, sound engineering judgement is required to ensure that the nails are not prematurely terminated in corestone boulders.

(7) The designer should check the land status to see whether the nails encroach into adjoining land and if so whether this is acceptable to the land owner.

Table of Contents Table of Contents Table of Contents Table of Contents

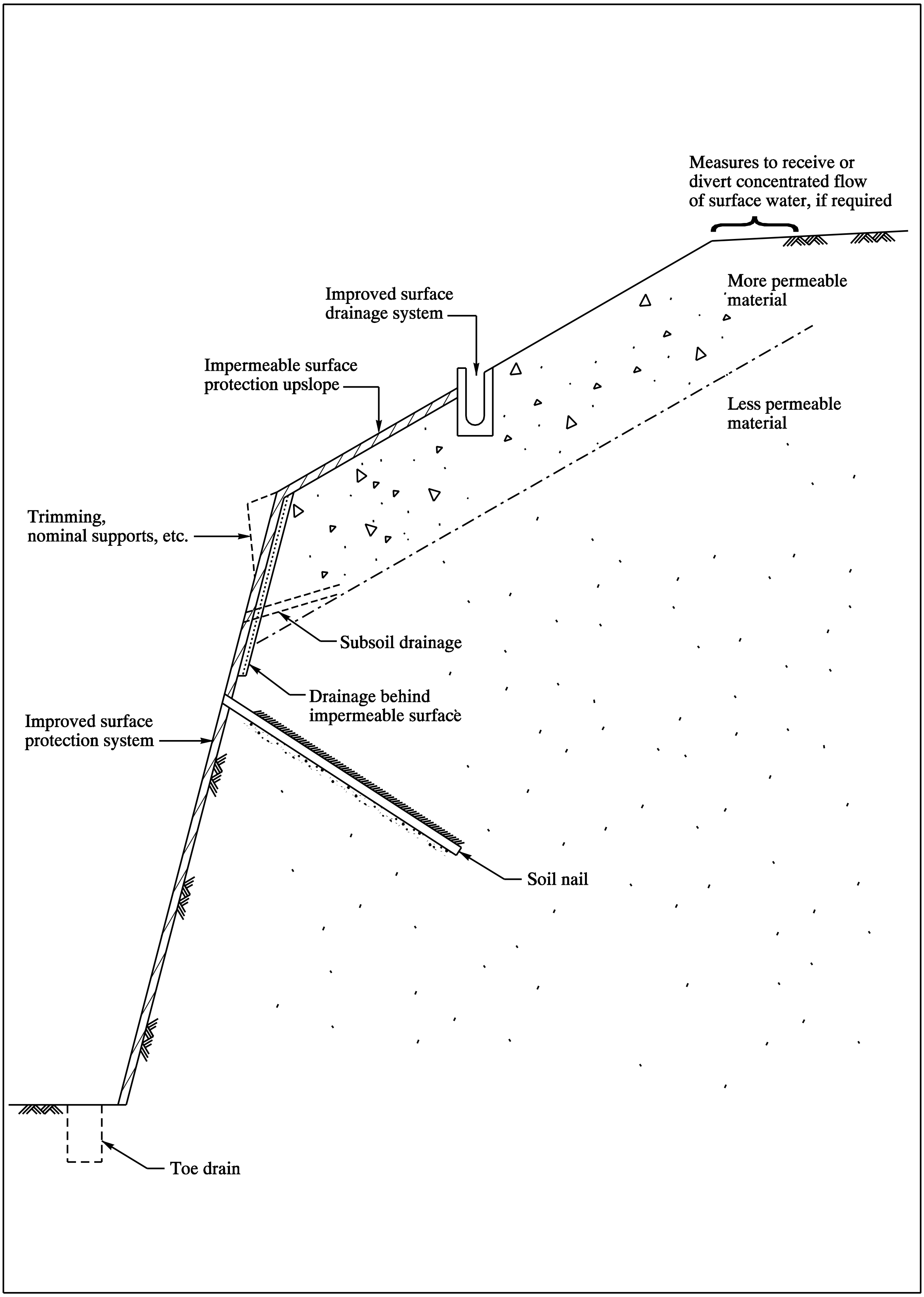
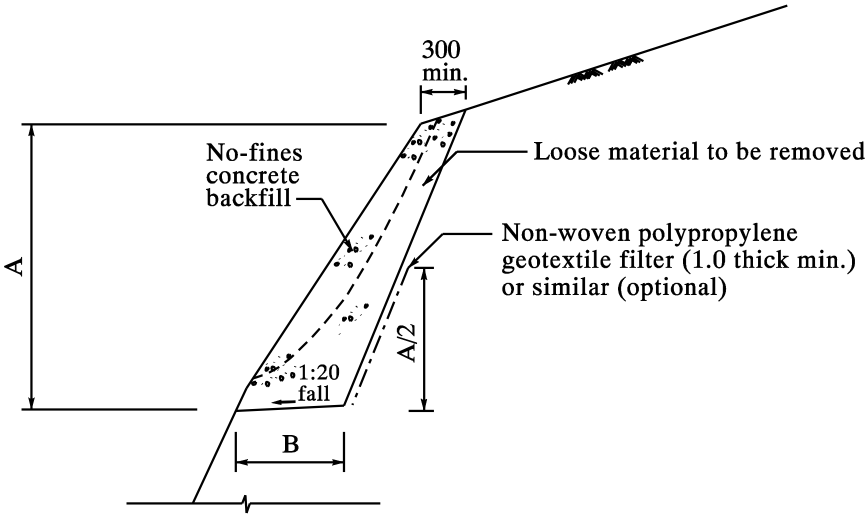
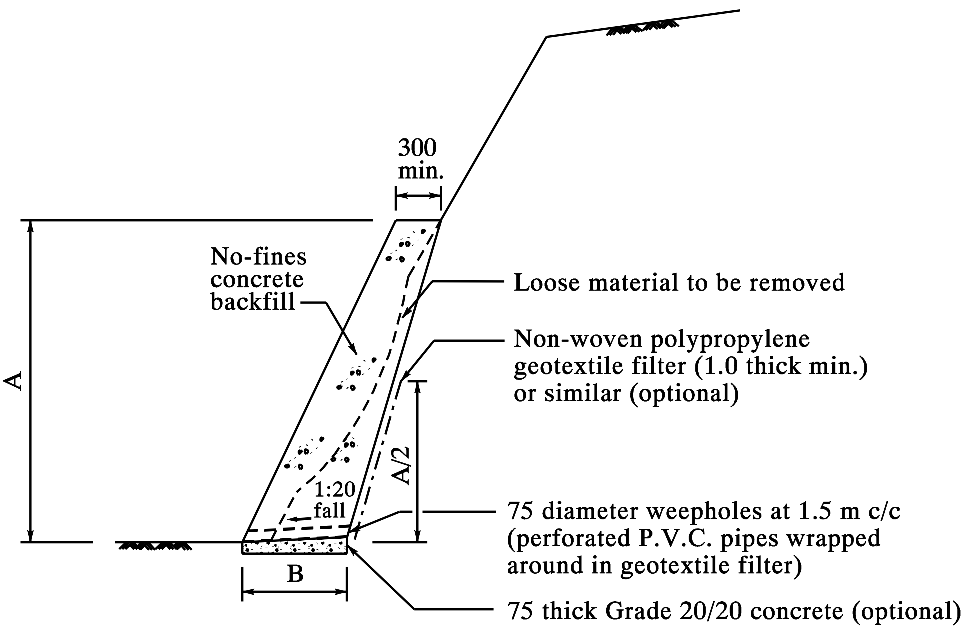


Figure D1 - Typical Prescriptive Measures for Soil Cut Slopes
(Adapted from Wong et al, 1999)



(a) At Upper Part of Slope

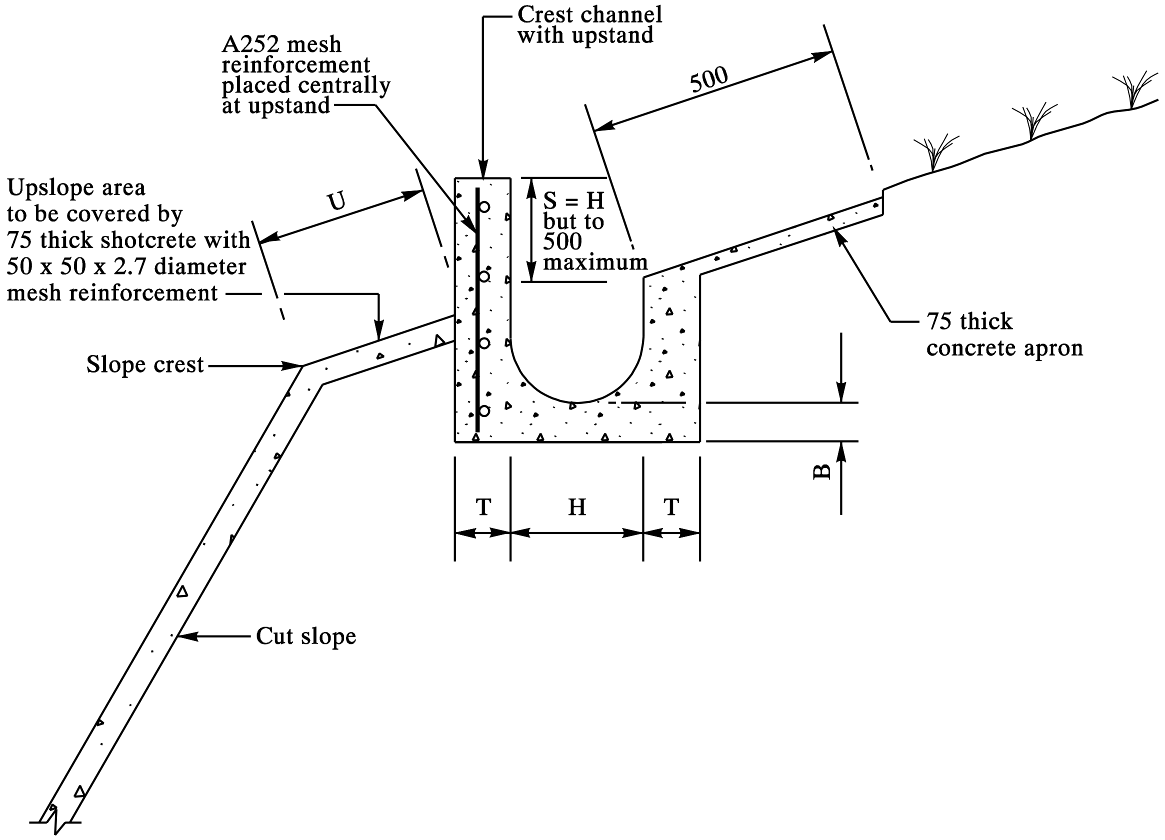


(b) At Lower Part of Slope or on Berm

Notes:
(1) Dimensions in mm unless stated otherwise.
(2) For A<1.5 m , B=0.3 m minimum. For A⩾1.5 m, B=0.5 m minimum.
(3) The geotextile filter behind the no-fines concrete block may be extended further upslope to cover seepage/potential seepage areas as specified by the designer.
(4) Where necessary to improve the stability of the no-fines concrete block, hot dip galvanised high yield deformed bars, typically 2 m long, 25 mm in diameter grouted in 50 mm diameter holes at spacings not exceeding 2 m in both the vertical and horizontal directions, may be provided to tie the no-fines concrete block to the slope.

Figure D2 - No-fines Concrete Backfill to Local Areas (Based on Wong et al, 1999)

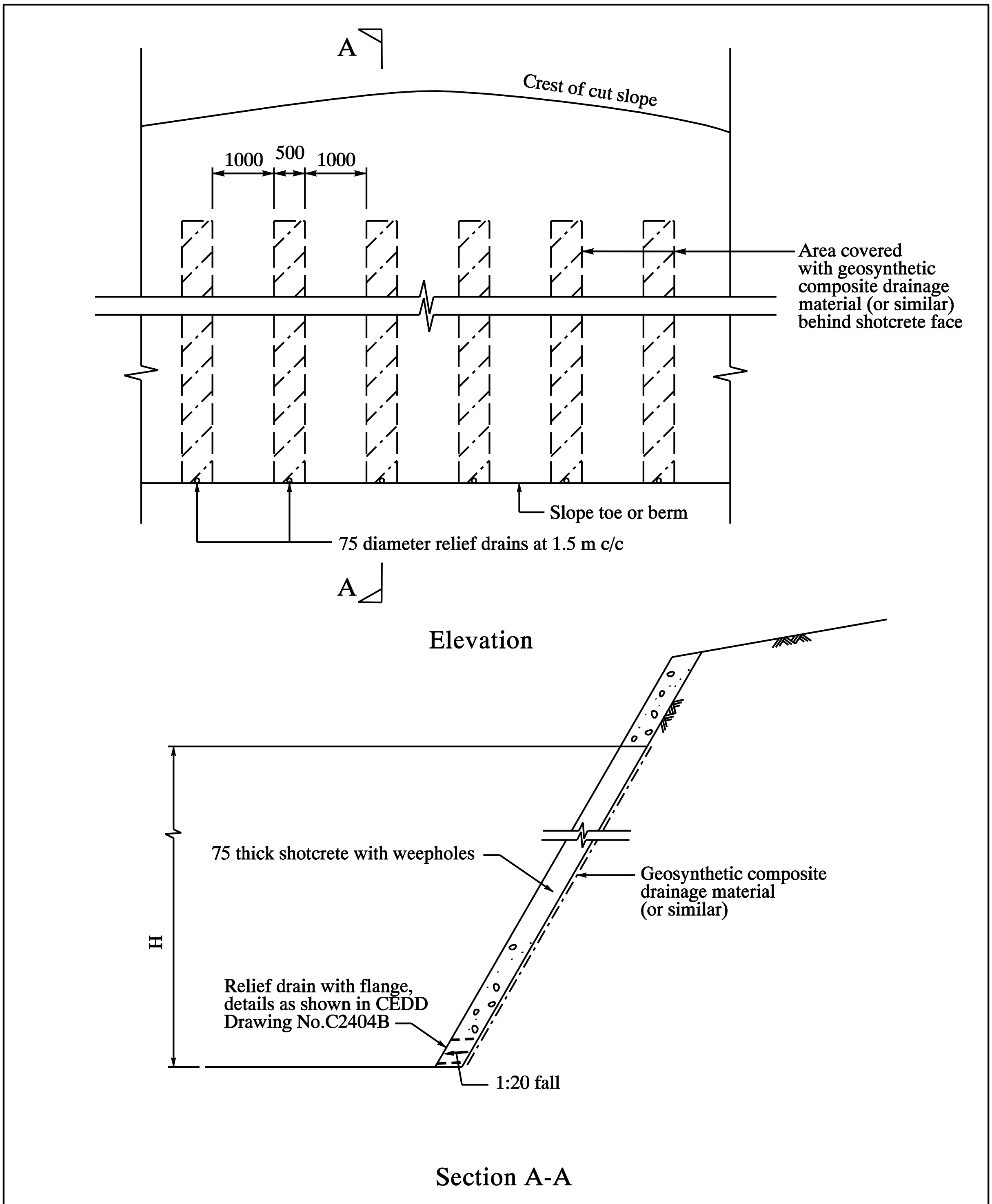
Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes:
(1) Dimensions in mm unless stated otherwise.
(2) For dimensions of channels (i.e. H, T & B), see CEDD Drawing No. C2409G.
(3) Dimension U to be determined by the designer to suit site conditions, typically about one-fourth of the height of the soil cut slope or 3 m, whichever is greater.
(4) Tree rings should be provided where required within the upslope area U. For details of tree rings, refer to CEDD Drawing No. C2104C.
(5) The slope crest channel with upstand should have a minimum gradient of 1 : 10.
(6) Concrete channel should be cast against insitu ground to avoid the use of external formwork.

Figure D3 - Shotcrete to Upslope Area and Crest Channel with Upstand (Adapted from Wong et al, 1999)

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes:

(1) Dimensions in mm unless stated otherwise.

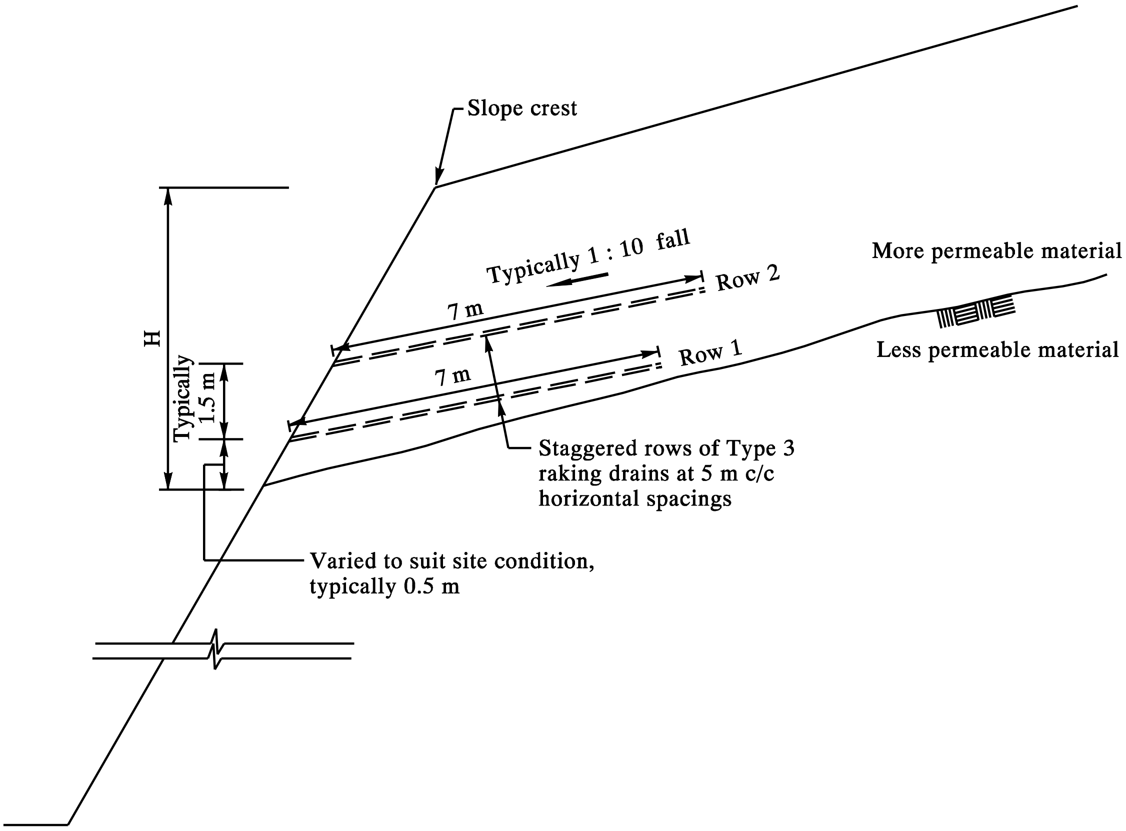
(2) Width and spacings of the geosynthetic composite drainage material (or similar) may be varied to suit site conditions, e.g. closer spacings in areas of observed or potential seepage.

(3) The height of the geosynthetic composite drainage material (or similar), H , to be specified by the designer.

(4) If H > 5 m, relief drains should also be provided at mid-height of the geosynthetic composite drainage material (or similar).

Figure D4 - Drainage behind Impermeable Slope Surface Cover (with Relief Drains) (Adapted from Wong et al, 1999)

Table of Contents
Table of Contents
Table of Contents
Table of Contents



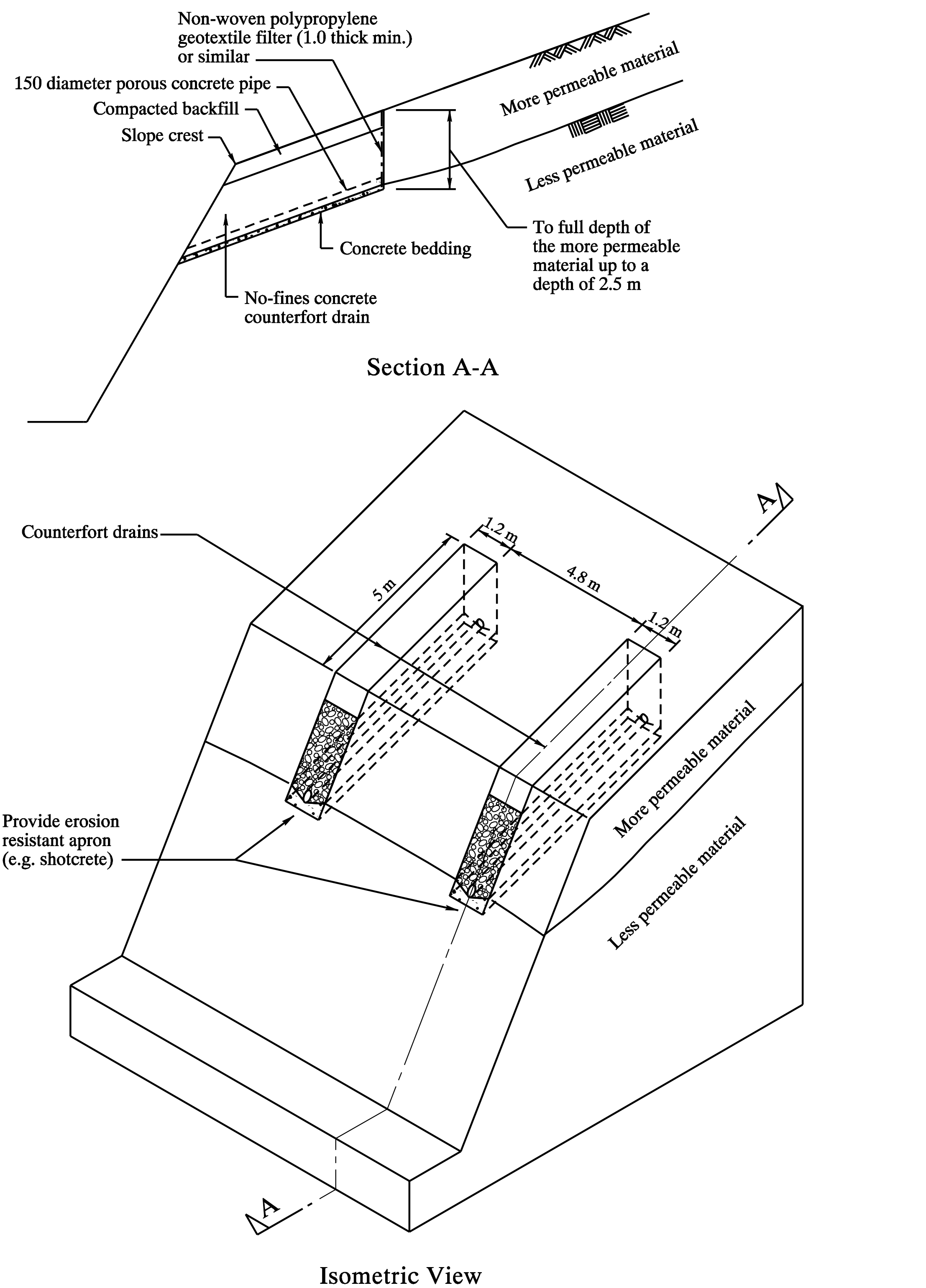
H (m)	≤ 3	> 3
No. of Rows Required	Row 1	Rows 1 & 2

Notes: (1) For details of raking drains, see CEDD Drawing No. C2403C.

(2) The spacings of the raking drains are nominal and may be varied to suit the site condition as determined by the designer.

Figure D5 - Raking Drains at Upper Part of Slope (Adapted from Wong et al, 1999)

Table of Contents
Table of Contents
Table of Contents
Table of Contents



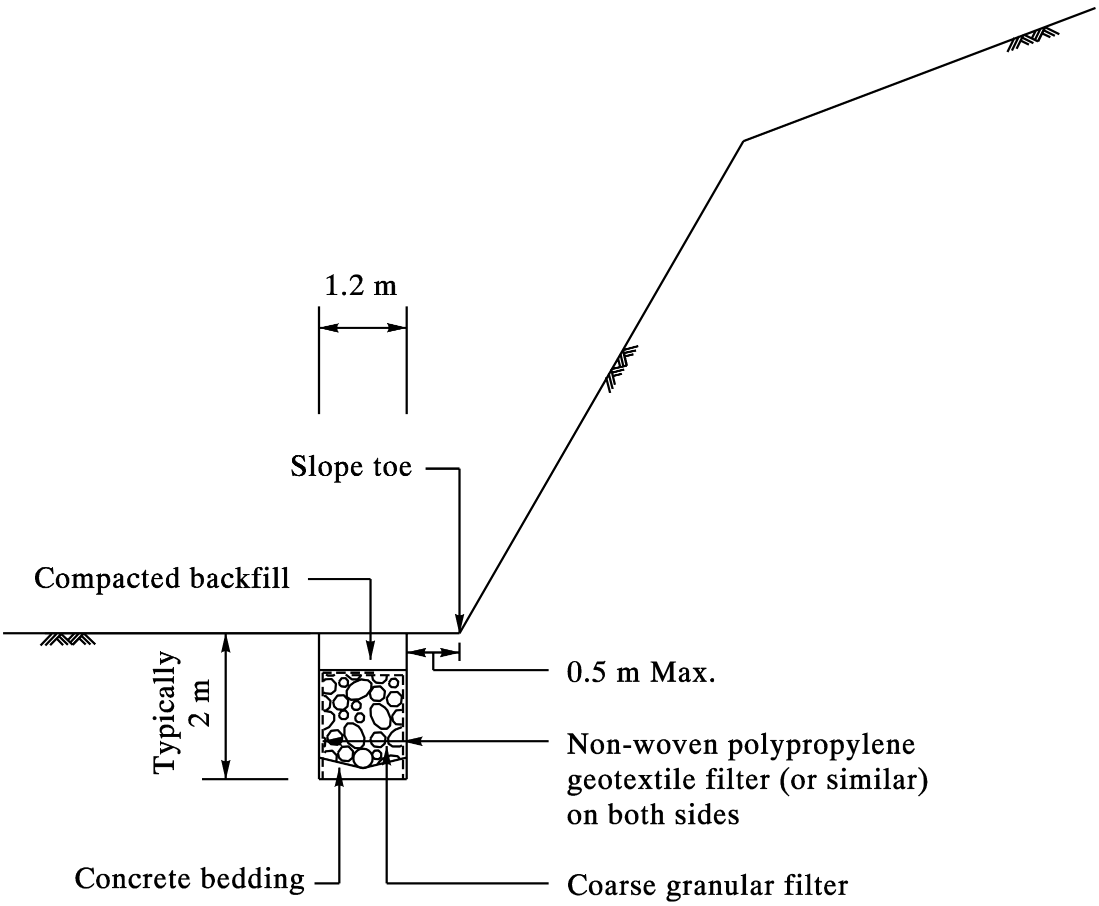
Notes:

(1) Details of counterfort drain should be similar to cut-off drain shown in CEDD Drawing No. C2401B except that the coarse granular filter material is replaced by no-fines concrete, and the non-woven polypropylene geotextile filter should be placed against both side walls of the trench.

(2) If required the compacted backfill to the drains may be replaced by concrete or shotcrete to blend in with the surrounding hard surfaces.

Figure D6 - Counterfort Drains at Upper Part to Slope (Adapted from Wong et al, 1999)

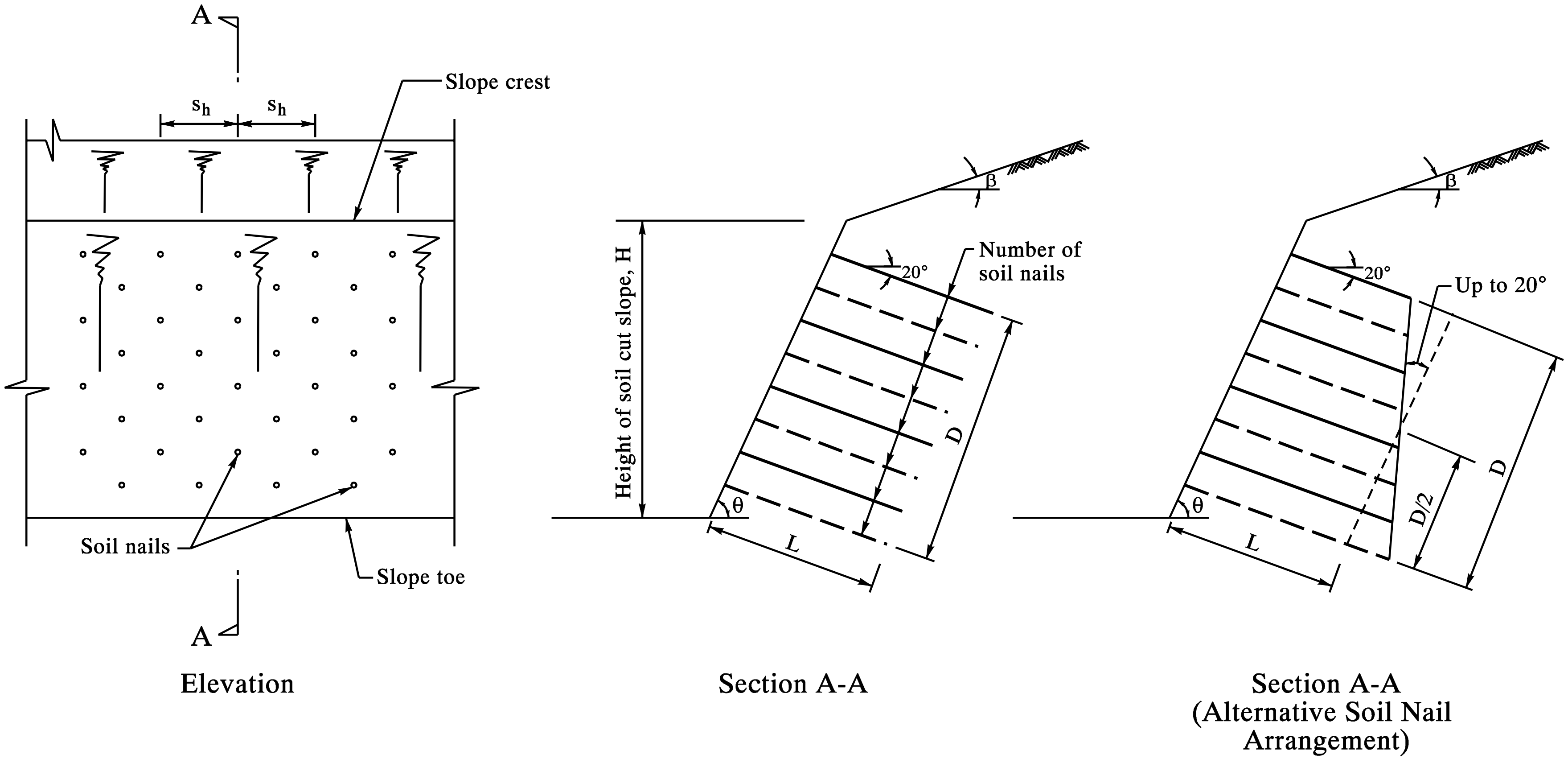
Table of Contents



Notes:
(1) Toe drain details should be similar to those of cut-off drain given in CEDD Drawing No. C2401B except that non-woven polypropylene geotextile filter should be placed against both side walls of the trench.
(2) If required the compacted backfill to the drains may be replaced by concrete or shotcrete to blend in with the surrounding hard surfaces.

Figure D7 - Toe Drain (Adapted from Wong et al, 1999)

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Notes:
(1) N, L, S_h and other dimensions for the soil nails are given in Table D2 based on the type of soil nail layout specified by the designer.
(2) See CEDD Drawing Nos. C2106/1G, 2D & 3D for details of soil nails.
(3) The alternative soil nail arrangement may be adopted as appropriate to suit site conditions.
(4) This Figure shows the arrangement of soil nails staggered at alternative rows. Alternatively, soil nails staggered at alternative columns may be adopted by the designer as appropriate to suit site conditions.

Figure D8 - Soil Nailing to Cut Slope (Adapted from Wong et al, 1999)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX E

DESCRIPTION OF CNPCS

E.1 THE COMBINED NEW PRIORITY CLASSIFICATION SYSTEM

A classification system was developed in 1998 (Wong, 1998) aiming at ranking slopes and retaining walls on risk basis. Since different types of feature are affected by different factors to differing degrees, separate priority classification systems were developed for soil cut slopes, rock cut slopes, fill slopes and retaining walls.

Under each system, a Total Score (TS) is calculated for each feature, reflecting the relative risk of landslide posed by the feature. The Total Score is obtained from the multiplication of an Instability Score (IS) and a Consequence Score (CS). The Instability Score is calculated based on an assessment of a number of key parameters that affect the likelihood of failure. The Consequence Score reflects the likely consequence of failure. The higher the Total Score, the higher is the priority for follow-up action on the feature generally.

In order to obtain a unified ranking of slope features, a Combined New Priority Classification System (CNPCS) Score has been determined from the following equations:

For soil cut slope, CNPCS Score = 0.19 x TS

For rock cut slope, CNPCS Score = 0.20 x TS

For retaining wall, CNPCS Score = 0.038 x TS

For fill slopes, CNPCS Score = 0.64 x e^{TS}

For mixed feature types, the individual CNPCS Score for the various feature types are summed to obtain the CNPCS Score for the feature

E.2 REFERENCE

Wong, C.K.L. (1998). The New Priority Classification Systems for Slopes and Retaining Walls (GEO Report No. 68). Geotechnical Engineering Office, Hong Kong, 117 p.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents

APPENDIX F

KEY FINDINGS ON EFFECTIVENESS OF PRESCRIPTIVE MEASURES IN RELATION TO DIFFERENT MECHANISMS OF FAILURE

Table of Contents
Table of Contents

F.1 BACKGROUND

Lantau Island was subjected to a severe rainstorm on 5 November 1993. This has led to the occurrence of about 300 landslips at man-made features. The large number of landslips provided an opportunity for a systematic study of the characteristics of landslips at man-made slopes. In addition, it was possible to assess the likely effectiveness of routine maintenance and possible use of prescriptive measures in preventing the occurrence of landslips.

F.2 KEY FINDING ON THE LIKELY EFFECTIVENESS OF PRESCRIPTIVE MEASURES

The Lantau investigation was carried out by Wong and Ho (1995). It is a systematic study of the performance of a large number of man-made slopes under severe rainfall conditions. With reference to the different failure mechanisms, it was judged that improvement in surface and subsurface drainage, together with the use of simple support systems such as soil nailing, would substantially reduce the likelihood of landslides even under severe rainfall conditions. Experience based, suitably conservative modules of such works have been developed for application without site investigation.

The proportion of landslips that could have been prevented using appropriate combination of the full range of prescriptive measures was estimated to be around 90%. If support measures were excluded, it was judged that approximately two-thirds of the landslips would not have occurred during the severe rainstorm of 5 November 1993. The effectiveness of prescriptive measures in relation to different mechanisms of failure is shown in Table F1.

F.3 REFERENCE

Wong, H.N. and Ho, K.K.S. (1995). General Report on Landslips on 5 November 1993 at Man-made Features in Lantau (GEO Report No. 44). Geotechnical Engineering Office, Hong Kong, 78 p.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table F1 - Effectiveness of Prescriptive Measures in Relation to the Mechanism of Failure

Possible Failure Mechanism	Likely Effectiveness of Prescriptive Measures
Seepage behind the ‘rigid’ surface cover	Expected to be very effective in preventing this type of failure
Wash-out	Most of the landslips of this nature could have been prevented by the prescriptive measures
Perched water pressure (e.g. in the case of saprolitic soils or weathered rocks overlain by colluvium)	The prescriptive measures may not be particularly effective in preventing failure of this kind, unless the colluvium stratum is very thin (say not more than one to two metres thick), or unless soil nails and simple sub-surface drains such as cut-off drains at the crest or short horizontal drains are included as prescriptive measures
Increase in base groundwater pressure	These landslips are generally deep and the prescriptive measures may not be particularly effective in preventing such failures
Others including localised relic geological weaknesses, re-activation of transported/failed material, influence of streamcourse, etc.	The prescriptive measures may be partially effective in dealing with these aspects, but the effectiveness will be substantially enhanced if soil nails and simple sub-surface drains such as cut-off drains at the crest or short horizontal drains are included as prescriptive measures

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX G

FAILURE FREQUENCIES FOR OLD AND NEW SLOPES

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table G1a - Average Annual Landslide Frequency for Old Soil Cut Slopes in 2004

Slope Height (m)	No. of Slopes	No of Failures (1984 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency (x 10^{-6}/year/m^2)
≤ 10	15,671	1,359	5,589	12.2
> 10 - ≤ 20	1,503	440	2,120	10.4
> 20	389	181	1,888	4.8
Total	17,563	1980	9,597	10.3

Table G1b - Average Annual Landslide Frequency for Old Rock Cut Slopes in 2004

Slope Height (m)	No. of Slopes	No of Failures (1984 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency (x 10^{-6}/year/m^2)
≤ 10	1,315	127	662	9.7
> 10 - ≤ 20	348	119	554	10.7
> 20	175	65	916	3.5
Total	1,838	311	2,132	7.3

Table G1c - Average Annual Landslide Frequency for Old Retaining Walls in 2004

Slope Height (m)	No. of Slopes	No of Failures (1984 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency (x 10^{-6}/year/m^2)
≤ 10	4,622	99	748	6.6
> 10 - ≤ 20	1,263	27	455	3.0
> 20	141	2	234	0.4
Total	6,026	128	1,437	4.5

Table G1d - Average Annual Landslide Frequency for Old Fill Slopes in 2004

Slope Height (m)	No. of Slopes	No of Failures (1984 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency (x 10^{-6}/year/m^2)
≤ 10	3,938	126	2,905	2.2
> 10 - ≤ 20	1,027	72	1,317	2.7
> 20	458	16	1,135	0.7
Total	5,423	214	5,357	2.0

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table G2a - Average Annual Landslide Frequency for New Soil Cut Slopes in 2004

Slope Height (m)	No. of Slopes	No of Failures (1997 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency (x 10^{-6}/year/m^2)
≤ 10	6,753	6	4,772	0.2
> 10 - ≤ 20	2,066	12	4,542	0.4
> 20	1,372	18	11,214	0.2
Total	10,191	36	20,528	0.3

Table G2b - Average Annual Landslide Frequency for New Rock Cut Slopes in 2004

Slope Height (m)	No. of Slopes	No of Failures (1997 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency (x 10^{-6}/year/m^2)
≤ 10	322	2	298	1.0
> 10 - ≤ 20	208	2	589	0.5
> 20	195	6	1,409	0.6
Total	725	10	2,296	0.6

Table G2c - Average Annual Landslide Frequency for New Retaining Walls in 2004

Slope Height (m)	No. of Slopes	No of Failures (1997 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency (x 10^{-6}/year/m^2)
≤ 10	2,784	1	659	0.2
> 10 - ≤ 20	1,313	2	575	0.5
> 20	140	0	143	0.0
Total	4,237	3	1,377	0.3

Table G2d - Average Annual Landslide Frequency for New Fill Slopes in 2004

Slope Height (m)	No. of Slopes	No of Failures (1997 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency (x 10^{-6}/year/m^2)
≤ 10	4,618	3	5,717	0.1
> 10 - ≤ 20	931	2	2,533	0.1
> 20	376	2	2,661	0.1
Total	5,925	7	10,911	0.1

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table G3a - Average Annual Landslide Frequency for Old Soil Cut Slopes affecting Registered Squatter Structures in 2004

Slope Height (m)	No. of Slopes	No of Failures (1984 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency ($x\ 10^{-6}/year/m^2$)
≤ 10	2,193	249	576	21.6
> 10 - ≤ 20	80	23	137	8.4
> 20	21	13	123	5.3
Total	2,294	285	836	17.0

Table G3b - Average Annual Landslide Frequency for Old Rock Cut Slopes affecting Registered Squatter Structures in 2004

Slope Height (m)	No. of Slopes	No of Failures (1984 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency ($x\ 10^{-6}/year/m^2$)
≤ 10	61	5	15	16.7
> 10 - ≤ 20	4	1	7	7.1
> 20	4	8	24	16.7
Total	69	14	46	15.2

Table G3c - Average Annual Landslide Frequency for Old Retaining Walls affecting Registered Squatter Structures in 2004

Slope Height (m)	No. of Slopes	No of Failures (1984 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency ($x\ 10^{-6}/year/m^2$)
≤ 10	804	30	95	15.8
> 10 - ≤ 20	106	4	26	7.7
> 20	11	1	10	5.0
Total	921	35	131	13.4

Table G3d - Average Annual Landslide Frequency for Old Fill Slopes affecting Registered Squatter Structures in 2004

Slope Height (m)	No. of Slopes	No of Failures (1984 - 2003)	Total Slope Area ($x10^3$ m^2)	Average Annual Failure Frequency ($x\ 10^{-6}/year/m^2$)
≤ 10	236	8	199	2.0
> 10 - ≤ 20	30	3	77	1.9
> 20	6	2	8	12.5
Total	272	13	284	2.3

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX H

LANDSLIDE CONSEQUENCE MODEL

H.1 BRIEF DESCRIPTION OF LANDSLIDE CONSEQUENCE MODEL

Landslide consequence is one of the key components in the quantification of landslide risk. The nature of damage that can be caused by landslides is complex and diffuse because of the many interacting factors. The consequence model used in the present study is described in Wong et al (1997), and it covers the influence of potential travel distance of debris, spatial and temporal distribution of the vulnerable population, and the potential loss of life. It starts with assessing the consequence that could be caused by a reference landslide of a prescribed size directly affecting a given type of facility located at the worst possible spot assuming occupation of the facility under average conditions. The assessed consequence is then scaled with respect to the size of the actual failure relative to the reference landslide and the vulnerability of the facility given its actual location relative to the zone of the landslide. The expected failure consequence is expressed in terms of Potential Loss of Life (PLL) given the occurrence of a landslide:

$$\begin{array}{l}\text{Expected Failure}\\ \text{Consequence (PLL)}\end{array} = \sum \left\{\begin{array}{l}\text{Expected no. of fatalities}\\ \text{for facilities directly}\\ \text{affected by a reference}\\ \text{landslide}\end{array}\right\} \left\{\frac{\text{Actual size of landslide}}{\text{Size of reference landslide}}\right\} \left\{\begin{array}{c}\text{Vulnerability}\\ \text{factor}\end{array}\right\}$$

In the above expression, the vulnerability factor indicates the estimated probability of death in the event of a reference landslide affecting a facility. It is a function of various factors including the nature, proximity and spatial distribution of the affected facilities, mobility of the landslide debris, size of failure and the degree of protection offered to persons by the facilities, etc.

The reference landslide used in the present consequence model is a 10-m wide failure with a volume of 50 m^3. The expected number of fatalities caused by a reference landslide affecting different types of facilities as shown in Table H1 has been determined from past statistics, observation and judgement. Tables H2 to H13 show the distribution of landslide debris volume, values of vulnerability factors for different types of facilities, and the distribution of width of landslides.

H.2 REFERENCES

Wong, C.K.L. (1998). The New Priority Classification Systems for Slopes and Retaining Walls (GEO Report No. 68). Geotechnical Engineering Office, Hong Kong, 117 p.

Wong, H.N., Ho, K.K.S. and Chan, Y.C. (1997). Assessment of consequence of landslides. Proceedings of the Landslide Risk Workshop, IUGS Working Group on Landslides, Honolulu, pp. 111-149.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H1 - Expected Number of Fatalities for Affected Facilities Used in the Analysis (Wong, 1998)

Facility Group No.	Facilities	Expected No. of Fatalities (Note 3)
1	(a) Building with a high density of occupation or heavily used (Notes 1 and 2) - residential building, commercial office, store and shop, hotel, factory, school, power station, ambulance depot, market, hospital/polyclinic/clinic, welfare centre	3
	(b) Others - bus shelter, railway platform and other sheltered public waiting area - cottage, licensed and squatter area - dangerous goods storage site - road with very heavy vehicular or pedestrian traffic density	3
2	(a) Building (Note 2) - built-up area (e.g. indoor car park, building within barracks, abattoir, incinerator, indoor game's sport hall, sewage treatment plant, refuse transfer station, church, temple, monastery, civic centre, manned substation)	2
	(b) Others - road with heavy vehicular or pedestrian traffic density - major infrastructure facility (e.g. railway, tramway, flyover, subway, tunnel portal, service reservoir) - construction sites	1
3	Roads & Open Space - densely-used open space and public waiting area - quarry - road with moderate vehicular or pedestrian traffic density	0.25
4	Roads & Open Space - lightly-used open-aired recreation area - non-dangerous goods storage site - road with low vehicular or pedestrian traffic density	0.03
5	Roads & Open Space - remote area - road with very low vehicular or pedestrian traffic density	0.001

Notes:

(1) To account for different types of building structure with different detailing of windows and other perforations, etc, multiple fatality factors of 1, 2, 3, 4 and 5 in proportions of 10%, 20%, 40%, 20% and 10% respectively are considered appropriate for Group No. 1(a) facilities. The multiple fatality factor accounts for the possibility that some incidents may result in a disproportionately larger number of fatalities than that envisaged. Thus, the expected number of fatalities for Group No. 1(a) facilities becomes 3x multiple fatality factors, i.e. 3x1 = 3, 6, 9, 12 and 15 in proportions of 10%, 20%, 40%, 20% and 10% respectively. The multiple fatality factors for the other Facility Groups are 1.

(2) For a failure involving collapse of buildings (slope height exceeds 20 m and failure volume exceeds 10,000 m^3), an additional number of fatalities of 100 is assumed.

(3) The expected number of fatalities refers to the occurrence of a reference landslide of 10 m wide with a volume of 50 m^3.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H2a - Distribution of Landslide Debris Volume for Old Soil Cut Slopes Affecting Developments

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≤ 10	82.27%	13.61%	3.46%	0.66%	0.00%	0.00%
> 10 - ≤ 20	74.55%	16.59%	8.41%	0.45%	0.00%	0.00%
> 20	67.41%	19.89%	9.39%	2.21%	1.10%	0.00%

Table H2b - Distribution of Landslide Debris Volume for Old Rock Cut Slopes Affecting Developments

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≤ 10	82.68%	11.02%	6.30%	0.00%	0.00%	0.00%
> 10 - ≤ 20	80.67%	15.97%	3.36%	0.00%	0.00%	0.00%
> 20	83.07%	12.31%	4.62%	0.00%	0.00%	0.00%

Table H2c - Distribution of Landslide Debris Volume for Old Retaining Walls Affecting Developments

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≤ 5	82.83%	14.14%	3.03%	0.00%	0.00%	0.00%
> 5 - ≤ 10	96.30%	3.70%	0.00%	0.00%	0.00%	0.00%
> 10	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table H2d - Distribution of Landslide Debris Volume for Old Fill Slopes Affecting Developments

Slope Height (m)	Landslides Debris Volume (m^3)										
	All		Sliding Failure			Liquefaction Failure			Major Washout Failure		
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 200	> 200 - ≤ 1000	> 1000	> 50 - ≤ 200	> 200 - ≤ 1000	> 1000	> 50 - ≤ 200	> 200 - ≤ 1000	> 1000
≤ 10	59.52%	23.81%	6.79%	0.71%	0.00%	1.51%	0.16%	0.00%	6.79%	0.71%	0.00%
> 10 - ≤ 20	66.66%	18.06%	3.13%	3.75%	0.00%	0.69%	0.83%	0.00%	3.13%	3.75%	0.00%
> 20	56.23%	12.50%	5.63%	8.44%	0.00%	1.25%	1.88%	0.00%	5.63%	8.44%	0.00%

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H3a - Distribution of Landslide Debris Volume for New Nailed Soil Cut Slopes Affecting Developments

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≥ 3 - ≤ 10	64.51%	32.25%	3.24%	0.00%	0.00%	0.00%
> 10 - ≤ 20	61.06%	30.52%	7.52%	0.90%	0.00%	0.00%
> 20	63.13%	31.57%	4.30%	0.86%	0.14%	0.00%

Table H3b - Distribution of Landslide Debris Volume for New Unsupported Soil Cut Slopes Affecting Developments

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≥ 3 - ≤ 10	56.49%	28.25%	15.26%	0.00%	0.00%	0.00%
> 10 - ≤ 20	41.84%	20.92%	33.25%	3.99%	0.00%	0.00%
> 20	51.24%	25.62%	18.76%	3.75%	0.63%	0.00%

Table H3c - Distribution of Landslide Debris Volume for New Rock Cut Slopes Affecting Developments

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≥ 3 - ≤ 10	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
> 10 - ≤ 20	87.23%	12.77%	0.00%	0.00%	0.00%	0.00%
> 20	88.52%	8.20%	3.28%	0.00%	0.00%	0.00%

Table H3d - Distribution of Landslide Debris Volume for New Retaining Walls Affecting Developments

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≥ 3 - ≤ 5	69.77%	30.23%	0.00%	0.00%	0.00%	0.00%
> 5 - ≤ 10	63.00%	37.00%	0.00%	0.00%	0.00%	0.00%
> 10	69.27%	30.73%	0.00%	0.00%	0.00%	0.00%

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H3e - Distribution of Landslide Debris Volume for New Fill Slopes Affecting Developments

Slope Height (m)	Landslide Debris Volume (m^3)										
	All Failure Mechanisms		Sliding Failure			Liquefaction Failure			Major Washout Failure		
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 200	> 200 - ≤ 1000	> 1000	> 50 - ≤ 200	> 200 - ≤ 1000	> 1000	> 50 - ≤ 200	> 200 - ≤ 1000	> 1000
≥ 3 - ≤ 10	35.85%	50.20%	0.68%	0.00%	0.00%	0.01%	0.00%	0.00%	13.26%	0.00%	0.00%
> 10 - ≤ 20	24.81%	34.73%	1.24%	0.74%	0.00%	0.03%	0.02%	0.00%	24.02%	14.41%	0.00%
> 20	22.35%	31.30%	1.36%	0.91%	0.00%	0.03%	0.02%	0.00%	26.42%	17.61%	0.00%

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H4a - Distribution of Landslide Debris Volume for Old Soil Cut Slopes Affecting Squatter Structures

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≤ 10	80.89%	17.30%	1.61%	0.20%	0.00%	0.00%
> 10 - ≤ 20	60.08%	25.75%	12.88%	1.29%	0.00%	0.00%
> 20	68.17%	22.73%	7.58%	1.52%	0.00%	0.00%

Table H4b - Distribution of Landslide Debris Volume for Old Rock Cut Slopes Affecting Squatter Structures

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≤ 10	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
> 10 - ≤ 20	66.67%	33.33%	0.00%	0.00%	0.00%	0.00%
> 20	80.00%	13.33%	6.67%	0.00%	0.00%	0.00%

Table H4c - Distribution of Landslide Debris Volume for Old Retaining Walls Affecting Squatter Structures

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2000	> 2000 - ≤ 10000	> 10000
≤ 5	96.67%	3.33%	0.00%	0.00%	0.00%	0.00%
> 5 - ≤ 10	85.71%	14.29%	0.00%	0.00%	0.00%	0.00%
> 10	66.67%	33.33%	0.00%	0.00%	0.00%	0.00%

Table H4d - Distribution of Landslide Debris Volume for Old Fill Slopes Affecting Squatter Structures

Slope Height (m)	Landslide Debris Volume (m^3)										
	All		Sliding Failure			Liquefaction Failure			Major Washout Failure		
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 200	> 200 - ≤ 1000	> 1000	> 50 - ≤ 200	> 200 - ≤ 1000	> 1000	> 50 - ≤ 200	> 200 - ≤ 1000	> 1000
≤ 10	97.56%	2.44%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
> 10 - ≤ 20	90.91%	9.09%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
> 20	66.67%	33.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H5a - Distribution of Vulnerability Factors for a Soil Cut Slope Affecting Buildings at the Toe

Failure Volume (m^3)	Shadow Angle									
	0^o - ≤ 20^o	> 20^o - ≤ 25^o	> 25^o - ≤ 30^o	> 30^o - ≤ 35^o	> 35^o - ≤ 40^o	> 40^o - ≤ 45^o	> 45^o - ≤ 50^o	> 50^o - ≤ 55^o	> 55^o - ≤ 60^o	> 60^o
< 20	0	0	0	0.000001	0.00014	0.00007	0.0255	0.00075	0.0013	0.002
20 - 50	0	0	0	0.00005	0.0006	0.00215	0.0057	0.011	0.016	0.02
50 - 500	0	0	0.003	0.019	0.0485	0.097	0.1575	0.2	0.2325	0.25
500 - 2,000	0	0.015	0.045	0.135	0.305	0.52	0.735	0.87	0.935	0.95
2,000 - 10,000	0	0.05	0.18	0.46	0.745	0.9	0.95	0.95	0.95	0.95
> 10,000	0	0.1	0.26	0.56	0.795	0.92	0.95	0.95	0.95	0.95

Table H5b - Distribution of Vulnerability Factors for a Soil Cut Slope Affecting Roads & Others Facilities (Except Buildings) at the Toe

Failure Volume (m^3)	Shadow Angle									
	0^o - ≤ 20^o	> 20^o - ≤ 25^o	> 25^o - ≤ 30^o	> 30^o - ≤ 35^o	> 35^o - ≤ 40^o	> 40^o - ≤ 45^o	> 45^o - ≤ 50^o	> 50^o - ≤ 55^o	> 55^o - ≤ 60^o	> 60^o
< 20	0	0	0	0.0002	0.0012	0.0046	0.017	0.034	0.065	0.1
20 - 50	0	0	0	0.01	0.04	0.11	0.23	0.35	0.46	0.5
50 - 500	0	0	0.0225	0.09	0.215	0.3825	0.545	0.635	0.665	0.7
500 - 2,000	0	0.06	0.24	0.48	0.725	0.87	0.935	0.95	0.95	0.95
2,000 - 10,000	0	0.15	0.44	0.745	0.9	0.95	0.95	0.95	0.95	0.95
> 10,000	0	0.2	0.52	0.795	0.92	0.95	0.95	0.95	0.95	0.95

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H6a - Distribution of Vulnerability Factors for a Soil Cut Slope Affecting Buildings at the Crest

Failure Volume (m^3)	L / H						
	0 - ≤ 0.25	> 0.25 - ≤ 0.5	> 0.5 - ≤ 0.75	> 0.75 - ≤ 1.0	> 1.0 - ≤ 1.25	> 1.25 - ≤ 1.5	> 1.5
< 20	0.00015	0	0	0	0	0	0
20 - 50	0.003	0.0005	0	0	0	0	0
50 - 500	0.034	0.009	0.002	0	0	0	0
500 - 2,000	0.23	0.11	0.04	0.0075	0	0	0
2,000 - 10,000	0.28	0.15	0.066	0.02	0.0025	0	0
> 10,000	0.36	0.24	0.12625	0.05	0.015	0.0025	0

Legend:

H Height of slope
L Distance between the crest of slope and the facility under consideration

Table H6b - Distribution of Vulnerability Factors for a Soil Cut Slope Affecting Roads & Others Facilities (Except Buildings) at the Crest

Failure Volume (m^3)	L / H						
	0 - ≤ 0.25	> 0.25 - ≤ 0.5	> 0.5 - ≤ 0.75	> 0.75 - ≤ 1.0	> 1.0 - ≤ 1.25	> 1.25 - ≤ 1.5	> 1.5
< 20	0.006	0	0	0	0	0	0
20 - 50	0.08	0.01	0	0	0	0	0
50 - 500	0.45	0.14	0.02	0	0	0	0
500 - 2,000	0.63	0.285	0.08	0.015	0	0	0
2,000 - 10,000	0.74	0.375	0.145	0.04	0.005	0	0
> 10,000	0.83	0.505	0.265	0.1	0.03	0.005	0

Legend:

H Height of slope
L Distance between the crest of slope and the facility under consideration

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H7a - Distribution of Vulnerability Factors for a Rock Cut Slope Affecting Buildings at the Toe

Failure Volume (m^3)	Shadow Angle									
	0^o - ≤ 20^o	> 20^o - ≤ 25^o	> 25^o - ≤ 30^o	> 30^o - ≤ 35^o	> 35^o - ≤ 40^o	> 40^o - ≤ 45^o	> 45^o - ≤ 50^o	> 50^o - ≤ 55^o	> 55^o - ≤ 60^o	> 60^o
< 20	0	0	0	0.000001	0.000014	0.00007	0.000255	0.00075	0.0013	0.002
20 - 50	0	0	0	0.00005	0.0006	0.00215	0.0057	0.011	0.016	0.02
50 - 500	0	0	0.003	0.019	0.0485	0.097	0.1575	0.2	0.2325	0.25
500 - 2,000	0	0.015	0.045	0.135	0.305	0.52	0.735	0.87	0.935	0.95
2,000 - 10,000	0	0.05	0.18	0.46	0.745	0.9	0.95	0.95	0.95	0.95
> 10,000	0	0.1	0.26	0.56	0.795	0.92	0.95	0.95	0.95	0.95

Table H7b - Distribution of Vulnerability Factors for a Rock Cut Slope Affecting Roads & Others Facilities (Except Buildings) at the Toe

Failure Volume (m^3)	Shadow Angle									
	0^o - ≤ 20^o	> 20^o - ≤ 25^o	> 25^o - ≤ 30^o	> 30^o - ≤ 35^o	> 35^o - ≤ 40^o	> 40^o - ≤ 45^o	> 45^o - ≤ 50^o	> 50^o - ≤ 55^o	> 55^o - ≤ 60^o	> 60^o
< 20	0	0	0	0.0002	0.0012	0.0046	0.017	0.034	0.065	0.1
20 - 50	0	0	0	0.01	0.04	0.11	0.23	0.35	0.46	0.5
50 - 500	0	0	0.0225	0.09	0.215	0.3825	0.545	0.635	0.665	0.7
500 - 2,000	0	0.06	0.24	0.48	0.725	0.87	0.935	0.95	0.95	0.95
2,000 - 10,000	0	0.15	0.44	0.745	0.9	0.95	0.95	0.95	0.95	0.95
> 10,000	0	0.2	0.52	0.795	0.92	0.95	0.95	0.95	0.95	0.95

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H8a - Distribution of Vulnerability Factors for a Rock Cut Slope Affecting Buildings at the Crest

Failure Volume (m^3)	L / H						
	0 - ≤ 0.25	> 0.25 - ≤ 0.5	> 0.5 - ≤ 0.75	> 0.75 - ≤ 1.0	> 1.0 - ≤ 1.25	> 1.25 - ≤ 1.5	> 1.5
< 20	0.00015	0	0	0	0	0	0
20 - 50	0.003	0.0005	0	0	0	0	0
50 - 500	0.034	0.009	0.002	0	0	0	0
500 - 2,000	0.23	0.11	0.04	0.0075	0	0	0
2,000 - 10,000	0.28	0.15	0.066	0.02	0.0025	0	0
> 10,000	0.36	0.24	0.12625	0.05	0.015	0.0025	0

Legend:

H Height of slope
L Distance between the crest of slope and the facility under consideration

Table H8b - Distribution of Vulnerability Factors for a Rock Cut Slope Affecting Roads & Others Facilities (Except Buildings) at the Crest

Failure Volume (m^3)	L / H						
	0 - ≤ 0.25	> 0.25 - ≤ 0.5	> 0.5 - ≤ 0.75	> 0.75 - ≤ 1.0	> 1.0 - ≤ 1.25	> 1.25 - ≤ 1.5	> 1.5
< 20	0.006	0	0	0	0	0	0
20 - 50	0.08	0.01	0	0	0	0	0
50 - 500	0.45	0.14	0.02	0	0	0	0
500 - 2,000	0.63	0.285	0.08	0.015	0	0	0
2,000 - 10,000	0.74	0.375	0.145	0.04	0.005	0	0
> 10,000	0.83	0.505	0.265	0.1	0.03	0.005	0

Legend:

H Height of slope
L Distance between the crest of slope and the facility under consideration

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H9a - Distribution of Vulnerability Factors for a Retaining Wall Affecting Buildings at the Toe

Failure Volume (m^3)	Shadow Angle									
	0° - ≤ 20°	> 20° - ≤ 25°	> 25° - ≤ 30°	> 30° - ≤ 35°	> 35° - ≤ 40°	> 40° - ≤ 45°	> 45° - ≤ 50°	> 50° - ≤ 55°	> 55° - ≤ 60°	> 60°
< 20	0	0	0	0.000001	0.00014	0.00007	0.0225	0.00075	0.0013	0.002
20 - 50	0	0	0	0.00005	0.0006	0.00215	0.0057	0.011	0.016	0.02
50 - 500	0	0	0.003	0.019	0.0485	0.097	0.1575	0.2	0.2325	0.25
500 - 2,000	0	0.015	0.045	0.135	0.305	0.52	0.735	0.87	0.935	0.95
2,000 - 10,000	0	0.05	0.18	0.46	0.745	0.9	0.95	0.95	0.95	0.95
> 10,000	0	0.1	0.26	0.56	0.795	0.92	0.95	0.95	0.95	0.95

Table H9b - Distribution of Vulnerability Factors for a Retaining Wall Affecting Roads & Others Facilities (Except Buildings) at the Toe

Failure Volume (m^3)	Shadow Angle									
	0° - ≤ 20°	> 20° - ≤ 25°	> 25° - ≤ 30°	> 30° - ≤ 35°	> 35° - ≤ 40°	> 40° - ≤ 45°	> 45° - ≤ 50°	> 50° - ≤ 55°	> 55° - ≤ 60°	> 60°
< 20	0	0	0	0.0002	0.0012	0.0046	0.017	0.034	0.065	0.1
20 - 50	0	0	0	0.01	0.04	0.11	0.23	0.35	0.46	0.5
50 - 500	0	0	0.0225	0.09	0.215	0.3825	0.545	0.635	0.665	0.7
500 - 2,000	0	0.06	0.24	0.48	0.725	0.87	0.935	0.95	0.95	0.95
2,000 - 10,000	0	0.15	0.44	0.745	0.9	0.95	0.95	0.95	0.95	0.95
> 10,000	0	0.2	0.52	0.795	0.92	0.95	0.95	0.95	0.95	0.95

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H10a - Distribution of Vulnerability Factors for a Retaining Wall Affecting Buildings at the Crest

Failure Volume (m^3)	L / H						
	0 - ≤ 0.25	> 0.25 - ≤ 0.5	> 0.5 - ≤ 0.75	> 0.75 - ≤ 1.0	> 1.0 - ≤ 1.25	> 1.25 - ≤ 1.5	> 1.5
< 20	0.000575	0.00625	0	0	0	0	0
20 - 50	0.035	0.009	0.002	0	0	0	0
50 - 500	0.23125	0.11125	0.04	0.0075	0	0	0
500 - 2,000	0.2825	0.15375	0.06625	0.02	0.0025	0	0
2,000 - 10,000	0.3575	0.235	0.12625	0.05125	0.015	0.0025	0
> 10,000	0.3575	0.235	0.12625	0.05125	0.015	0.0025	0

Legend:

H Height of slope
L Distance between the crest of slope and the facility under consideration

Table H10b - Distribution of Vulnerability Factors for a Retaining Wall Affecting Roads & Others Facilities (Except Buildings) at the Crest

Failure Volume (m^3)	L / H						
	0 - ≤ 0.25	> 0.25 - ≤ 0.5	> 0.5 - ≤ 0.75	> 0.75 - ≤ 1.0	> 1.0 - ≤ 1.25	> 1.25 - ≤ 1.5	> 1.5
< 20	0.0255	0.0025	0	0	0	0	0
20 - 50	0.5	0.14	0.02	0	0	0	0
50 - 500	0.63	0.285	0.08	0.015	0	0	0
500 - 2,000	0.7375	0.375	0.145	0.04	0.005	0	0
2,000 - 10,000	0.8325	0.505	0.265	0.1	0.03	0.005	0
> 10,000	0.8325	0.505	0.265	0.1	0.03	0.005	0

Legend:

H Height of slope
L Distance between the crest of slope and the facility under consideration

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H11a - Distribution of Vulnerability Factors for a Fill Slopes Affecting Buildings at the Toe

Failure Volume (m^3)	Shadow Angle (Sliding)									
	0° - ≤ 10°	> 10° - ≤ 15°	> 15° - ≤ 20°	> 20° - ≤ 25°	> 25° - ≤ 30°	> 30° - ≤ 35°	> 35° - ≤ 40°	> 40° - ≤ 45°	> 45° - ≤ 50°	> 50°
< 20	0	0	0	0	0	0.00001	0.00014	0.0008	0.002	0.002
20 - 50	0	0	0	0	0	0.00025	0.00275	0.0125	0.02	0.02
50 - 200	0	0	0	0	0.002	0.02	0.103	0.31	0.450	0.45
200 - 1,000	0	0	0	0	0.02	0.105	0.345	0.7	0.915	0.95
> 1,000	0	0	0	0.013	0.075	0.263	0.588	0.863	0.95	1

Failure Volume (m^3)	Shadow Angle (Liquefaction)									
	0° - ≤ 10°	> 10° - ≤ 15°	> 15° - ≤ 20°	> 20° - ≤ 25°	> 25° - ≤ 30°	> 30° - ≤ 35°	> 35° - ≤ 40°	> 40° - ≤ 45°	> 45° - ≤ 50°	> 50°
< 20	-	-	-	-	-	-	-	-	-	-
20 - 50	-	-	-	-	-	-	-	-	-	-
50 - 200	0	0	0	0.002	0.02	0.103	0.31	0.45	0.45	0.45
200 - 1,000	0	0	0.005	0.045	0.18	0.475	0.81	0.95	0.95	0.95
> 1,000	0	0.015	0.115	0.335	0.63	0.87	0.95	0.95	1	1

Failure Volume (m^3)	Shadow Angle (Major Washout)									
	0° - ≤ 10°	> 10° - ≤ 15°	> 15° - ≤ 20°	> 20° - ≤ 25°	> 25° - ≤ 30°	> 30° - ≤ 35°	> 35° - ≤ 40°	> 40° - ≤ 45°	> 45° - ≤ 50°	> 50°
< 20	-	-	-	-	-	-	-	-	-	-
20 - 50	-	-	-	-	-	-	-	-	-	-
50 - 200	0	0	0	0.00005	0.00075	0.0047	0.017	0.043	0.08	0.1
200 - 1,000	0	0	0.00002	0.0021	0.02008	0.078	0.18	0.32	0.4	0.4
> 1,000	0	0.001	0.015	0.084	0.25	0.5	0.72	0.8	0.8	0.8

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H11b - Distribution of Vulnerability Factors for a Fill Slopes Affecting Roads & Others Facilities (Except Buildings) at the Toe

Failure Volume (m^3)	Shadow Angle (Sliding)									
	0° - ≤ 10°	> 10° - ≤ 15°	> 15° - ≤ 20°	> 20° - ≤ 25°	> 25° - ≤ 30°	> 30° - ≤ 35°	> 35° - ≤ 40°	> 40° - ≤ 45°	> 45° - ≤ 50°	> 50°
< 20	0	0	0	0	0	0.002	0.012	0.026	0.05	0.05
20 - 50	0	0	0	0	0	0.05	0.15	0.3	0.4	0.4
50 - 200	0	0	0	0	0.015	0.115	0.32	0.52	0.6	0.6
200 - 1,000	0	0	0	0	0.08	0.34	0.7	0.915	0.95	0.95
> 1,000	0	0	0	0.05	0.25	0.588	0.863	0.95	0.95	1

Failure Volume (m^3)	Shadow Angle (Liquefaction)									
	0° - ≤ 10°	> 10° - ≤ 15°	> 15° - ≤ 20°	> 20° - ≤ 25°	> 25° - ≤ 30°	> 30° - ≤ 35°	> 35° - ≤ 40°	> 40° - ≤ 45°	> 45° - ≤ 50°	> 50°
< 20	-	-	-	-	-	-	-	-	-	-
20 - 50	-	-	-	-	-	-	-	-	-	-
50 - 200	0	0	0	0.015	0.115	0.32	0.52	0.6	0.6	0.6
200 - 1,000	0	0	0.02	0.16	0.475	0.81	0.95	0.95	0.95	0.95
> 1,000	0	0.02	0.16	0.475	0.81	0.95	0.95	0.95	1	1

Failure Volume (m^3)	Shadow Angle (Major Washout)									
	0° - ≤ 10°	> 10° - ≤ 15°	> 15° - ≤ 20°	> 20° - ≤ 25°	> 25° - ≤ 30°	> 30° - ≤ 35°	> 35° - ≤ 40°	> 40° - ≤ 45°	> 45° - ≤ 50°	> 50°
< 20	-	-	-	-	-	-	-	-	-	-
20 - 50	-	-	-	-	-	-	-	-	-	-
50 - 200	0	0	0	0.001	0.01	0.044	0.125	0.25	0.36	0.4
200 - 1,000	0	0	0.002	0.02	0.088	0.25	0.5	0.72	0.8	0.8
> 1,000	0	0.005	0.045	0.18	0.475	0.81	0.95	0.95	0.95	0.95

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table H12a - Distribution of Vulnerability Factors for a Fill Slopes Affecting Buildings at the Crest

Failure Volume (m^3)	Crest Distance (m)											
	Sliding				Liquefaction				Washout			
	≤ 3	> 3 - ≤ 6	> 6 - ≤ 10	> 10	≤ 3	> 3 - ≤ 6	> 6 - ≤ 10	> 10	≤ 3	> 3 - ≤ 6	> 6 - ≤ 10	> 10
< 20	0	0	0	0	0	0	0	0	0	0	0	0
20 - 50	0.004	0.0000005	0	0	0.0035	0.0000005	0	0	0.00014	0.000005	0	0
50 - 200	0.0058	0.00025	0	0	0.0058	0.00025	0	0	0.025	0.00225	0	0
200 - 1,000	0.02	0.0033	0.0002	0	0.02	0.0033	0.0002	0	0.052	0.012	0.001	0
> 1,000	0.053	0.01	0.0005	0	0.053	0.01	0.0005	0	0.15	0.045	0.0075	0

Table H12b - Distribution of Vulnerability Factors for a Fill Slopes Affecting Roads & Others Facilities (Except Buildings) at the Crest

Failure Volume (m^3)	Crest Distance (m)											
	Sliding				Liquefaction				Washout			
	≤ 3	> 3 - ≤ 6	> 6 - ≤ 10	> 10	≤ 3	> 3 - ≤ 6	> 6 - ≤ 10	> 10	≤ 3	> 3 - ≤ 6	> 6 - ≤ 10	> 10
< 20	0.001	0	0	0	0.001	0	0	0	0	0	0	0
20 - 50	0.03	0.0001	0	0	0.121	0.0001	0	0	0	0	0	0
50 - 200	0.145	0.005	0	0	0.145	0.005	0	0	0.1125	0.0225	0	0
200 - 1,000	0.4	0.0405	0.002	0	0.4	0.0405	0.002	0	0.25	0.064	0.002	0
> 1,000	0.542	0.074	0.002	0	0.542	0.074	0.002	0	0.315	0.12	0.006	0

Table H13 - Distribution of Width of Landslide

	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2,000	> 2,000 - ≤ 10,000	> 10,000
Expected Width of Landslide (m)	4	7	15	20	25	30

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX I

QRA WORKED EXAMPLE

I.1 GENERAL

QRA provides a mathematical tool for determining landslide risk. In the context of QRA, the landslide risk of an individual feature is defined as the product of the probability of landsliding and the consequence of its occurrence. The global landslide risk is the summation of landslide risk attributed to individual slopes as given below:

$$\text{Global Landslide Risk} = \sum_{\text{all slopes}} \sum_{\substack{\text{all landslide} \\ \text{mechanisms}}} \{\text{Probability of Landsliding}\}\{\text{Consequence}\}$$

Slopes have been classified into four types, viz. soil cut slopes, rock cut slopes, fill slopes and retaining walls. In practice, there are different combinations of feature types. For the sake of simplicity, mixed features are classified under one of the four feature types in accordance with the approach outlined in Appendix K.

A worked example demonstrating the method for calculating the landslide risk for an old soil cut slope is given below.

I.2 WORKED EXAMPLE

A road of very high vehicular density is situated at a certain distance away from the toe of an old soil cut slope with a shadow angle of 32^{o} as shown in Figure I1. The shadow angle, which reflects the proximity of the toe facility to the slope, is defined as the angle between the horizon and a line joining the toe facility to the slope crest. The height, length and surface area of the cut slope are 20 m, 30 m and 300 m^2, respectively.

The procedure for determining the average annual landslide risk posed by the old soil cut slope on the toe facility (i.e. the road) is illustrated below.

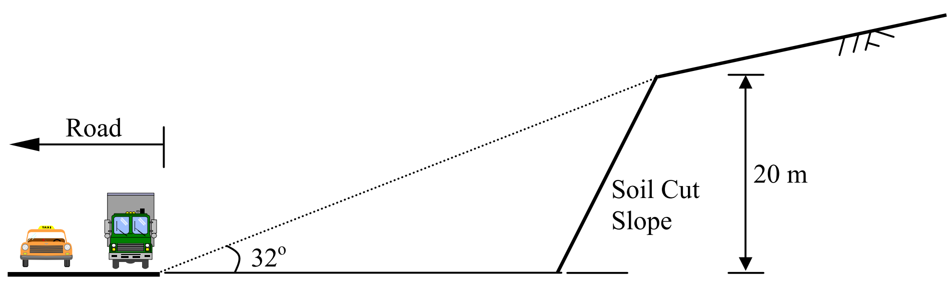


Figure I1 - Cross-section of a Hypothetical Old Soil Cut Slope

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Step 1: Determine the characteristics of the slope and toe facility

Slope:

(i) Slope height = 20 m

(ii) Slope length = 30 m

(iii) Surface area of the slope = 300 m^2

(iv) Slope type = old soil cut slope

Toe facility:

(i) Grouping of facility (road) = 1(a) (the grouping is based on the actual Annual Average Daily Traffic and the number of road lanes, see Wong (1998))

(ii) Expected no. of fatalities if a reference landslide (a 10 m-wide landslide with failure volume of 50 m^3) occurs = 3 (see Table H1 in Appendix H)

(iii) Shadow angle = 32^o

Step 2: Determine the distribution of possible failure debris volume

The distribution of failure debris volume and slope height as shown in Table I1 (same as Table H2a in Appendix H) has been determined based on data in the GEO landslide database (spanning from 1984 to 2003).

Table I1 - Distribution of Landslide Debris Volume for Old Soil Cut Slopes Affecting Developments

Slope Height (m)	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2,000	> 2,000 - ≤ 10,000	> 10,000
≤ 10	82.27%	13.61%	3.46%	0.66%	0.00%	0.00%
> 10 - ≤ 20	74.55%	16.59%	8.41%	0.45%	0.00%	0.00%
> 20	67.41%	19.89%	9.39%	2.21%	1.10%	0.00%

For the subject cut slope, the relevant distribution of failure debris volume is highlighted in the above Table. For example, if a landslide occurs, the probability for a slope with a height between 10 m and 20 m to have a landslide debris volume less than 50 m^3 will be about 0.92 (i.e. 0.75 + 0.17).

Step 3: Determine the vulnerability factor for the toe facility

The distribution of vulnerability factors (defined as the probability of death in the

Table of Contents
Table of Contents
Table of Contents
Table of Contents

event of a landslide) for a soil cut slope affecting roads and other toe facilities (other than buildings) is shown in Table I2 (same as Table H5b in Appendix H). In deriving the vulnerability factors, due regard has been given to the likely distribution of landslide travel distance, the location of the toe facilities relative to the slope and the likely degree of damage upon impact of the facility by the landslide debris.

Table I2 - Distribution of Vulnerability Factors for a Soil Cut Slope Affecting Roads and Other Facilities (Except Buildings) at the Toe

Failure Volume (m^3)	Shadow Angle									
	0^o - $\leq 20^o$	> 20^o - $\leq 25^o$	> 25^o - $\leq 30^o$	> 30^o - $\leq 35^o$	> 35^o - $\leq 40^o$	> 40^o - $\leq 45^o$	> 45^o - $\leq 50^o$	> 50^o - $\leq 55^o$	> 55^o - $\leq 60^o$	> 60^o
< 20	0	0	0	0.0002	0.0012	0.0046	0.017	0.034	0.065	0.1
20 - 50	0	0	0	0.01	0.04	0.11	0.23	0.35	0.46	0.5
50 - 500	0	0	0.0225	0.09	0.215	0.3825	0.545	0.635	0.665	0.7
500 - 2,000	0	0.06	0.24	0.48	0.725	0.87	0.935	0.95	0.95	0.95
2,000 - 10,000	0	0.15	0.44	0.745	0.9	0.95	0.95	0.95	0.95	0.95
> 10,000	0	0.2	0.52	0.795	0.92	0.95	0.95	0.95	0.95	0.95

As aforementioned, the expected number of fatalities has been calculated to be 3, based on a 10 m-wide reference landslide with a failure volume of 50 m^3. The actual expected number of fatalities is determined by scaling up or down this figure with respect to the expected width of failure. Table I3 (same as Table H13 in Appendix H) shows the distribution of expected width of failure against failed volume derived from the landslide records from 1984 to 2003.

Table I3 - Distribution of Width of Landslide

	Landslide Debris Volume (m^3)					
	≤ 20	> 20 - ≤ 50	> 50 - ≤ 500	> 500 - ≤ 2,000	> 2,000 - ≤ 10,000	> 10,000
Expected Width of Landslide (m)	4	7	15	20	25	30

Using the distribution of failure debris volume as highlighted in Table I1 for the 20 m high soil cut slope and the expected failure widths in Table I3, the equivalent vulnerability factor for the road concerned can be calculated as follows, taking into account the probability of the failure belonging to each class of failure volume:

(74.55%)(0.0002)(4/10) + (16.59%)(0.01)(7/10) + (8.41%)(0.09)(15/10) +
(0.45%)(0.48)(20/10) + (0%)(0.745)(25/10) + (0%)(0.795)(30/10) = 0.01689

Step 4: Determine the landslide consequence

The consequence of landslide on the subject slope expressed in terms of Potential Loss of Life (PLL) = 3 x 0.01689 = 0.05067.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Step 5: Determine the probability of landslide

Based on Table G1a in Appendix G of this report, the annual failure frequency of an old soil cut slope of height ranging from 10 m to 20 m is 10.4 x 10^{-6}/year/m^2. Thus, the failure probability of the subject old soil cut slope = 10.4 x 10^{-6} x 300 = 3.12 x 10^{-3} per year.

Step 6: Determine the landslide risk

The average annual landslide risk in terms of PLL posed by the soil cut slope on the road is therefore given by:

$$\text{Landslide Risk} = \{\text{Probability of Landslide}\}\{\text{Consequence}\}$$
$$= (3.12 \times 10^{-3})(0.05067)$$
$$= 1.58 \times 10^{-4}$$

I.3 REFERENCE

Wong, C.K.L. (1998). The New Priority Classification Systems for Slopes and Retaining Walls (GEO Report No. 68). Geotechnical Engineering Office, Hong Kong, 117 p.

Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX J

COST BENEFIT ANALYSIS

Assumptions
Number of man-made slopes to be upgraded = 1500
Estimated cost of works for each slope = $2M to $2.5M
Estimated overhead staff cost = 20% of cost of works
Design life of a slope = 120 years

Analysis
Estimated landslide risk reduction = 30 % (see Figure J1)
Reduction in potential loss of life as a result of the works =5.6 (PLL in a year) x 120 (no. of year) x 30% = 202
Total cost of works (including staff cost) = $3600M to $4500M
Average cost per life saved = $18M to $22M

Discussion
The average cost per life saved assessed using the above methodology is a conservative estimate, since the increase in PLL due to future population growth has not been considered and hence the number of fatalities averted has been under-estimated.

Landslides can result in economic losses, such as road closure, disruption to the community and injuries, apart from fatalities. The above assessment is not a full cost-benefit analysis in that the benefits to the community arising from reduction in economic losses as a result of the slope upgrading works have not been considered. Also, if a substandard slope is upgraded, the chance of future landslides on the slope is significantly reduced and there would be saving in expenditure on urgent repairs. Such saving has not been included in the above assessment. Thus, the cost-benefit ratio of the slope upgrading works is under represented by the calculated average cost per life saved.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

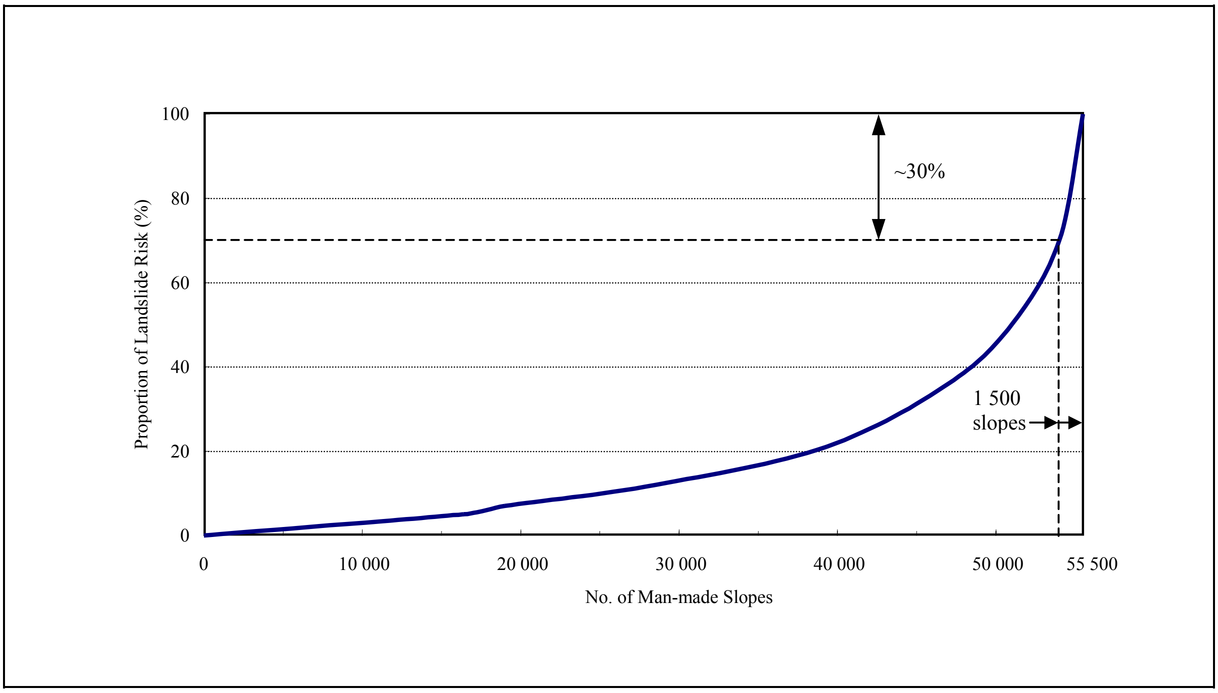


Figure J1 - Distribution of Landslide Risk among Man-made Slopes

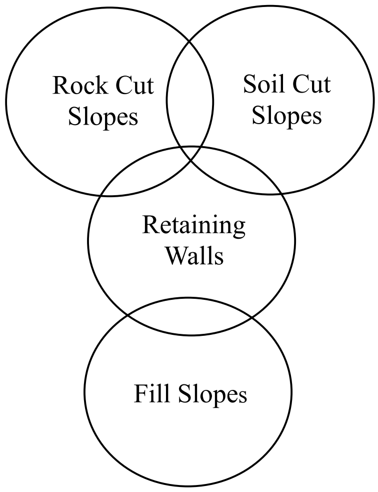
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

APPENDIX K

APPROACH FOR CLASSIFYING MIXED FEATURES

The following steps show the approach of classifying mixed features under one of the four basic feature types, namely soil cut slopes, rock cut slopes, fill slopes and retaining walls.



Note: The overlapping areas correspond to the respective mixed feature types. For example, the overlapping area between retaining walls and fill slopes comprises “FR” features.

Figure K1 - Venn Diagram Illustrating the Original Distribution of Slope Features

Step 1: Separation into soil cut and rock cut slopes

For a cut slope, if the height of the soil portion is < 3 m and the height of the rock portion ≥ 3 m, the cut slope is regarded as a rock cut slope, otherwise it is classified as a soil cut slope.

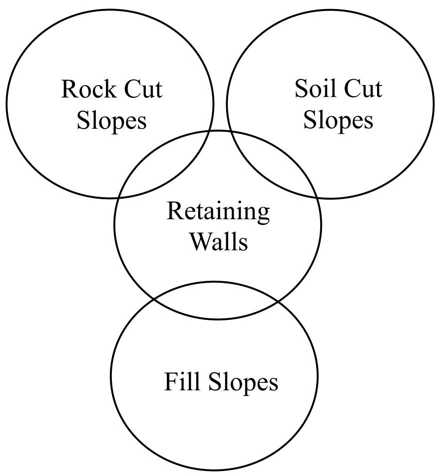


Figure K2 - Venn Diagram Illustrating the Distribution of Slope Features after Separation into Soil Cut and Rock Cut Slopes

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Step 2: Separation into retaining walls and other slope feature types

(a) For a soil cut slope and retaining wall

If the ratio of wall height to total feature height is < 0.5, the feature is regarded as a soil cut slope. Otherwise, it is classified as a retaining wall.

(b) For a rock cut slope and retaining wall

If the ratio of wall height to total feature height is < 0.5, the feature is regarded as a rock cut slope. Otherwise, it is classified as a retaining wall.

(c) For a fill slope and retaining wall

If the ratio of wall height to total feature height is < 0.5, the feature is regarded as a fill slope. Otherwise, it is classified as a retaining wall.

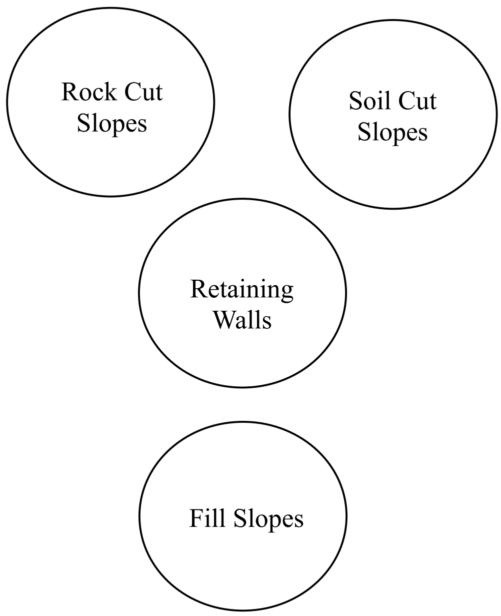


Figure K3 - Venn Diagram Illustrating the Distribution of Slope Features after Total Separation

Table of Contents
Table of Contents
Table of Contents
Table of Contents

GEO PUBLICATIONS AND ORDERING INFORMATION
土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2000).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2000).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 2	Model Specification for Reinforced Fill Structures (1989), 135 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/96	Pile Design and Construction (1996), 348 p. (Reprinted, 2003).
GEO Publication No. 1/2000	Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls (2000), 146 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents

Table of Contents
Table of Contents
Table of Contents
Table of Contents